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Sustaining Agropastoralism on the Bolivian Altiplano: The Case of San José Llanga

How culture, livestock, technical innovation and rural/urban linkages influence a societies' ability to cope with drought and economic change

Global Livestock Collaborative Research Support Programme

Sustaining Agropastoralism on the Bolivian Altiplano: The Case of San José Llanga

How culture, livestock, technical innovation and rural/urban linkages influence a societies' ability to cope with drought and economic change

Edited by

D. Layne Coppock and Corinne Valdivia***

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Global Livestock Collaborative Research Support Programme

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Front cover: *Aymara* woman herding sheep (Drawing courtesy of Ms. Joyce Turk, USAID)

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Agropastoralismo Sostenible en el Altiplano Boliviano: El Caso de San José Llanga

Como la cultura, el ganado, la innovación técnica y las conecciones rurales/urbanas influencian la habilidad de una sociedad para enfrentar la sequía y los cambios económicos

Editado por

D. Layne Coppock y Corinne Valdivia***

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Programa de Apoyo e Investigación Cooperativa en el Ganado a Nivel Global

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Cubierta: mujer *Aymará* arreando ovejas (Dibujo cortesía de la Sra. Joyce Turk, USAID)

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D. Layne Coppock and Corinne Valdivia

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D. Layne Coppock y Corinne Valdivia

Preface

In the transition of the Small Ruminant CRSP to the Global Livestock CRSP we have dedicated considerable resources to better understanding the challenges facing people in developing countries as related to their livestock production. One of the elements that emerged from a global analysis conducted during this transition is reinforced by our work in Bolivia that is reported here, namely the large role of uncertainty in the development process. Development uncertainty is an important factor that influences the physical, social and economic environment of rural people world-wide.

The world's human population is estimated to have recently passed six billion. That density almost assures that our most productive lands have been settled and an increasing portion of the population lives in environments that can be described as marginal. These marginal lands have a lower productivity than higher-potential lands, but the former are most often characterised by their highly variable climate regimes. In the past under lower population densities, many traditional forms of social and economic systems evolved that coped reasonably well with low productivity and high variability. In Africa, for example, several pastoral groups have been found to be as productive as ranchers in the developed world when animal production per unit area is considered.

However, the success of the human species has in itself changed the environment in ways that affect, and often deplete, the resources that traditional peoples depend upon to buffer themselves against unpredictability. Without these key resources such systems can become unsustainable. The Bolivian studies reported here capture a snapshot of a period of this adjustment, where local and national dynamics impinge upon a rural population coping with a harsh, variable environment and struggling to survive as households and communities.

One of the key points that emanates from work presented here is that the development process is in itself, unpredictable. In the few years since our field work in Bolivia ended in the mid-1990s, the government institution with which we worked was closed, and the population of our study area increased dramatically, reversing a decline observed over the previous 20 years. This population surge was apparently a result of a "potato boom," one of several episodic shifts in commodity demand that were documented since the 1960s. The point is that none of these phenomena were predicted. We thus have a pronounced inability to forecast the vagaries of institutions, climate, economics, policy or technology adoption. This should give a signal to researchers and development practitioners that along with creating major efforts that commit us to advocate particular development pathways, we need to arm rural people with the capacity to effectively respond to new problems and opportunities given our predictions and assumptions can be inadequate or incorrect.

The studies in this volume provide a number of examples of the haphazard path of technology adoption and development change. Over the past 30 years a number of new introductions of germplasm, both animal and plant, were made into the central Altiplano region. Our research has revealed that several new technologies have been blended into the traditional agropastoral production system at San José Llanga, and this has improved the lives of the residents in many cases. New and appropriate technologies can give rural people a more diverse set of possible responses to ever-changing economic and climatic circumstances. The work in this volume also shows that some investments by development agencies, often made long ago and likely nearly forgotten, have eventually taken hold to provide development solutions at the local level. Technology adoption has been observed to have numerous ripple effects, and appears to be ultimately dependent on favorable market signals for given commodities. Indeed, it appears that a combination of technical intervention, rural investment, attractive commodity markets, and a development focus on improved risk management can influence something as profound as human migration patterns. This, in turn, has ramifications for limiting the unbridled urban growth that has been a recent concern of some Bolivian planners. Food security is also promoted by efforts that help rural people maintain links to the land.

There exists perhaps no more effective weapon against uncertainty than knowledge. The CRSPs have always distinguished themselves in the development arena by focusing on the creation of knowledge through research and human capacity building. The simple axiom that we need to understand production systems in order to intervene effectively has often been ignored. In the short-term, the urgency of acute challenges often lures us to design and implement interventions based on hunches and half-truths, and then we consequently postpone research and human capacity building for another day. In the long-term this approach will doom us to failure because sustainable development is ultimately founded on a strong knowledge base and an improved capacity of human beings to confront new challenges.

This CRSP project was unique in its ability to tap into the young and creative minds of 27 Bolivian students and connect them with the wise and durable spirit of the people of San José Llanga. By living in the community for extended periods and variously incorporating social, economic, and ecological dimensions into their projects, the students gained the experience of thinking in a systems context and, importantly, they learned not to be fearful of engaging rural people on their own terms.

Montague W. Demment
GL-CRSP Director

Prólogo

En la transición de los Pequeños Rumiantes CRSP a la Ganadería Global CRSP hemos dedicado considerables recursos para un mejor entendimiento de los desafíos que enfrenta la gente en paises en desarrollo en relación a la producción del ganado. Uno de los elementos que emergió de un análisis global hecho durante esta transición se refuerza con nuestro trabajo en Bolivia, presentado aquí, y que es el enorme papel de la incertidumbre en el proceso de desarrollo. La incertidumbre del desarrollo es un factor importante que influencia el desarrollo fisico, social y económico de la gente en áreas rurales alrededor del mundo.

La población humana mundial estimada recientemente sobrepasa los seis mil millones de personas. Con esta densidad es casi seguro que las tierras más productivas han sido pobladas y una creciente proporción de la población vive en medios que pueden ser descritos como marginales. Estas tierras marginales tienen una menor productividad que las tierras con un potencial más alto, pero las anteriores son más a menudo caracterizadas por un clima altamente variable. En el pasado, bajas densidades poblacionales y varias formas tradicionales de sistemas sociales y económicos evolucionaron razonablemente bien con una baja productividad y una alta variabilidad. En Africa, por ejemplo, varios grupos pastoriles han sido encontrados tan productivos como granjeros en paises desarrollados cuando se considera la producción animal por unidad de área.

Sin embargo, el éxito de la especie humana como tal, el medio ha sido cambiado de tal manera que los recursos con los que la gente tradicional depende, son afectados y muchas veces los agotan, en vez de apoyarse en contra de lo impredecible. Sin esos recursos claves, tales sistemas pueden llegar a ser insostenibles. Los estudios bolivianos referidos aqui captan una fotografía de un período de este ajuste, donde las dinámicas locales y nacionales impactan a una población rural que se esfuerza duramente en un medio variable y lucha por sobrevivir como familias y comunidades .

Uno de los puntos claves que emana de este trabajo presentado aquí es que el proceso de desarrollo en si mismo es impredecible. En los pocos años desde que nuestro trabajo en Bolivia terminara a mediado de los 1990s, la institución de gobierno con la cual trabajamos fue cerrada y la población de nuestra área de estudio aumentó dramáticamente, revirtiendo una baja poblacional observada en los últimos 20 años. Este aumento rápido de la población fue aparentemente un resultado del “boom de la papa”, uno de los tantos cambios en las demandas de mercaderías que fueron documentadas desde los 1960s. El punto es que ninguno de estos fenómenos fueron predichos. Es así como no estamos preparados para predecir los caprichos institucionales, climáticos, económicos, o la adopción de políticas o tecnologías. Esto podría dar una señal a investigadores y planificadores de desarrollo, que junto con crear esfuerzos mayores que nos obliguen a abogar por los caminos de desarrollo en particular. Dado que nuestras predicciones y suposiciones pueden ser inadecuadas o incorrectas, necesitamos armar a los campesinos con la capacidad para que puedan responder eficientemente a nuevos problemas y oportunidades que se les presenten.

Los estudios de este volúmen proveen un número de ejemplos de los caminos inciertos en la adopción de tecnologías y cambios de desarrollo. A travéz de los últimos 30 años un número de nuevas presentaciones de germoplasma, tanto animal como vegetal han sido hechos en la región central del Altiplano. Nuestra investigación ha revelado que nuevas tecnologías han sido mezcladas en el sistema de producción agro-pastoril tradicional en San José Llanga, lo que en muchos casos ha mejorado la vida de los residentes. Nuevas y apropiadas tecnologías pueden dar a los campesinos una mayor diversidad de posibles respuestas a circunstancias económicas y climáticas altamente dinámicas. El trabajo de este volúmen también muestra algunas inversiones de agencias de desarrollo, a menudo hechas tiempo atrás y seguramente casi olvidadas, las que eventualmente han tomado control para proveer soluciones de desarrollo a un nivel local. La adopción de tecnologías que han sido observadas tiene numerosos efectos que pareciera ser esencialmente dependiente de signos de mercado favorables para ciertas mercaderias. Pareciera que la combinación de la intervención técnica, la inversión rural, el mercado de productos atractivos y un desarrollo enfocado a mejorar el riesgo de manejo, los que pueden influenciar profundamente los patrones de migración humana. Esto a cambio tiene ramificaciones al limitar el desenfrenado crecimiento urbano que ha sido una reciente preocupación de algunos planificadores bolivianos. La seguridad de alimentos es también promovido por esfuerzos que ayudan a los campesinos a mantener lazos con la tierra.

No existe quizás ningún arma más efectiva en contra de la incertidumbre que el conocimiento. El CRSPs se ha distinguido siempre el campo del desarrollo por concentrarse en la creación de conocimiento a travéz de la investigación y la construcción de la capacidad humana. El simple axioma de tener que entender los sistemas de producción para intervenir efectivamente, ha sido ignorado a menudo. A corto plazo, la urgencia de desafios agudos nos ha llevado a diseñar e implementar intervenciones basadas en tincadas y verdades a medias, y por ello entonces posponemos la investigación y la construción de la capacidad humana para otro día. A largo plazo este acercamiento nos condenará al fracazo dado que un desarrollo sostenido está esencialmente fundamentado en una base de conocimientos fuertes y en una mejor capacidad de los seres humanos para que puedan afrontar nuevos desafios.

Este proyecto de CRSP fue único en su abilidad para dar palmaditas en la mente creativa de 27 estudiantes bolivianos y conectarlos con el espiritu sabio y eterno de la gente de San José Llanga. La residencia de los estudiantes en la comunidad por períodos largos incorporando la variedad social y económica y las dimensiones ecológicas en sus proyectos, los hizo ganar la experiencia de pensar en un sistema de contexto. Más importante aún, aprendieron a no tener miedo de comprometerse con los campesinos en sus propios términos.

Montague W. Demment

GL-CRSP Director de Programa

Dedication

To the people of San José Llanga

Dedicatoria

A los pobladores de San José Llanga

Executive Summary

This volume is a synthesis of field research carried out from 1991-5 by a joint IBTA/SR-CRSP (Instituto Boliviano de Tecnología Agropecuria/ Small Ruminant Collaborative Research Support Programme) project on the central Altiplano. Analysis and interpretation of data continued through 1998, and we have added an epilogue that covers recent events through 1999. We therefore have strived to provide a perspective relevant for the decade of the 1990s. Most of the field data for the project were collected by 27 Bolivian undergraduates who completed theses as part of their degree requirements at Bolivian universities.

The broad framework of the project was to identify factors that threatened the sustainability of agropastoral production in semi-arid systems. Urban areas on or near the Altiplano had experienced large in-fluxes of rural immigrants in recent years. It was unclear the degree to which this migration was due to environmental, social or economic factors. If environmental degradation was pushing people to leave rural areas, it was important to understand the degree to which environmental degradation was caused by human-related activity or the result of uncontrollable forces such as drought or increasing soil salinity. If human activities were responsible, it was important to understand if problems were related to over-grazing, mis-management of farming resources or some other issue. If changes in grazing, farming or other aspects of natural resource management could help solve problems, we wanted to identify technical or policy interventions that could be useful to improve the situation. To this end we had a particular interest in how to strengthen the role of sheep in agropastoral systems. If, however, emigration was not due to environmental or technical factors, but caused by social or economic factors such as changing lifestyle aspirations or low commodity prices, this would focus more attention on non-technical solutions for development problems.

First we present a description of the system we studied to set the context. We then address the questions posed above and recommend some priorities for future research, outreach and policy consideration. Readers interested in more details should consult Chapter 8: *Conclusions and recommendations*.

The study site was the Cantón of San José Llanga, a 72-km^2 area located about 120 km southeast of the cities of La Paz and El Alto and 17 km south of the town of Patacamaya on the Pan American Highway. Home to about 400 people and over 5600 head of livestock during the early 1990s, the production system was typical of those found on the flat, alluvial plains of the central Altiplano in many respects. San José Llanga was atypical, however, with regards to its proximity to large markets and the fact that it has had over 30 years of experience with technology transfer due to the presence of the Patacamaya Experiment Station, created in 1958. These attributes of access to markets and technology, however, would make San José Llanga an ideal "living laboratory" to observe development processes.

Our research was multi- and inter-disciplinary and included biological, ecological and social sciences. Students and their supervisors spent long hours at the site. Methods included extensive inventory and analysis of animal, plant, soil and water resources. Measures of agricultural productivity were performed. Experimental trials were conducted in some cases. Individuals, households and focus groups were extensively interviewed using a variety of formal and informal methods.

The people of San José Llanga are indigenous *Aymara* Indians. Hundreds of years ago the community was part of a larger, traditional socioeconomic unit or *ayllu* called Llanga that operated across several agroecological zones. This *allyu* was ultimately broken-up by Spanish invaders by the mid- to late-1500s. As with many indigenous people of Bolivia, people at San José Llanga were subjected to centuries of prejudice and oppression by colonial forces and subsequent republican governments. The community of San José Llanga has a history of fierce resistance to outsiders. Over the past 50 years, however, revolutionary change has finally occurred in the national political sphere. The people of San José Llanga have been able to pursue formal education, adopt new agricultural technology and participate in emerging markets. In terms of living standards, however, the population was having mixed success by the early 1990s. On one hand the proportion of adults who were literate was fairly high. On the other hand child nutrition and health were assessed to be potential community risks. Problems of public sanitation and lack of routine access to professional health care were noted by researchers.

In the early 1990s the people at San José Llanga were distributed among six settlements located along a north/south band through the middle of the cantón. These settlements varied in size and resource endowments. We estimated that fewer than 100 households occupied the cantón in the 1890s, and this grew to about 125 households by the 1970s. At the time of our work the number of households declined to about 100. We projected that the number of households would stabilise at around 80 in the near future as a result of pervasive emigration of youths and the passing of elderly residents. Emigration in the early- to mid-1990s was reportedly related to changing aspirations of residents who desired lifestyle changes that San José Llanga could not provide. Most emigrants headed for urban areas to find jobs and pursue secondary education. Emigrants were not on the move because of environmental degradation. A creative and aggressive community leadership, however, was attempting to help stem emigration by investing in improvements in household water supplies, electricity, crop irrigation systems, latrines and building a new secondary school. This leadership was an excellent example of the importance of social capital to promote sustainability of a rural community.

Farming was typically conducted on slightly elevated parts of an otherwise flat landscape. Moisture was supplied to crops either from precipitation or several forms of natural sub-irrigation or human-created irrigation systems. Drought and frost were pervasive risks for farming—households widely distributed dozens of plots to mitigate such risks. Crop production largely occurred on controlled-access plots and was dominated by production of potatoes, cereal grains and cultivated forages. Fallow fields were important for grazing and harvest of fuel wood from abundant shrubs. Food crops were typically for home consumption except in bumper years when surpluses could be sold. Wealthier households were more likely to have surpluses because they had access to larger areas of cultivated land. Cultivated forages such as alfalfa were primarily produced to support cross-bred dairy cattle, and secondarily to support cross-bred sheep. Cultivated forages often occurred where irrigation was possible and this was dictated by landscape position. Livestock were also very important for the production system. Sheep were comprised of Criollo and improved crosses such as Criollo x Corriedale. Cattle were comprised of Criollo for draught and improved crosses for milk production such as Criollo x Holstein (Friesian). Grazing was the dominant source of livestock feed and resources included unimproved rangeland covering a dry, saline lake bed as well as strategic reliance on alfalfa fields and crop residues. Sheep have been traditionally important to provide manure for fertilising potato fields. Donkeys carry the manure to the fields and small amounts are applied to potato seedlings using human labour. Sheep were an important source of routine income, cheap meat and capital for the system. Sheep management and marketing fell in the domain of women—women sold sheep to purchase welfare-related items such as food, clothing and school supplies. In our analysis of sheep production we found that mortality rates for lambs and adults were very low, but morbidity challenges were high due to poor health management. Improved cross-bred sheep were more productive than indigenous Criollo breeds. Small-holder dairying based on improved cattle within a subsidised framework has been a recent and popular addition to the system. This apparently fulfilled a need for higher and more frequent sources of income in the community—San José Llanga became one of the top milk producers in the region by the mid-1990s. Dairy cattle were also an important means to accumulate capital. Ultimately this capital could be diversified into off-farm investments in some cases. Because the six settlements varied with regards to location they also varied with regards to irrigation potential, cultivated forage production and ability to support improved cattle and sheep breeds. Settlements able to support small-holder dairying reportedly had fewer residents seeking employment off-farm compared to those reliant on rain-fed forage production and Criollo livestock breeds. This illustrated that interventions such as small-holder dairying could help stabilise the local household economy.

The period of our field work was largely a time when annual precipitation was near the long-term average of 406 mm, but 1995 was a drought year when precipitation was 40% below average. This provided an opportunity to observe effects of a drought year on the system.

During the drought year of 1995 we expected to observe that households would suffer due to lower levels of crop production compared to the near-average rainfall year of 1993. Households more able to sell livestock products and pursue off-farm employment were expected to mitigate drought problems to the highest degree. Commodity prices during 1995, however, exhibited substantial increases (by 30 to 400%) compared to those for 1993. This positive price effect contributed to typically higher incomes for households in 1995 compared to 1993. As predicted, some households did sell more sheep and seek more off-farm employment in 1995 compared to 1993. Overall, the people were able to cope quite effectively with a one-year drought. They generally used their higher incomes in 1995 to buy more food to cover potential food deficits caused by lower crop production. These patterns illustrated the important role of small ruminants, well-functioning markets and off-farm employment for drought mitigation. Past drought was also reported to have encouraged people to increase involvement in smallholder dairying to increase and diversify income.

The drought year of 1995 and various emigration patterns also helped clarify aspects of resource tenure at San José Llanga. In general, the trend over the past 50 years has been for more privatised control over the higher-value parcels of farmland, which used to be under more communal regulations of use. The current trend began with national land reform initiatives in the early 1950s when the then-users of land received access rights. The subsequent pattern has been an intergenerational transfer of private access property from fathers to sons, although a land market does not exist per se since property is not deeded. In some cases this has resulted in increased fragmentation of holdings in recent years. In contrast to cultivated land, grazing lands are held under a more diverse and dynamic pattern of access. Highest quality grazing tended to be under controlled access, while lower value grazing tended to be under communal access. The resulting access matrix was complex and challenging for shepherds who strived to obey rules. Clever herding was thus a mainstay of the system. Female teenagers in particular were highly skilled shepherds. Flocks were taken to remnant patches of forage as the year progressed and lambs were able to maintain suitable rates of growth. Emigrants selected care-takers to look after crops and livestock while they were away, with traditional forms of resource sharing and in-kind compensation as forms of payment. This sharing and care-taking behaviour allowed poorer households to gain access to livestock and crop resources in the absence of formal markets. These arrangements also helped emigrants reduce risks of emigration and keep strong ties to the local community.

The people of the central Altiplano have experienced over 30 years of technology transfer efforts, starting in the 1950s. Packages for producing improved potato were introduced in the 1960s during a "potato boom," a time of higher potato prices. A cooperative was formed. A tractor was purchased and reliance on cheap chemical fertilisers began. The 1960s were also a time of a "wool boom," and improved sheep were imported as part of bilateral aid efforts to upgrade the productive potential of Criollo sheep for wool and meat production. This technical package included establishment of an improved forage base of alfalfa fields on sites having high water tables. Nearly 30 years later in the mid-1990s both improved potato and cross-bred sheep have been well integrated within the traditional production system at San José Llanga. Improved potato and cross-bred sheep have been typically emphasised more for market in recent years, although in the case of sheep the meat production has been valued more than wool production. In contrast, local potato varieties and Criollo sheep tended to be used more for household consumption. Roughly half of the sheep flocks across eight local communities in Aroma Province were comprised of Criollo x Corriedale animals by 1995. Adoption of cross-bred sheep appeared to be associated more with production systems on plains sites rather than hillside systems, probably due to more favourable mixes of crops and forages in the former locales. People exposed to extension training programmes had a greater likelihood of adopting improved sheep if they also had the capability of making forage improvements. For potato, seeds of improved varieties were commonly sown along with seeds of indigenous "bitter" varieties during the course of our research—each variety reportedly offered complementary production traits with regards to drought and frost risk. Cross-bred dairy cattle were adopted by about one-third of the households at San José Llanga between 1989 and 1995. Wealthier households with access to irrigated forage were more likely to be involved in small-holder dairying.

Technology adoption appeared to have ripple effects over time. Although alfalfa fields were originally established in the 1960s to support improved sheep, there was a renewed interest in expanding cultivated forage with the advent of smallholder dairying in the early 1990s. This incentive followed a "dairy boom" and compelled many households to convert some acreage formerly devoted to food crops to the production of cultivated forages. The dairy boom even helped initiate ambitious community irrigation projects that included diversion of the local, rain-fed *Kora Jahuira* River to create a fertile alluvial fan near the main *Barrio,* and a 23-km channel was built from the saline Desaguadero River to irrigate other locales such as the deltaic deposits. These efforts to establish more cultivated forage for cattle in recent years have thus come full circle to ultimately benefit cross-bred sheep once again as a secondary enterprise.

Although the record of technology adoption at San José Llanga has been favourable in general, it appears that technology adoption has been biased towards wealthier households and may have created more work for females. Wealth polarisation in the community may be an issue of concern. How new technologies fuel such polarisation, rather than diminish it, is an important consideration.

The mixing of new and traditional technology has allowed the people of San José Llanga to become more economically diverse and thus better able to respond in opportunistic ways to new market opportunities; it also has helped protect them against a variable climate. This appears to be a somewhat different path to development than that promulgated by the "modernisation paradigm," whereby adoption of new technology leads to a systematic reduction in traditional practices and an increased degree of producer specialisation.

Although we established the main cause of emigration from San José Llanga to be related to people being pulled away to seek improvements in their standard of living, and not being pushed out by environmental degradation per se, we did note a few patterns of environmental change and degradation. These observations helped us better understand the inherent complexity of environmental dynamics. Importantly, we learned that it was very difficult to generalise about environmental change because it varied according to different landscape units and had varied causes. Sometimes people and livestock were contributors to environmental degradation, but the most pervasive degradation seemed to be due to uncontrollable, non-management factors such as seasonal flooding and gradual processes of soil salinisation on low-lying sites.

We concluded that the landscape unit most threatened by unfavourable management factors was the alluvial terrace where most of the food crops were grown via rain-fed methods. The perception of the residents was that the cultivated lands of the alluvial terrace were "tired" and had been producing below capacity for some time. We hypothesised that a recent period of below-average rainfall was the simplest explanation for this perceived trend. Our other hypothesis was that crop productivity could be declining due to gradual and insidious effects of "agricultural modernisation" over the past 30 years, namely, the replacement of sheep manure by chemical fertilisers and/or expanded use of tractor tillage. In particular, we speculated that compared to chemical fertilisers, sheep manure is probably much better for the structure, fertility and water-holding capacity of alluvial soils. Use of chemical fertilisers has been encouraged primarily because they are inexpensive and easier to handle than bulky manure. People have also been selling more manure to traders in recent years, and traders then take it to peri-urban vegetable producers. We also speculated that use of tractors for tillage may serve to enlarge cultivated plots. This could allow more soil to be lost from the crop land matrix as wind-blown erosion compared to that for traditional tillage practices using animal draught power or manual methods. In sum, the seemingly beneficial forces that promote labour savings, technology adoption and increased efficiency for the management of cultivation could be undermining the long-term sustainability of food crop production on the alluvial terrace. In contrast to the alluvial terrace, there was one clearer example where recent alterations in management had led to negative changes in the cropping system. A smaller cultivated area called the deltaic deposits was observed to exhibit negative characteristics—invasion by halophytic cushion plants—due to irrigation with saline water from the Desaguadero River during the past decade. In this case, the impetus to quickly increase production of irrigated forages in support of smallholder dairying was apparently having long-term environmental consequences.

Although the rangelands of San José Llanga appear heavily utilised and have probably been substantially modified by hundreds of years of livestock grazing, there was, paradoxically, little evidence of contemporary change directly attributable to livestock pressure. Sacrifice zones nearer to settlements exhibited changes in grass species composition that were attributable to heavy livestock grazing, but this added to less than 8% of the area of the cantón overall. The vegetation dynamics of the rangelands in general were most likely dictated by uncontrollable phenomena such as drought, flooding and salinisation. Large barren sites that give an impression of over-grazing have actually been created by seasonal flooding, while dynamic patches of changing salinity in the top soil appeared to encourage a sparse cover of small, halophytic cushion plants at the expense of perennial forage grasses. It was concluded that there was little one could do in terms of grazing management to improve this system. Sheep and cattle were highly complementary in ecological terms. Use of grazing resources was extremely efficient with little waste. The residents of San José Llanga even strategised to sell the current year's lamb crop to make way for next year's lamb crop. Criollo cattle were also reduced in number by some producers to make more resources available for improved dairy cattle. These examples illustrate that the people were conscious of a livestock "carrying capacity" and tried to manage accordingly. Good market access helped them achieve such goals. There were virtually no wastage losses of animals to starvation (overstocking) during our research period.

In summary, when viewed in the big picture, the pattern of environmental degradation at San José Llanga was largely a consequence of landscape position on a large scale. Simply because San José Llanga occurs at lower elevations in the middle of the Altiplano means that it serves as a sink for water, nutrients and salt accumulation. In other words, it is a site that is vulnerable to natural forms of degradation (i.e., flooding or soil salinisation), yet it also tends to be resistant to human-induced modifications. The latter is true because soil moisture and other nutrients may typically be in adequate supply for major grazing areas during much of the year. One example of such resistance is how a deferred grazing system has resulted from the natural pattern of seasonal flooding on low-lying portions of the rangelands. During the height of the growing season forage on much of the saline lake bed is less accessible to livestock because of muddy conditions—at this time livestock graze more on fallow fields and other resources. Because forage on the saline lake bed tends to be grazed more after the top soil dries and the main growing period has ended, the risk that vegetation would be seriously and permanently damaged by chronic grazing pressure is greatly lessened. The composition of the rangeland plant community thus tends to be fairly resilient as a result.

All of these examples from cultivated land and range simply illustrate that for one research site, effects of climate, soils, humans and livestock can interact in different ways to variously affect each landscape unit. It is erroneous to always assume that human effects on the environment tend to be negative; we observed situations where effects of people and livestock were either positive or neutral. While the system dynamics observed at San José Llanga are likely to be seen in similar plains sites of the central Altiplano, it is abundantly clear that our findings cannot be generalised to other types of production systems. This is especially true when considering systems dominated by hillside agriculture, for example, that commonly occur along the Andean footslopes. In mixed hillside systems with terraced agriculture, heavy grazing or labour shortages could rapidly result in erosion and other serious environmental problems. In this light the dynamics of production systems on the alluvial plains must be regarded as distinct from those elsewhere.

The role of sheep in this agropastoral system, and how to improve or strengthen this role, was a prominent perspective on the project. We concluded that the critical aspect that needed further attention was the manure function described previously. In other words, the hypothesis that a switch to chemical fertilisers from sheep manure has had negative implications for soil management, and hence sustainable crop production, is a key idea for further research, outreach and policy formulation (see below). Other traditional sheep functions such as providing income and investment capital appeared, for many households at San José Llanga, to be of less concern. This was simply because the advent of small-holder dairying and prevalence of off-farm employment seemed to be making these other functions of sheep somewhat redundant in today's economy. This raises the issue as to whether investment in sheep production is still the best way to enhance livestock inputs, and hence sustainability, for the agropastoral system. At least in recent years, our observations suggested that given a choice, many people seemed to prefer to invest in dairy cattle or the education of their children rather than in sheep. This is not to say that sheep were unimportant—they were indeed vital as a ready source of disposable income and cheap protein and dietary fat, with substantial welfare and gender equity implications for households. Rather, it is to say that the marginal returns from investing in sheep and their risky rangeland forages probably tended to make sheep a less attractive investment option compared to returns that could be gained from investment in dairy cattle and irrigated forage or paying for a child's education. It is important to note, however, that the relative success of smallholder dairying at San José Llanga in recent years is due in large measure to the fact that it is subsidised. If these subsidies were removed the picture for places like San José Llanga could change dramatically. Sheep therefore provide a complementary and solid back-up system for many households should dairying become diminished in the future. Back-up systems and built-in redundancies are also critical for sustainability.

When looking at the overall production system at the conclusion of our work in 1998, it was obvious to us that sustaining agropastoralism on the Altiplano was not just a function of investment in crops or livestock, but also investment to improve standards of living to help rural communities be attractive places to live. Potable water, electricity, transportation and access to local education are thus vital. The advent of the Popular Participation Act in 1994, which espoused a redistribution of public money to help solve problems in rural areas, has been a positive move in this direction. Such a policy can help people be mobile and opportunistic, nurture cultural roots, and create social capital. It thus contributes to improved risk management for society at large.

We made a number of recommendations for management of research in Bolivia, research priorities and concepts for outreach. We advocated that more research be moved off-station and become more problem-oriented, integrated and inter-disciplinary. Bringing rural people into the planning loop in a participatory process is vital. More investment in research and promising young staff should occur. We found our training model, in which 27 Bolivian undergraduates lived together in the field and shared a dynamic office space in La Paz, to have been ideal. The students, mostly from urban backgrounds, saw how their small piece of research fit into a larger picture and they learned to not be fearful of mixing within a rural community.

For research, priorities included: (1) Getting a better understanding of possible precipitation cycles on the Altiplano; (2) rigorously examining the issue of the alleged decline in productivity of crop lands—seen as an important food-security issue—and linking this to possible soil management problems associated with "agricultural modernisation;" (3) socioeconomic work devoted to improving risk management for rural households and communities including marketing, policy review and formulating strategies that promote a vigilant and diversified rural population able to track and respond to new economic opportunities; (4) verifying patterns of possible child malnutrition and childhood morbidity; (5) technology and management interventions to mitigate problems of salinisation and frost on food crop and fodder production; (6) verify causes of livestock morbidity and seek cost-effective and culturally sensitive methods to reduce morbidity rates; and (7) range improvements to reclaim damaged sites, with more emphasis on range management.

For outreach, we recommended engaging more communities on topics like sheep marketing strategies to improve profitability, how to enhance soil fertility management on cultivated lands, and appropriate and cost-effective means to improve sustainable irrigation systems. Outreach could also be useful to find ways to tackle problems involving child malnutrition, childhood illness and family planning. Information on foods and their nutritive values could be useful given the high variety of foodstuffs in local markets.

All conclusions and recommendations above were written prior to obtaining knowledge about what had happened at San José Llanga during the late 1990s. We were able to get an up-date as of November, 1999, and some findings were very surprising.

First, our partner institution IBTA was closed in the late 1990s as a casualty of government decentralisation. It is envisioned that private regional research centres will be created by the year 2000 or shortly thereafter. These will solicit and fund proposals dealing with priority problems in rural areas. This is viewed as an approach that will be more effective in helping research meet the needs of rural people.

Next, the people of San José Llanga surprised us in several respects. Rather than continue a precipitous decline in population, the number of households increased to 130 by 1999, a combination of returning emigrants and young couples who decided to settle rather than leave. The driving factor? Apparently an incipient "potato boom" favouring improved breeds of potatoes—the first since the heyday of the 1960s. Even another cooperative association of potato producers is under consideration. Crop lands of the alluvial terrace are still viewed as "tired" and underproductive, however. A renewed interest in potato production may now, in turn, stimulate interest in improving soil management systems. Dairying is still commonly practiced, and donors have pledged to support smallholder programmes throughout the central Altiplano at least until 2003. One NGO has received funds under the auspices of the 1994 Popular Participation Act and is helping some households at San José Llanga rehabilitate saline range for sheep using halophytic forage plants. In terms of social issues, the new secondary school originally pushed by community leaders in the early 1990s has graduated its first group of young women (nine) in 1999.

These observations remind us that change is constant and people strive to improve themselves if given a chance. It is very important to note that it would have been almost impossible to model or predict these recent events that will fundamentally alter community dynamics. This demonstrates the large role of uncertainty in the development process, and challenges deterministic notions held by some researchers and development practitioners. The overall pattern illustrates that the crucial collective resource decision is simply where people decide to live, and this seems to have been largely dictated by market signals. The fact that people have settled in San José Llanga in large numbers testifies to the idea that given an opportunity to earn higher incomes they may indeed be happiest to return home considering other local improvements in their living standards. The message for policy makers seems simple: Policy actions that support sustainable production of key commodities from the Altiplano, and support improvement in rural living conditions, are very useful to better manage the rural/urban dynamic. This prominently includes attention to development and trade factors that constrain prices for crops and livestock products. Higher commodity prices should promote more sustainable rural communities on the Altiplano as long as basic living conditions are satisfactory. Such a comprehensive approach would also benefit national food security by keeping these very capable people linked to the land.

D. Layne Coppock

Resumen ejecutivo

Este documento es una síntesis de la investigación de campo realizada entre 1991-5 por el proyecto conjunto IBTA/SR-CRSP (Instituto Boliviano de Tecnología Agropecuaria/Programa Colaborativo de Apoyo a la Investigación en Rumiantes Menores) en el Altiplano central. El análisis e interpretación de los datos continuaron hasta 1998, se ha incluido un epilogo que cubre eventos recientes hasta 1999. Nosotros, por lo tanto, nos hemos esforzado para proporcionar una perspectiva relevante para la década de 1990-2000. La mayoría de los datos de campo para este proyecto fue obtenido por 27 estudiantes bolivianos quienes completaron sus tesis como parte de los requisitos de las universidades Bolivianas para su graduación.

La meta general del proyecto fue identificar los factores que amenazan la sostenibilidad de la producción agropastoril en sistemas semi-áridos. Recientemente, áreas urbanas en el o cerca del Altiplano, han experimentado un notable incremento del flujo de emigrantes del área rural. No es claro si el grado en que la migración ocurre se debiese a factores medioambientales, sociales o económicos. Si la degradación medioambiental fue el factor que presionó a la gente para abandonar las áreas rurales, era importante entender si estos cambios fueron causados por actividades relacionadas a la gente o se deben, mas bien, a fuerzas naturales incontrolables, como la sequía o el incremento de la salinidad del suelo. Si las actividades humanas fueron las responsables, era importante entender si éstas se relacionan al sobrepastoreo, al mal-manejo de los recursos utilizados para la producción agrícola, o algún otro factor. Si cambios en la producción ganadera, praderas, cultivos u otros aspectos de manejo de recursos naturales pudiesen ayudar a resolver los problemas, se intentó identificar las intervenciones técnicas y políticas que podrían ser útiles para mejorar la situación. Para conseguir estas metas se prestó un interés particular de cómo fortalecer el rol de los ovinos en los sistemas de producción agropastoriles. Al contrario, sin embargo, si la migración no fue causada por factores medioambientales o técnicos, y, se debió mas bien, a factores sociales y económicos, tales como, las aspiraciones de cambio en el estilo de vida de los agricultores o a los precios bajos de sus productos, lo que llevaría a poner más atención en soluciones no-técnicas para los problemas del desarrollo.

Primero, para establecer el contexto se presenta una breve descripción del sistema que se estudió. Luego, se contestó las preguntas presentadas en el párrafo anterior y se recomendaron algunas prioridades para futuras investigaciones, extensión, y consideraciones sobre políticas. Los lectores interesados en más detalles deberán consultar el Capitulo 8: *Conclusiones y Recomendaciones.*

El lugar de estudio fue el Cantón de San José Llanga, una comunidad con un área de 72 km^2, ubicada aproximadamente a 120 km sureste de las ciudades de La Paz y El Alto y 17 km al sur del pueblo de Patacamaya en la carretera internacional Panamericana. Residencia de aproximadamente 400 personas (100 familias) y más de 5600 cabezas de ganado durante los primeros años de la década de 1990-2000, el sistema de producción es típico, en muchos aspectos, a los de las planicies aluviales del Altiplano central. Sin embargo, San José Llanga fue atípico, con respecto a su proximidad a grandes mercados y al hecho de haber tenido mas de 30 años de experiencia en transferencia de tecnología debido a la presencia de la Estación Experimental de Patacamaya, establecida en 1958. Estos atributos de accesibilidad a mercados y tecnología hicieron de San José Llanga, sin embargo, un "laboratorio viviente" ideal para observar procesos de desarrollo.

La investigación fue multi- e inter-disciplinaria e incluyó las ciencias de biología, ecología, y sociología. Los estudiantes y sus supervisores pasaron mucho tiempo en la comunidad. Los métodos de investigación incluyeron inventarios muy elaborados y análisis de los recursos animales, vegetales, suelos e hídricos. Se efectuaron medidas de la productividad agrícola. En algunos casos se realizaron experimentos. Entrevistas con individuos, familias y grupos focales también fueron ampliamente efectuadas usando una variedad de métodos formales e informales.

La gente de San José Llanga son indígenas autóctonos Aymaras. Hace algunos siglos, la comunidad de San José era parte de una unidad socioeconómica tradicional o *Ayllu* llamada Llanga, que operaba a través de varias zonas agroecológicas. Este *Ayllu* fue destruido por los

invasores Españoles entre la mitad y el final de la centuria de 1500-600. Tal como ocurrió con muchos indígenas en Bolivia, la gente de San José Llanga fue sometida a centurias de prejuicio y opresión impuestos por las fuerzas coloniales y posteriores gobiernos de la republica. La comunidad de San José Llanga tiene una historia de fuerte resistencia a los forasteros. En los últimos 50 años, sin embargo, cambios revolucionarios han ocurrido en la esfera de la política nacional. La gente de San José Llanga ha sido capaz de conseguir educación formal, adoptar nueva tecnología agrícola y participar de los mercados emergentes. En términos de nivel de vida, sin embargo, la población a comienzos de la década de los noventa a estado mostrando éxitos mezclados. Por una parte, la proporción de alfabetos adultos fue muy alta. Por otra parte, la nutrición y salud de los niños fueron determinados como riesgos potenciales para la comunidad. Problemas de sanidad pública y falta de acceso rutinario a cuidados profesionales en salud también fueron observados por los investigadores.

En los primeros años de la década de 1990, la gente de San José Llanga se distribuía en seis asentamientos (estancias) localizados a lo largo de una banda central norte / sur que corre a través de la mitad del cantón. El tamaño y los recursos disponibles en cada asentamiento fueron muy variables. Se ha estimado que menos que 100 familias ocupaban el cantón en 1890, creciendo hasta 125 familias en 1970. Al tiempo de esta investigación, la población decreció hasta alrededor de 100 familias. Nosotros proyectamos, que en el futuro, el número de familias se estabilizará en alrededor de 80 debido a la constante migración de los jóvenes y el fallecimiento de los residentes ancianos. La migración desde los primeros años hasta la mitad de la década de 1990-2000 fue relacionada a cambios en las aspiraciones de los residentes, quienes deseaban cambios en su estilo de vida que San José Llanga no podía ofrecer. La mayoría de los emigrantes se dirigieron a centros urbanos para encontrar trabajos y continuar con la educación secundaria. Los emigrantes no se movilizaron debido a la degradación medioambiental. Bajo un liderazgo comunal creativo y agresivo, sin embargo, se intentó detener la migración a través de inversiones en el mejoramiento de los servicios de agua potable, energía eléctrica, sistemas de riego para cultivos, letrinas y la construcción de un nuevo colegio secundario. Este liderazgo fue un ejemplo excelente de la importancia del capital social para promover sostenibilidad en comunidades rurales

La agricultura típicamente se hacía en las partes ligeramente elevadas en un paisaje de otra manera casi plano. El agua para los cultivos fue proporcionada ya sea, por la precipitación natural, diferentes formas semi-naturales o sistemas de riego construidos por el hombre. La sequía y la helada fueron riesgos permanentes para la agricultura para mitigar estos riesgos los productores distribuían ampliamente docenas de parcelas tanto temporal como espacialmente. La producción agrícola se hacia mayormente en parcelas de acceso controlado y fue dominada por producción de papa, cereales y forrajes cultivados. Las tierras en descanso fueron importantes para el pastoreo y para la cosecha de los abundantes arbustos para leña. Los cultivos de productos para alimentación humana fueron típicamente para consumo familiar excepto en años de abundancia cuando el excedente pudo ser vendido. Las familias pudientes tenían mayor probabilidad de excedentes debido a que tenían acceso a mayores extensiones de tierra agrícola. Los forrajes cultivados, tal como la alfalfa, fueron producidos mayormente para alimentar vacas lecheras mestizas, y secundariamente para ovinos mejorados. Los forrajes se cultivaban donde había riego disponible, lo que dependía de su posición en el paisaje. La ganadería también fue un componente muy importante para el sistema de produccion. Las razas de ovinos incluían la Criolla y el cruce entre el Criollo y Corriedale. Los vacunos constituían Criollos para tracción animal y de mezclas mejoradas para leche, tal como la de Criollo y Holstein (Friesian). El pastoreo era la fuente dominante de alimento para el ganado y estas fuentes incluyeron praderas naturales no mejoradas que cubrían una llanura seca y salina de origen lacustre así como una estratégica dependencia de los cultivos de alfalfa y de residuos de cosecha. Los ovinos han sido tradicionalmente importantes para proveer estiércol para fertilizar los cultivos de papa. Los burros transportan el abono a los terrenos y pequeñas cantidades son aplicadas manualmente a la siembra de papa. Los ovinos fueron una fuente importante de ingreso regular, carne barata y capital para el sistema. Los ovinos mejorados fueron mayormente para el mercado y el Criollo para consumo familiar. El manejo de los ovinos y su comercialización estaba bajo el dominio de la mujer—la mujer vendía ovejas para comprar productos requeridos para la familia tales como comida, vestimenta y material escolar. En nuestro análisis de la producción de ovinos encontramos que las tazas de mortalidad de corderos y adultos fueron muy bajas, pero desafíos de morbilidad fueron altos debido al pobre manejo sanitario. Los ovinos mejorados fueron más productivos que las razas Criollas indígenas. La lechería de pequeños productores estaba basada en razas mejoradas dentro de una estructura subvencionada la que ha sido una incorporación reciente y muy popular al sistema. Esta actividad aparentemente satisfizo una necesidad por mayores y más frecuentes fuentes de ingreso en la comunidad San José Llanga, en la mitad del decenio de 1990-2000, fue uno de los mayores productores de leche de la región. La ganadería de leche fue también una fuente importante para la acumulación de capital. Ultimadamente, en algunos casos, este capital podría ser diversificado en inversiónes fuera de la unidad de producción. Debido a que las seis estancias variaron en relación con su ubicación, estas también variaron en potencial de riego, producción de forrajes cultivados, y capacidad de criar vacunos y ovinos mejorados. En las estancias capaces de mantener pequeñas lecherías, de acuerdo a lo reportado, había menos familias que buscaban trabajo de corto o largo plazo fuera de la unidad de producción, comparadas con las familias de las estancias que dependían de la lluvia para la producción de forraje y que criaban solamente razas de ganado Criollo. Esto ilustra, que intervenciones tal como la de pequeños productores lecheros podrían ayudar a estabilizar la economía familiar.

El trabajo de campo incluye mayormente el periodo cuando la precipitación anual estuvo cerca al promedio de largo tiempo de 406 mm, excepto, 1995 que fue un año seco cuando la precipitación fue 40% más baja que el promedio. Esta situación presentó la oportunidad de observar los efectos de un año seco en el sistema.

Durante el año seco de 1995, esperamos observar que las familias de productores sufrirían debido a los bajos niveles de producción comparados con el año 1993 que presentó una precipitación muy cerca al promedio. Se anticipo que las familias con mayor capacidad de vender productos de la ganadería y buscar empleo fuera de la unidad de producción podrían mitigar en mejor grado los impactos de la sequía. Los precios de los productos durante 1995, sin embargo, exhibieron incrementos substanciales (entre 30 hasta 400%) comparados con aquellos de 1993. Tal como se predijo, algunas familias vendieron mas ovejas y buscaron más empleo fuera de la unidad de producción en 1995 comparando con 1993. En general, la gente fue capaz de mitigar muy efectivamente la sequía de un año. Ellos usaron generalmente sus mayores ingresos de 1995 para comprar más comida para cubrir la potencial falta de alimentos causada por la baja producción de los cultivos. Estos patrones ilustraron el importante rol de los rumiantes menores, el buen funcionamiento del mercado y el empleo fuera de la unidad de producción para la mitigación de la sequía. Sequías pasadas fueron también reportadas en promover en la gente un mayor interés en lechería a nivel de pequeños productores para incrementar y diversificar el ingreso familiar.

El año seco de 1995 y varios patrones de migración también ayudaron a clarificar aspectos de la tenencia de los recursos en San José Llanga. En general, la tendencia durante los últimos 50 años ha sido hacia un mayor control privado de las parcelas agrícolas de alto valor, las cuales estaban anteriormente y mayormente bajo regulaciones comunales de uso. La tendencia actual se inició con las iniciativas de la reforma agraria nacional en los primeros años de la década de 1950-60 cuando los que trabajaban la tierra recibieron derechos de acceso a esas tierras. La tendencia subsiguiente ha sido de una transferencia entre-generaciones de acceso privado a la propiedad de los padres a los hijos, aunque el mercado de la tierra no existe *per se* debido a que la propiedad no es legalmente vendible. En algunos casos, últimamente, esta tendencia ha resultado en el incremento de la fragmentación de las propiedades. En contraste a la tierra de cultivo, los campos naturales de pastoreo se mantienen bajo patrones de acceso más diversos y dinámicos. Tierras de pastoreo de alta calidad podrían estar bajo acceso controlado, mientras que las praderas de menor calidad son de acceso comunal. La matriz de acceso resultante es compleja y son un desafió para los pastores quienes deben esforzarse en obedecer las reglas de uso. El pastoreo inteligente es por lo tanto un aspecto relevante del sistema. En particular, mujeres jóvenes son pastoras muy bien calificadas. Los rebaños son llevados a pequeñas manchas remanentes de forraje de acuerdo al avance del año y los corderos son capaces de mantener tasas de crecimiento aceptables. Los emigrantes seleccionan cuidadores para cuidar los cultivos y el ganado mientras ellos estén ausentes, con formas tradicionales de uso común de los recursos y compensación en-productos como forma de pago. Esta conducta de compartir los recursos y la de cuidadores permiten a las familias pobres ganar acceso a los recursos de ganado y de cultivos ante la ausencia de mercados formales. Estos acuerdos también ayudan a los emigrantes a reducir los riesgos de la migración y mantener fuertes conexiones con la comunidad local.

La gente del Altiplano central ha experimentado más que 30 años de esfuerzos en transferencia de tecnología, empezando en la década de 1950-60. Paquetes tecnológicos para mejorar la producción de papas fueron introducidos en la década de 1960-70 durante el "potato boom", o cuando los precios eran mas altos. Fue organizada una cooperativa. Se compró un tractor y empezó la dependencia en fertilizantes baratos. La década de 1960-70 fue también tiempo del "wool boom" y ovinos mejorados fueron importados como parte de esfuerzos bilaterales de ayuda para mejorar el potencial productivo de lana y carne del ovino Criollo. Este paquete técnico incluye el establecimiento de una base de forraje mejorado a través de cultivo de alfalfa en áreas con altos niveles de agua subterránea. Cerca de 30 años después, en la mitad de la década de 1990-2000 tanto la papa como los ovinos mejorados se han integrado bien en el sistema de producción tradicional de San José Llanga. Recientemente la papa y los ovinos mejorados han sido típicamente preferidos para el mercado, aunque en el caso de los ovinos la producción de carne ha sido más valorada que la de lana. En contraste, las variedades locales de papa y el ovino criollo tienden a ser más usados para consumo familiar. Aproximadamente la mitad de los rebaños de ovinos de ocho comunidades locales de la provincia Aroma estaban conformados por cruzas Criollo x Corriedale en 1995. La adopción de los ovinos mejorados parece estar asociada más con los sistemas de producción en la llanura que con los de las laderas de las serranías, lo que probablemente se debe a la mayor disponibilidad y variabilidad de cultivos y forrajes en los primeros. La gente expuesta a programas de extensión y entrenamiento tienen una mayor predisposición a adoptar ovinos mejorados siempre que ellos sean también capaces de mejorar la producción de forrajes. En papa, durante el curso de esta investigación semillas de variedades mejoradas fueron comunmente sembradas con semillas de variedades de papas indígenas "amargas"—de acuerdo a los reportes cada variedad ofrece cualidades complementarias con respecto al riesgo de helada y sequía. Vacas lecheras mejoradas fueron adoptadas por cerca de un tercio de las familias de San José Llanga entre 1989 y 1995. Las familias pudientes con acceso a forraje bajo riego fueron las más predispuestas a involucrarse como pequeños productores lecheros.

La adopción de tecnología parece tener efectos ondulantes en el tiempo. Aunque, las parcelas de alfalfa fueron originalmente establecidas en la década de 1960-70 para soportar ovinos mejorados, hubo un renovado interés para la expansión del cultivo de forraje con el advenimiento de la pequeña producción de leche en los primeros años de la década 1990-2000. A esta iniciativa siguió un "dairy boom" y forzó a muchas familias a convertir tierras de cultivos de alimentos a cultivos de forraje. El "dairy boom", también ayudó a iniciar proyectos comunales ambiciosos de riego, que incluyeron el desvió del río temporal *Kora Jahuira* para crear una fértil terraza aluvial cerca del asentamiento llamado Barrio en el centro de la comunidad y de un canal de 23-km que fue construido desde el río Desaguadero de agua salina, para regar otras áreas tal como la de los depósitos délticos. Estos esfuerzos para establecer más forraje cultivado para vacunos en años recientes, ha resultado en un círculo completo que ultimadamente beneficia, una vez mas, a los ovinos mejorados como una actividad secundaria.

Aunque, en general, los datos de la adopción de tecnología en San José de Llanga han sido favorables, parecería que esta adopción ha sido viciada hacia las familias pudientes y podría haber creado más trabajo para las mujeres. La polarización de la riqueza en la comunidad puede ser un problema de importancia. De qué modo las nuevas tecnologías alimentan la mencionada polarización, en lugar de disminuirla, es una importante consideración.

La mezcla de tecnología nueva con la tradicional ha permitido a la gente de San José Llanga a ampliar la diversificación de su economía y, por lo tanto, ser más capaz de responder en formas oportunistas ante las nuevas opciones del mercado; Esto, también ayudó a proteger contra un clima variable. Lo descrito parece seguir un camino algo diferente de desarrollo, que el indicado, por el "paradigma de modernización", donde la adopción de nueva tecnología lideriza a una sistemática reducción en prácticas tradicionales y al incremento del grado de especialización del productor.

Aunque, se estableció que la causa mayor de la migración de San José de Llanga estaba relacionada a la gente siendo movida en busca de un mejor nivel de vida, y que no fue promovida por la degradación ambiental *per se*, se notaron pocas muestras de cambio medioambiental y de degradación. Estas observaciones nos ayudaron a entender mejor la inherente complejidad de la dinámica medioambiental. Muy importante, se aprendió que fue muy difícil hacer generalizaciones acerca de cambios medioambientales porque estos variaban de acuerdo a las diferentes unidades de paisaje y tuvieron diferentes causas. Algunas veces la gente y el ganado contribuyeron a la degradación medioambiental, pero la degradación más persistente parece deberse a factores incontrolables no-manejables tales como inundaciones estacionales y procesos graduales de salinización del suelo en sitios que se encuentran en lugares bajos.

Se concluyó que, la terraza aluvial, donde la mayor parte de los cultivos para consumo humano fueron efectuados vía métodos con agua de lluvia, fue la unidad de paisaje más amenazada por factores de manejo inapropiado. La percepción de los residentes fue que las tierras cultivadas de la terraza aluvial estaban “cansadas” y que han estado produciendo por debajo de su capacidad por algún tiempo. Nosotros hipotizamos de que un reciente periodo de lluvia bajo el promedio fue la explicación más simple para esta tendencia. Otra de nuestras hipótesis fue que la productividad de los cultivos podría estar declinando debido a un gradual y pernicioso efecto de la “modernización agrícola” en los últimos 30 años, particularmente, el reemplazo del estiércol de ovino por fertilizante químico y/o el uso intensivo del tractor para trabajar el suelo. En particular nosotros especulamos que comparando al fertilizante químico, el estiércol de ovino es probablemente mucho mejor para la estructura, fertilidad y para la capacidad de retención de agua de los suelos aluviales. El uso de los fertilizantes químicos ha sido promovido primeramente por que no son caros y son más fáciles de manejar que el voluminoso abono orgánico. Se observó, también, en años recientes, que la gente esta vendiendo más abono orgánico a comerciantes, luego, los comerciantes transportan el abono para venderlo a los productores de vegetales peri-urbanos. También especulamos que el uso menos preciso del tractor para la preparación de suelo pudo servir para agrandar las parcelas de cultivo. Esto podría permitir una mayor perdida de suelo de la matriz de tierras de cultivo como erosión eólica comparada a aquella producida por las prácticas tradicionales de preparación de suelo con fuerza de los animales de tiro o métodos manuales. En suma, las fuerzas aparentemente beneficiosas que promueven el ahorro de mano de obra, adopción de tecnología y el incremento de la eficiencia en el manejo de los cultivos podría estar minando la sotenibilidad en el largo-plazo de la producción de cultivos en la terraza aluvial. En contraste a la terraza aluvial, hubo un claro ejemplo donde alteraciones recientes en manejo han derivado en cambios negativos en el sistema agrícola. Una pequeña área cultivada llamada los depósitos délticos fue observada mostrando características negativas—invasión de plantas postradas halófilas—debido a la irrigación con agua salina del Río Desaguadero durante la década pasada. En este caso, el impacto de incrementar rápidamente la producción de forrajes con riego para apoyar la producción de los pequeños lecheros esta aparentemente teniendo en el largo-plazo consecuencias medioambientales.

Aunque, los campos naturales de pastoreo de San José Llanga aparentan estar pesadamente utilizados y probablemente han sido substancialmente modificados por cientos de años de pastoreo por el ganado, hubo, paradójicamente, poca evidencia de cambios contemporáneos directamente atribuibles a la presión de pastoreo. Zonas de sacrificio cerca de los asentamientos exhibieron cambios en la composición de especies de pastos que fueron atribuibles a la fuerte presión de pastoreo del ganado, pero esto no suma más del 8% del total del la cantón. La dinámica vegetal de los campos de pastoreo, en general, parece más posiblemente determinada por fenómenos incontrolables tales como la sequía, inundaciones y salinización. Grandes áreas descubiertas que dan la impresión de sobrepastoreo, actualmente, han sido creadas por inundación estacional, mientras que la dinámica de los manchones que cambian con la salinidad del suelo superficial parece favorecer una cobertura dispersa de pequeñas plantas halófilas de crecimiento postrado, a costa de pastos forrajeros perennes. Se concluyó que muy poco se puede hacer en términos de manejo del pastoreo para mejorar el sistema. Ovinos y vacunos fueron altamente complementarios en términos ecológicos. El uso de los recursos forrajeros fue extremadamente eficiente con muy poco desperdicio. Los residentes de San José Llanga, llegaron a planificar para vender la cosecha de corderos del año para habilitar espacio y recursos para los corderos de la cosecha del siguiente año. El número de vacunos Criollos también fue reducido por algunos productores para disponer de mayores recursos para sus vacunos lecheros mejorados. Estos ejemplos ilustraron, que la gente estaba conciente de la "capacidad de carga" del ganado y que trataban de manejar de acuerdo a este concepto. El acceso a un buen mercado ayudó, entonces, a alcanzar tales objetivos. No hubo virtualmente perdidas de ganado por hambruna (sobrecarga) durante el periodo de esta investigación.

En resumen, visualizando la gran figura, el patrón de degradación medioambiental en San José Llanga fue mayormente una consecuencia de su posición en el paisaje en una gran escala. Simplemente, San José Llanga se localiza en las partes más bajas del centro del Altiplano lo que significa que sirve como un colector de agua, y para la acumulación de nutrientes y sal. En otras palabras, es un sitio vulnerable a las formas naturales de degradación (p.e., inundación o salinización del suelo), además tiende a ser también resistente a modificaciones inducidas por los seres humanos. Lo último es cierto por que la humedad del suelo y otros nutrientes pueden típicamente estar presentes en cantidades adecuadas en las principales áreas de pastoreo durante gran parte del año. Un ejemplo de esta resistencia es que un sistema de pastoreo diferido ha resultado del patrón natural de inundaciones estacionales en las porciones bajas de los campos de pastoreo. Durante el máximo periodo de crecimiento del forraje en la mayor parte del área de suelo salino lacustre, éste es menos accesible al ganado debido a la condición fangosa del suelo en este período el ganado pastorea mayormente en las tierras de cultivo en descanso y en otros recursos. Debido a que el forraje en el área de suelo lacustre del lago seco salino tiende a ser pastoreado mayormente luego que la parte superficial del suelo se ha secado y el principal periodo de crecimiento de las plantas ha finalizado, por lo tanto, el riesgo de que la vegetación podría ser seria y permanentemente dañada por presión de pastoreo crónico disminuye significativamente. Como resultado, el sistema de pastoreo, por lo tanto, tiende a ser altamente resiliente.

Todos estos ejemplos en tierras cultivadas y praderas nativas simplemente ilustran que para un sitio de investigación, los efectos de clima, suelos, humanos y del ganado pueden interactuar de diferentes maneras y afectar en forma variada a cada unidad de paisaje. Es erróneo asumir que los efectos antrópicos en el medioambiente, siempre, tienden a ser negativos, tanto así que nosotros observamos situaciones donde los efectos de la gente y del ganado fueron o positivos o neutrales. Mientras los modelos observados en San José Llanga están probablemente presentes en otros sitios planos del Altiplano central, es abundantemente claro que nuestros descubrimientos no pueden ser generalizados a otros tipos de sistemas de producción. Lo anterior, es especialmente cierto cuando se consideran sistemas dominados por agricultura en laderas, por ejemplo, lo que ocurre comúnmente a lo largo de los piedemontes. En sistemas mixtos en ladera con agricultura en terrazas, el pastoreo pesado o falta de mano de obra rápidamente pueden resultar en erosión u otros serios problemas medioambientales. En vista de esto, la dinámica de los sistemas de producción sobre suelos aluviales debe ser considerada como distinta a cualquier otra.

El rol de los ovinos en este sistema agropastoril, y de qué manera mejorar o fortalecer su rol, fue un aspecto importante de este proyecto. Se concluyó que se requiere futura atención al rol crítico de la función del estiércol previamente descrito. En otras palabras, la hipótesis de que el cambio del estiércol de ovino por fertilizante ha tenido implicaciones negativas para el manejo del suelo y, por lo tanto, para la producción sostenible de cultivos, es una idea clave para futura investigación, extensión y formación de políticas (ver abajo). Otras funciones tradicionales de los ovinos, tales como el proveer ingresos y acumulación de capital, parecen ser, para muchos habitantes de San José Llanga, de menor interés. Esto es simplemente porque el incremento de la lechería de pequeños productores y la prevalencia de empleo fuera de la unidad de producción parecería están haciendo las otras funciones de los ovinos algo redundantes en la economía actual. Lo mencionado, pone en tapete el problema de que si la inversión en la producción de ovinos es todavía la mejor forma de incrementar los ingresos de la ganadería, y por lo tanto, la sostenibilidad del sistema de producción agropastoril. Por lo menos, en años recientes, nuestras observaciones sugirieron que dada la selección, mucha gente parece preferir la inversión en vacas lecheras o en la educación de sus hijos mós que en ovinos. Esto no quiere decir que los ovinos no son importantes—ellos fueron, en efecto, vitales como una fuente inmediatamente disponible de ingresos, proteína barata y grasa, con implicaciones substanciales para el nivel de vida y equidad de genero para las familias. En todo caso, seria apropiado decir que los retornos marginales de la inversión en ovinos y de sus fuentes riesgosas de forraje de las praderas probablemente hicieron de estos una opción de inversión menos atrayente comparada con el retorno que se podría ganar de invertir en vacas lecheras y forrajes cultivados o pagando por la educación de los niños. Es importante notar, sin embargo, que el éxito relativo de los pequeños productores lecheros en San José Llanga en años reciente se debe en gran medida al hecho de que ésta es subsidiada. Si estos subsidios fueran removidos el panorama para lugares iguales a San José Llanga podría cambiar dramáticamente. Si la lechería disminuyera en el futuro, los ovinos, por lo tanto, proveerían una complementaria y sólida reserva al sistema para muchas familias. Sistemas de seguro y acumulación de excedentes son también críticos para la sostenibilidad.

Cuando se observa a todo el sistema de producción a la conclusión del trabajo en 1998, fue obvio para nosotros que el agropastorilismo sostenible en el Altiplano era no solo función de inversiones en ganado o cultivos, pero también de inversiones en mejorar el nivel de vida para ayudar a las comunidades rurales a ser lugares atractivos para vivir. Agua potable, electricidad, transporte y acceso a educación local son, por lo tanto, vitales. La promulgación de la Ley de Participación Popular en 1994, la que determina una redistribución del dinero público para ayudar a resolver problemas en áreas rurales, ha sido un movimiento positivo en esta dirección. Políticas como la mencionada puede ayudar a la gente ser más dinámica y oportunista, promover las raíces culturales, y crear capital social. Esto, por lo tanto, contribuye de gran manera para el mejoramiento del manejo del riesgo para la sociedad.

Nosotros hicimos un número de recomendaciones para el manejo de la investigación en Bolivia, prioridades de investigación y conceptos para extensión. Nosotros recomendamos que gran parte de la investigación debe ser trasladada fuera de las estaciones de investigación y debe ser más orientada a resolver problemas críticos, integrada e interdisciplinaria. La inclusión de la gente del área rural dentro del círculo de la planificación en un proceso participativo es vital. También debería hacerse más inversiones en investigación y en capacitación de jóvenes técnicos prometedores. Se encontró que nuestro modelo de entrenamiento, en el cual 27 egresados Bolivianos vivieron juntos en el campo y compartieron una dinámica oficina en La Paz, resultó ser ideal. Los estudiantes, la mayoría de origen urbano, vieron como sus pequeñas piezas de investigación cabían dentro de una figura mayor y aprendieron a no ser temerosos de mezclarse dentro de la comunidad rural.

Las prioridades de investigación incluyen: (1) Conseguir un mejor entendimiento de los posibles ciclos de precipitación en el Altiplano; (2) examinar rigurosamente el problema de la alegada declinación de la productividad de las tierras agrícolas—parece ser un importante problema de seguridad alimentaría—y relacionarlo a posibles problemas de manejo de suelos asociados con la “modernización de la agricultura”; (3) trabajo en socioeconomía dedicado al mejoramiento del manejo del riesgo para las familias rurales y comunidades incluyendo comercialización, revisión de políticas y formulación de estrategias que promuevan a una vigilante y diversificada población rural, capaz de seguir y responder a las nuevas oportunidades de la economía; (4) verificar pautas de posible mala nutrición en los niños y morbilidad infantil; (5) tecnología e intervenciones de manejo para mitigar problemas de salinización y heladas en los cultivos para alimentación humana y la producción de alimentos para el ganado; (6) verificar casos de morbilidad del ganado, buscar métodos costo-efectivos y culturalmente aceptables para reducir las tasas de morbilidad; y (7) mejoramiento de los campos naturales de pastoreo para recuperar sitios dañados, con mayor énfasis en manejo de praderas.

Para extensión, incluir más comunidades en tópicos como estrategias de comercialización de ovinos para mejorar las ganancias, como mejorar el manejo de la fertilidad del suelo en tierras cultivadas, y formas adecuadas y costo-efectivas para mejorar y hacer sostenibles los sistemas de irrigación. Extensión puede ser también útil para encontrar formas de atacar los problemas de malnutrición de los niños, enfermedades infantiles y planificación familiar. Información sobre los alimentos y sus valores nutritivos pueden ser útiles dada la gran variedad de productos alimenticios en los mercados locales.

Todas las conclusiones y recomendaciones presentadas fueron escritas previamente a conocer lo que pasó en San José de Llanga durante los últimos años de la década de 1990-2000. Nosotros fuimos capaces de obtener una actualización hasta Noviembre de 1999 y algunos hallazgos fueron muy sorprendentes.

Primero, nuestra institución contraparte IBTA fue cerrada en los últimos años de la década del 1990-2000 como una baja de la descentralización gubernamental. Se pretende que centros privados de investigación regional serán creados para el año 2000 o algún tiempo después. Estos solicitaran y financiaran propuestas relacionadas con problemas prioritarios en áreas rurales. Esto se visualiza como una aproximación que será más efectiva ayudando a determinar las necesidades de investigación de la población rural.

Luego, la gente de San José Llanga nos sorprendió en varios aspectos. En lugar de continuar una precipitada caída en población, el número de familias se incrementó hasta 130 en 1999, una combinación de retorno de emigrantes y de parejas jóvenes que decidieron permanecer en la comunidad en lugar de partir. ¿Cuál fue el factor impulsor? Aparentemente un incipiente "potato boom" favoreciendo razas de papas mejoradas—el primero desde el sorprendente "potato boom" de la década de 1960-70. Aun, otra asociación cooperativa de productores de papa esta bajo consideración. Sin embargo, las tierras de cultivo de la terraza aluvial son vistas todavía como "cansadas" e improductivas. Un renovado interés en la producción de papa puede, a su vez, estimular el interés en el mejoramiento de los sistemas de manejo del suelo. La lechería es todavía comúnmente practicada, y donantes han garantizado apoyar programas para pequeños productores a lo largo del Altiplano central por lo menos hasta el 2003. Una ONG ha recibido fondos por la Ley de Participación Popular de 1994 y esta ayudando algunas familias de San José Llanga en la rehabilitación de praderas salinas para ovinos usando plantas forrajeras halófilas. En términos de temas sociales, el nuevo colegio secundario originalmente impulsado por los lideres de la comunidad en los primeros años de la década de 1990-2000 ha graduado su primer grupo de mujeres jóvenes (nueve) en 1999.

Estas observaciones nos recuerdan que el cambio es constante y la gente se esfuerza para mejorar por si misma si se les da la oportunidad. Es muy importante hacer notar, que habría sido casi imposible modelar o predecir estos eventos recientes que alteraron fundamentalmente la dinámica de la comunidad. Esto demuestra el gran rol de incertidumbre en los procesos de desarrollo, y desafía nociones determinístas sostenidas por algunos investigadores y practicantes de desarrollo. El modelo general ilustra, que la decisión colectiva crucial, es simplemente donde la gente decide vivir, y ésto, parece estar mayormente determinado por señales del mercado. El hecho, de que la gente se ha establecido en San José Llanga en gran número confirma la idea, que, dada una oportunidad para ganar mayores ingresos, la gente, en efecto, fácilmente retorna a casa considerando otras mejoras locales en su nivel de vida. El mensaje para los políticos parece ser simple: Acciones de políticas que apoyen la producción sostenible de productos clave del Altiplano, y apoyo al mejoramiento de las condiciones de vida en el área rural, son muy útiles para mejor manejar la dinámica rural / urbana. Esto incluye prominentemente la atención a factores de desarrollo e intercambio que restringen los precios de productos de agricultura y de ganaderia. Precios de productos mas altos debieran promover comunidades rurales mas sostenibles en el Altiplano, siempre y cuando las condiciones básicas de vida sean satisfactorias. Tal extensivo enfoque debiera también beneficiar la seguridad alimentaria nacional manteniendo a esta gente muy capaz ligada a la tierra.

D. Layne Coppock

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Mr. Aguilar, Bolivian, was a research associate in economics with the IBTA/SR-CRSP programme during 1994. His contributions focused on the economics of sheep production at San José Llanga. He has recently been an instructor in economics at the Technical University of Beni, Beni, Bolivia.

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Dr. Alzérreca, Bolivian, was chief of the IBTA Livestock and Forage Production Programme until 1991 and served as a national coordinator and co-investigator in range ecology from 1991-2. He supervised the initial work of two B.Sc. students and participated in the selection of other national co-investigators and students. Recognized as a Bolivian expert in Andean range ecology, he was a key participant in the initial planning and site selection for SR-CRSP activities during 1990-1. Dr. Alzérreca completed his Ph.D. in Range Science at Utah State University in 1997 based on studies of salt-desert vegetation in Utah and currently works in Bolivia. He has written several articles and a book on native forages and production systems for the Bolivian Andean Zone.

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Dr. Flores, Peruvian, is Professor Emeritus of the National Agrarian University, La Molina, Peru. He briefly served as the initial coordinator for the SR-CRSP in Bolivia when the project started in 1991. Dr. Flores also helped initiate *RERUMEN* in Bolivia during 1991, a network for small ruminant research in Latin America. He has consulted on forage research for dairy production and has written several books on native forages and pastures for the Andean region. He participated in the initial planning and site selection.

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Christian Jetté

Mr. Jetté, a Canadian citizen and Bolivia resident since 1985, variously served the SR-CRSP as a national co-investigator and acting resident scientist in sociology during 1991-6. He also served as project liaison with campesino communities. His research interests broadly dealt with sociology, history and economic issues at both San José Llanga and Santiago de Machaca. He directly supervised work of several B.Sc. students. An IBTA research associate from 1991-5, Mr. Jetté has recently worked for the United Nations Development Programme (UNDP) based in La Paz.

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Dr. Markowitz, a U.S. national, served the SR-CRSP as resident scientist for sociology from 1992-4. Her research interests dealt with technology adoption, living standards assessments and social anthropology at San José Llanga and Santiago de Machaca. She directly supervised the work of several B.Sc. students. A cultural anthropologist, Dr. Markowitz has recently become a faculty member in the Department of Anthropology at the University of Louisville, Louisville, Kentucky, USA.

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Ms. Medicaneli, Bolivian, served the SR-CRSP in 1993 as a consultant studying human demography in Aroma Province, which contains San José Llanga. A historian by training, she has recently worked as a researcher and faculty member in the Department of History at the Major University of San Andrés in La Paz. She has worked for a master's degree at the International University of Andalusia, Spain.

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Dr. Nolan, a U.S. national, was principal investigator for sociology on the Bolivian SR-CRSP from 1990-4. During this time he was also the leader of the Social Science Unit in the College of Agriculture, Food and Natural Resources, and a professor in the Department of Rural Sociology, both at the University of Missouri, Columbia.

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Dr. Ortega, Chilean, served the SR-CRSP as programme representative and resident scientist for animal nutrition in Bolivia during 1991-2. He continued as a U.S.-based scientist with the project until 1994. Dr. Ortega's research dealt with livestock feeding ecology at San José Llanga and he directly supervised work of six B.Sc. students. Dr. Ortega has worked as a research associate in the Department of Range, Wildlife, and Fisheries Management at Texas Tech University, Lubbock. He has more recently served as a faculty member in the Department of Natural Resource Management and Engineering at the University of Connecticut, Storres, Connecticut, USA.

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Dr. Ospina, Colombian, was principal investigator for economics on the Bolivian SR-CRSP from 1990-4. During this time he was a resource economist and director of the Center for Institutional and Human Resource Development at Winrock International, Morrilton, Arkansas. In 1994 Dr. Ospina became head of the economic analysis section for the National Coffee Growers Association of Colombia in Bogotá.

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Ms. Paredes, Bolivian, had her B.Sc. thesis research supported by the SR-CRSP/USAID. She obtained her degree in economics from the Department of Economics at the Major University of San Andrés in La Paz. Her research focused on relations between conservation practices and household income at San José Llanga under the supervision of Dr. Mauricio Cuesta. Ms. Paredes has completed a master's degree at the Institute of Ecology at the Major University of San Andrés in La Paz. She has served as a consultant in the Indigenous Programme of UNDP and as a researcher for the non-governmental organisation called Andean Ecology.

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João S. de Queiroz

Dr. de Queiroz, a U.S. national, served the SR-CRSP as resident scientist for range ecology during 1994-5. His research dealt with both San José Llanga and Santiago de Machaca. Topics included characterisation of soils, plant communities and management of grazing, manure and crop residues. He initiated field trials for interventions to enhance productivity of rangeland and fallow fields. Dr. de Queiroz directly supervised research of many B.Sc. students in Bolivia. He has recently worked as a technical specialist in agricultural development with USAID, based in Nairobi, Kenya and Guatemala.

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Ms. Sammels, a U.S. national, conducted research in Bolivia on attitudes among urban residents concerning consumption of llama meat. This work was done in collaboration with sociologists of the SR-CRSP. The research was used to help fulfill requirements for her B.A. degree at Harvard University, Cambridge, Massachusetts, USA.

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Dr. Scholtz, German, served the SR-CRSP as resident scientist for economics during 1992-3. Her research dealt with how campesinos at San José Llanga make resource allocation decisions. She directly supervised research of several B.Sc. students.

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Ms. Sherbourne, a U.S. national, collaborated with SR-CRSP sociologists during 1993. Her research focused on household economics, and was used to help fulfill requirements for her M.Sc. degree in Agricultural Economics from the University of Missouri, Columbia. Ms. Sherbourne has subsequently pursued a doctoral degree at Johns Hopkins University, Baltimore, Maryland, USA.

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Dr. Valdivia, a U.S. national, served as co-principal investigator for sociology from 1991-4 and principal investigator for sociology and economics during 1994-5. Her main research interests included analysis of peasant household economic portfolios, income and production strategies under risk, and gender dimensions of food security and technology. Co-editor of the final synthesis volume, she is a research assistant professor in the Department of Agricultural Economics at the University of Missouri, Columbia.

Jaime Valdivia Contreras

Mr. Valdivia, Bolivian, served the SR-CRSP as national co-investigator in range ecology from 1993-4. During this time he was also a research associate at IBTA. Mr. Valdivia's main research focused on forage production. He helped supervise research of seven B.Sc. students, most of whom worked at San José Llanga. Mr. Valdivia also collaborated in research concerning nutritive value of crop residues and adoption of sheep production innovations.

Silvia Valencia

Ms. Valencia, Bolivian, had her B.Sc. thesis research supported by the SR-CRSP/USAID. She obtained her degree in sociology from the Department of Sociology at the Major University of San Andrés in La Paz. Her research focused on social aspects of household management at Santiago de Machaca under the supervision of Mr. Christian Jetté. She also collaborated on studies of evolving terms of trade in the Department of La Paz. Ms. Valencia has also worked as a specialist in rural community organisation for the Prefecture of the Department of La Paz.

John Vargas

Mr. Vargas, Bolivian, served the SR-CRSP as national co-investigator in economics from 1991-4. During this time he also was an associate researcher in economics at IBTA. His special interests were in livestock production costs. He supervised research of one B.Sc. student working at San José Llanga. Mr. Vargas has worked in La Paz as a professor in the Department of Economics at the Major University of San Andrés, and as a specialist in development planning for the Prefecture of the Department of La Paz.

Zulma Rocío Victoria

Ms. Victoria, Bolivian, had her B.Sc. thesis research supported by the SR-CRSP/USAID. She obtained her degree in agronomy from the Department of Agronomy and Animal Production at Tomás Frias University in Potosí, Bolivia. Her research focused on spatial and temporal distribution of livestock at San José Llanga under the supervision of Dr. Isaac M. (Morty) Ortega and Mr. Rodolfo Puch. She also collaborated in studies of manure management under the supervision of Dr. João S. de Queiroz.

Betty M. Villanueva Pardo

Ms. Villanueva, Bolivian, had her B.Sc. thesis research supported by the SR-CRSP/USAID. She obtained her degree in agronomy from the Department of Agronomy and Animal Production at the Technical University of Oruro, Oruro, Bolivia. Her research focused on sheep production at San José Llanga under the supervision of Dr. Jim Yazman and Dr. Carlos Salinas.

Robert Washington-Allen

Mr. Washington-Allen, a U.S. national, was supported by the SR-CRSP as an M.Sc. candidate in the Department of Rangeland Resources at Utah State University, Logan. He completed an analysis of vegetation dynamics at San José Llanga based on remotely-sensed data under the supervision of Drs. Brien E. Norton and R. Doug Ramsey. He ihas recently been a Ph.D. candidate in range ecology at Utah State, but is based at the Oak Ridge National Laboratory, Oak Ridge, Tennessee, USA.

Mark Wilson

Mr. Wilson, a U.S. national, collaborated with the SR-CRSP when he was a graduate student at Michigan State University (East Lansing) and an intern with Winrock International. He received his M.Sc. degree based on studies of technology transfer among national research institutions and non-governmental organizations in Boliva. Mr. Wilson also helped the project develop data management systems.

Jim Yazman

Dr. Yazman, a U.S. national, variously served the SR-CRSP as resident scientist for animal nutrition and range ecology during 1993-5. He was also programme representative during this period. His research dealt with nutritional strategies to improve productivity of grazing sheep at San José Llanga. He supervised research for several B.Sc. students, and played a key role in production of final project documentation in Bolivia. Dr. Yazman continued in his position as animal scientist and senior programme officer with the Agricultural Productivity Division at Winrock International in Arlington, Virginia, USA and has recently worked in Bolivia and focused on small-holder dairy development.

Chapter 1

Project objectives and research approach
Objetivos del proyecto y enfoque de la investigación

by D. Layne Coppock and Corinne Valdivia

Summary

This chapter provides an introduction to the Small Ruminant Collaborative Research Support Programme (SR-CRSP), including a brief review of the origin and mandate of the programme as well as how programme activities have been organised in Bolivia and elsewhere around the world. Some background is also provided on the Bolivian Altiplano and how the project research framework was developed there with respect to contemporary theory in sustainable agriculture, agropastoral systems analysis, rangeland ecology, economic development and technology transfer.

The initiative to establish Collaborative Research Support Programmes (CRSPs) was mandated by the Title XII provision of the International Development and Food Assistance Act passed by the US Congress in 1975. The mandate was for US Land Grant universities to partner with institutions in developing countries to combat world hunger, low food production and poverty. The United States Agency for International Development (USAID) was tabbed as the entity to administer the CRSPs. There were eight active CRSPs in 1994 dealing with a variety of agricultural issues and commodities. The SR-CRSP was specifically targeted at small ruminants because sheep and goats tend to be held by poorer inhabitants of developing nations. Small ruminants also tend to be a low priority in the agricultural research activities of developing nations, and the SR-CRSP would help redress this imbalance. The SR-CRSP focused on projects to improve the efficiency and output of small ruminant production through technical and policy interventions without compromising the environment-- this strategy has been intended to improve the well-being of those who produce small ruminants. Another goal of the SR-CRSP is to enhance research capabilities of host countries.

The SR-CRSP was established in Bolivia in 1991. The targeted zone for study was the semi-arid, high elevation Altiplano and the national partner was the Instituto Boliviano de Tecnología Agropecuaria (IBTA). The first goal of the joint IBTA/SR-CRSP project was to select a representative site where a typical agropastoral production system operated and learn how the system functioned. The second goal was to identify what aspects of the system, if any, were unsustainable and why. The third goal was to identify technical and policy interventions that could help promote sustainability of agropastoral production in light of predominant social, economic and/or ecological constraints. The primary study site was the Cantón (municipality) of San José Llanga (SJL), an agropastoral community located on 7200 ha about 120 km from the capital city of La Paz. By virtue of its close proximity to a prominent government research station, urban markets and an all-weather highway, SJL had been exposed to decades of technology diffusion and dynamic change in market opportunities.

The IBTA/SR-CRSP project in Bolivia was organised around four key US institutions, each of which took responsibility for one disciplinary research component. The institutions included Winrock International (economics component), University of Missouri-Columbia (sociology component), Texas Tech University (range animal nutrition and production component) and Utah State University (rangeland ecology component). Principal investigators, resident scientists, national co-investigators and students were ultimately organised according to research discipline and the respective home institution in the US. Twenty-seven Bolivian students enrolled at four Bolivian universities provided the backbone of the research effort. They successfully completed research projects largely designed by IBTA/SR-CRSP scientists. The students wrote and defended theses as partial requirements for obtaining bachelor's degrees. Several students from the US also received training opportunities.

The initial and central research question of the project was: "What is the role of small ruminants in sustaining agropastoralism on the Altiplano, and can this role be strengthened or otherwise improved through better use of technology, management or policy?" A framework for analysing

sustainability for this system is outlined in this chapter, with a focus on the maintenance of critical inputs of land, labour and capital for rangeland and cropland components. Special attention was given to potential sources of environmental degradation (i.e., over-grazing or poor cultivation techniques) and how such impacts could be mitigated. For example, would degradation be found more in the rangeland or cropland component of the system? If degradation was found, would it tend to be old or recent in origin? Is degradation an irreversible or reversible threat to the productivity of the system? Are dominant sources of degradation abiotic (i.e., related to climate or natural salinisation) or linked to activities of people and livestock? If the latter is true, are there realistic interventions to mitigate negative trends?

Research was undertaken using an interdisciplinary perspective. Work expanded to include other system components besides those strongly related to small ruminants. Dairy cattle and food crop production were thus gradually incorporated. Research questions expanded to include more social science topics such as: (1) Clarifying the role of human capital in community development; (2) noting how changing aspirations of campesinos influence rates of out-migration and hence labour availability and sustainability of the production system; (3) the role of crops, livestock and wage employment in promoting food security; (4) documenting patterns of technology adoption including examining how technical innovation and change have influenced potentially vulnerable subgroups of the resident population such as females and the very poor; and (5) economic development theory.

The period of field work at SJL was four years, 1991-5. Data analysis and write-up continued for several years thereafter. Social sciences dominated the first years of field work because understanding system structure and function was the top priority, and this could be most easily addressed using interview methods to obtain clues pertaining to long-term trends otherwise difficult to detect within our short timeframe. Evidence reviewed in this chapter indicates communities on the Altiplano have been subjected to a wide variety of social, economic and environmental upheavals in the past several hundred years. The occurrence of key events coinciding at any given time likely drive the system in different directions. Our study would only capture a small, and unique, sliver of time in the 500-year history of SJL.

Resumen

En este capitulo se presenta una introducción al Programa de Apoyo a la Investigación Colaborativa en Pequeños Rumiantes (SR-CRSP), incluyendo una breve revisión de su origen y mandato, y también de como las actividades del Programa han sido organizadas en Bolivia y en otras partes del mundo. Por otro lado, se presentan algunos antecedentes del Altiplano de Bolivia y como se desarrolló el enfoque de investigaciones con respecto a teorías contemporáneas de agricultura sostenible, análisis de sistemas agropastoriles, ecología de campos naturales de pastoreo, desarrollo económico y transferencia de tecnología.

La iniciativa para crear los Programas de Apoyo a la Investigación Colaborativa (CRSPs) fue establecida por la Provisión Titulo XII del acta para el Desarrollo Internacional y Asistencia Alimenticia pasada por el Congreso de Estados Unidos en 1975. El mandato dispone la provisión de recursos financieros a universidades Americanas que trabajen con instituciones contrapartes en países en desarrollo para combatir el hambre en el mundo, la baja producción de alimentos y la pobreza. La Agencia Internacional para el Desarrollo de los Estados Unidos (USAID) fue designada como la entidad para administrar los CRSPs. En 1994 había ocho CRSPs activos trabajando en una variedad de problemas y actividades relacionadas a la agricultura. El trabajo del SR-CRSP fue específicamente dirigido a los pequeños rumiantes debido a que ovejas y cabras tienden a ser criados por los habitantes más pobres de las naciones en desarrollo. Los pequeños rumiantes también tienden a tener baja prioridad en las actividades de investigación agropecuaria en estos países. El trabajo del SR-CRSP enfatiza los proyectos dirigidos a incrementar la eficiencia y los rendimientos de la producción de pequeños rumiantes a través de intervenciones técnicas y de políticas que no comprometan el medio ambiente—con esta estrategia se intenta como objetivo final mejorar el nivel de vida de los productores. Otro objetivo del SR-CRSP es elevar la capacidad en investigación de los países anfitriones.

El SR-CRSP fue implementado en Bolivia en 1991. La zona seleccionada para este estudio fue el Altiplano semi-árido de gran altitud y la contraparte nacional fue el Instituto Boliviano de Tecnología Agropecuaria (IBTA). El primer objetivo

del proyecto conjunto IBTA/SR-CRSP fue seleccionar un sitio representativo donde operaba un sistema de producción agropastoril y aprender como este sistema funciona. El segundo objetivo fue el de identificar, si es que existiera, que aspectos del sistema serian no-sostenibles y determinar el por que? de esta situación. El tercer objetivo, fue identificar intervenciones técnicas y políticas que podrían ayudar a promover la sostenibilidad de la producción agropastoril, considerando las limitaciones predominantes de carácter social, económico y/o ecológico. El sitio de estudio principal fue el Cantón (Municipio) San José de Llanga (SJL), una comunidad agropastoril con un área de 7.200 ha ubicada aproximadamente a 120 km de la ciudad sede del gobierno de La Paz. Debido a su proximidad a una prominente estación de investigación del estado, a mercados urbanos y a una carretera con circulación durante todas las épocas del año, SJLL ha sido expuesta a décadas de difusión de tecnología y a cambios dinámicos en las oportunidades de comercialización.

El Proyecto IBTA/SR-CRSP en Bolivia fue organizado alrededor de cuatro Instituciones Americanas clave, cada una de las cuales tomo la responsabilidad de un componente en una disciplina de investigación. Estas Instituciones fueron: Winrock International (componente económico), Universidad de Missouri-Columbia (componente de sociología), Texas Tech University (componente de nutrición animal en praderas y producción), y Utah State University (componente de ecología de campos naturales de pastoreo). Investigadores principales, científicos residentes, co-investigadores nacionales y estudiantes se organizaron de acuerdo a las disciplinas de investigación y de acuerdo con su respectiva institución originaria en Estados Unidos. Veinte-siete estudiantes Bolivianos, matriculados en 4 diferentes universidades nacionales constituyeron la columna principal de los esfuerzos de investigación. Los estudiantes completaron exitosamente con los proyectos de investigación mayormente diseñados por los científicos del IBTA/SR-CRSP. Los estudiantes redactaron y defendieron sus tesis como parte de los requerimientos para obtener el titulo de licenciados. Varios estudiantes de Estados Unidos también utilizaron las oportunidades de entrenamiento.

La pregunta inicial y central del proyecto fue: Cual es el rol de los pequeños rumiantes en el agropastorilismo sostenible en el Altiplano, y si este rol puede ser fortalecido o de otra manera mejorado a través de una mejor tecnología, manejo o política? En este capitulo se establece un marco de referencia para el análisis de la sostenibilidad del sistema, con énfasis en el mantenimiento de los factores críticos de tierra, trabajo y capital para los componentes de praderas y tierras agrícolas. Se dió especial atención a fuentes potenciales de degradación medio ambiental (p.e. sobrepastoreo o técnicas de cultivo inapropiadas) y de como tales impactos podrían ser mitigados. Por ejemplo, sería la degradación que se detecte más común en el componente de praderas o en el de tierras agrícolas del sistema?. Si se encuentra degradación, es ésta de origen antiguo o reciente?. Es la degradación una amenaza reversible o irreversible para la productividad del sistema?. Son las causas de degradación de origen abiótico (p.e. relacionadas al clima o salinización natural) o están relacionadas a las actividades de la gente y del ganado?. Si lo último es cierto, habrían intervenciones realistas para mitigar las tendencias negativas?.

Las investigaciones fueron realizadas usando una perspectiva interdisciplinaria. El trabajo se amplio para incluir otros componentes del sistema además de los estrechamente relacionados a los pequeños rumiantes. En esta línea fueron gradualmente incorporados los Vacunos para leche y producción de alimentos. Las preguntas de investigación se expandieron para incluir tópicos de las ciencias sociales, tales como: (1) Clarificar el rol del capital humano en el desarrollo de la comunidad, (2) identificar como los cambios en las aspiraciones de los campesinos influye en la tasa de migración y por lo tanto, la disponibilidad de mano de obra y la sostenibilidad del sistema de producción; (3) el rol de la producción agrícolas, ganadería y empleo por salario para lograr la seguridad alimentaría; (4) documentación de patrones de adopción de tecnología incluyendo el análisis de como la innovación tecnológica y el cambio han influenciado sobre subgrupos potencialmente vulnerables de la población residente, tales como son el de las mujeres y el de los muy pobres; y (5) teoría de desarrollo económico.

El periodo de trabajo de campo en SJL fue de cuatro años, 1991- 5. El análisis de los datos y la redacción de los documentos continuaron posteriormente por varios años. Las ciencias sociales dominaron los primeros años del trabajo de campo debido a que el entender la estructura y función del sistema fue la máxima prioridad, y esto se logró más fácilmente usando el método de entrevistas para identificar indicadores de tendencias en el largo plazo, de otra manera, hubiese sido muy difícil detectar cambios en el largo plazo en el corto periodo de ejecucion del trabajo en Bolivia. En este capítulo, la evidencia revisada indica que el Altiplano ha estado sujeto a una amplia variedad de cambios tanto sociales, económicos y medioambientales, en los siglos pasados. La ocurrencia de eventos claves coincidentes en un tiempo cualquiera podrían seguramente mover el sistema en direcciones diferentes. Nuestro estudio sólo puede capturar una pequeña, y probablemente única porción de tiempo de los 500 años de historia de SJL.

1.1 Introduction

In this chapter we briefly describe the origin, mandate, organisation and philosophy of the Small Ruminant Collaborative Research Support Programme (SR-CRSP). This is approached from a global perspective to a local perspective relevant to Bolivia.

1.2 Background of the SR-CRSP worldwide

To promote the capability of the world's food-deficient regions to supply their own food, the US Congress passed the International Development and Food Assistance Act in 1975 (Johnson 1994, xvii). Included in the act was a provision called Title XII—Famine Prevention and Freedom from Hunger. This provision states:

> *"…in order to prevent famine and establish freedom from hunger the United States should strengthen…capacities of US land grant…universities in programs related to agricultural institution development and research…[to] improve their participation in the US government's international efforts to apply more effective agricultural sciences to the goal of increasing world food production and in general should supply increased and longer term support to the application of science to solving food and nutrition problems of the developing countries."*

The International Development and Food Assistance Act also specified that the US Agency for International Development (USAID) should administer and fund Title XII from its existing budget. The act authorised the president of the US to create a Board for International Food and Agricultural Development and Economic Cooperation (BIFADEC) to serve as the implementing agent (Johnson 1994, xvii). The BIFADEC appointed a Joint Committee on Research and Development (JCORD) to oversee the research-related aspects of Title XII. It was BIFADEC's recommendation that Title XII-sponsored research be implemented through Collaborative Research Support Programmes (CRSPs). Small ruminants were among several priority topics initially suggested for research attention; a total of eight CRSPs remained active in 1994 covering a wide range of agricultural issues and commodities. The rationale for prioritising small ruminants had to do with the proposition that no matter what livestock research or extension occurred in the developing world, it tended to be focused more on large ruminants such as cattle, which are often held by producers who, on average, are relatively wealthier and more influential. In contrast, species such as sheep, goats or camelids [i.e., llama (*Llama glama*) and alpaca (*L. pacos*)] tend to be held by poorer people living under marginal circumstances. Small ruminants are often exceptionally hardy and inexpensive to maintain given their ability to persist on few resources under stressful conditions. Having one CRSP focus on small ruminants was therefore intended to help rectify a perceived imbalance in research and extension between large and small ruminants in the developing world and thus better satisfy the tenets of Title XII.

One overall goal of the SR-CRSP was to improve the efficiency and output of small ruminant production (i.e., meat, milk, fibre, by-products, etc.) by promotion of technical and policy interventions identified through research. Enhanced efficiency and productivity of small ruminants should then be targeted to improve the economic welfare and diets of smallholders (i.e., those persons who typically manage "smaller" flocks, often in combination with other agricultural enterprises). Such a development process, however, should not contribute to environmental degradation (Johnson 1994, xvii). Another important goal of the SR-CRSP was to strengthen research capabilities of agricultural institutions. This includes institutions in developing nations as well as their counterparts in the US.

The SR-CRSP was organised in 1978 with 17 institutions. The University of California, Davis, was designated as the management entity for the programme. Since its inception the SR-CRSP has had extensive field activities in Peru, Brazil, Morocco, Kenya and Indonesia. Several projects have been completed and turn-over in institutional participants has consequently occurred. In 1994, nine US institutions participated in the SR-CRSP. These were dominated by Land Grant universities, but also included a private voluntary organisation (PVO). Three institutions from outside the US participated in the SR-CRSP during 1994-- these were agricultural research institutions in the then host countries of Kenya, Indonesia and Bolivia. Funds for the SR-CRSP are granted for a five-year period by USAID. A minimum cost-sharing of 25% from participating US institutions was required.

Since research in developing countries was a cornerstone of the SR-CRSP, a special effort was made to select work sites that met the following criteria: (1) Sites must represent the various ecozones and production systems which typify the humid tropics, sub-humid tropics or arid lands; and (2) host countries must have established agricultural research institutions with whom SR-CRSP investigators could collaborate. Such institutions must also provide viable links to extension that are pivotal to implementation of research findings.

1.2.1 Introduction to the GL-CRSP

By 1997 the SR-CRSP was being re-engineered into a programme called the Global Livestock (or GL) CRSP, with an intermediate title of SR/GL-CRSP. The GL-CRSP was formally recognized in 1999 and the “SR” was dropped from the name. The GL-CRSP still deals with improvement of livestock systems in the poorer regions of the developing world, but the focus has been broadened to include a wider variety of livestock. It also is embracing such issues as livestock development policy, the role of livestock in economic development, and means to improve management of risk for households and societies at large. This transition is reviewed in Johnson (1997).

1.3 Background of the SR-CRSP in Bolivia

The SR-CRSP was established in Bolivia in 1991. A Memorandum of Understanding was signed between the SR-CRSP and the Bolivian Institute of Agricultural Technology (Instituto Boliviano de Tecnología Agropecuaria, or IBTA). Created in 1975, IBTA was administered within the Ministry of Peasant Affairs and Agriculture (MACA) and had a high degree of institutional autonomy. The headquarters for IBTA were in La Paz. There were five IBTA research stations in the Bolivian Andean zone including facilities at Belen, Patacamaya, Ulla Ulla, Chinoli and Tarija. Alzérreca (1992, 196-8) listed 16 research or field stations in the Andean zone overall and these were administered by IBTA and eight other governmental and non-governmental organisations. The traditional focus of IBTA has been technical production research and technology transfer on the dry Altiplano and more mesic High Valleys. The high-elevation Altiplano is described below. The mesic High Valleys, in contrast to the Altiplano, occur at intermediate elevations on the eastern slopes of the Andean Cordillera called the Cordillera Oriental, and these are sites where mixed farming systems prevail (see Section 2.2.1: *National highlights of physical geography and environment* and Section 2.3: *Overview of the Bolivian Altiplano*). Activities at IBTA were organised into five programmes. One of these was the Livestock and Forages Programme, and this was the entity which had links to the SR-CRSP. The focus of the IBTA/SR-CRSP bi-lateral collaboration was to be systems analysis, problem diagnosis, technology generation and policy-oriented research relevant to improving agropastoral systems on the Altiplano.

The primary study site selected for the IBTA/SR-CRSP programme was the Cantón of San José Llanga (or SJL), a 7200-ha site occupied by about 100 campesino (peasant) households in the central, semi-arid Altiplano. The people are *Aymara* Indians, the numerically dominant ethnic group in Bolivia (Plate 1.1). Aspects of history and the agropastoral system at SJL are reviewed in Section 2.3.2: *Regional historical highlights* and Section 2.4: *Overview of the study area at San José Llanga*).

As SJL is located relatively far from footslopes of the Cordilleras, the landscape is relatively level. The modest relief and variation in the salinity of ground water and soils, however, permits a surprisingly high degree of agricultural diversification. Households were distributed throughout six settlements in the cantón. Households managed about 5600 head of livestock in total comprised of sheep, cattle and donkeys, and about 3600 ha of croplands used to grow food crops and cultivated forages. The SJL site was primarily chosen because it was readily accessible for research and had been subjected to several decades of tech-

Plate 1.1 Aymara *campesinos at the market in Patacamaya town on the Bolivian Altiplano.* Photograph: D. Layne Coppock

nology diffusion by virtue of its close proximity to the Patacamaya Experiment Station (see Chapter 7: *Patterns of technology adoption at San José Llanga).* San José Llanga is also only about 120 km from major urban centres of La Paz and El Alto, and has recently experienced important changes in agricultural marketing opportunities. The agricultural system is therefore dynamic and has long been affected by vagaries of climate and shifts in production practices, marketing opportunities and technology diffusion (see Chapter 7: *Patterns of technology adoption at San José Llanga*). For example, shifts in varieties and acreages of indigenous and introduced food and forage crops are pervasive. Sheep, donkeys and mechanised transport gradually led to extirpation of the llama at SJL earlier this century. More recently, smallholder dairying and forage cultivation has expanded in response to subsidisation of milk collection and growing milk markets (see Section 2.4: *Overview of the study area at San José Llanga* and Chapter 4: *Household economy and community dynamics at San José Llanga).*

Besides the main project focus at SJL, the IBTA/SR-CRSP programme also had a few secondary research sites. These tended to be located at colder and drier locales at higher elevations compared to SJL and were also more remote from major urban markets. Because of the harsher climate and poorer access to large markets, these secondary sites consequently had greater representation of camelids (relative to other livestock) and more reliance on indigenous food or forage crops (relative to introduced food or forage crops). Research conducted in the secondary sites tended to be more ancillary to the overall thrust of the programme and results are not reported fully in this volume. Secondary sites included: (1) Santiago de Machaca (3980-m elevation) located 125 km to the southwest of La Paz in the José Manuel Pando Province, Department of La Paz (Johnson 1994, 59-63; see Annex B); (2) Aguas Calientes (3800-m elevation) located about 240 km to the southwest of La Paz (Luna 1994); and (3) Cosapa (3900-m elevation) located 260 km to the southwest of La Paz and 50 km to the southeast of Aguas Calientes (Buttolph 1998).

Throughout most of the history of the Bolivian region the Altiplano has been a cultural, economic and agricultural hub for indigenous peoples. Today, however, poverty is pervasive in communities on the rural Altiplano and recent, widespread emigration of rural people to large urban areas has occurred. There is, however, considerable site variation in the extent of emigration (see Chapter 2: *National, regional and local context*). The IBTA/SR-CRSP programme on the Altiplano was, in part, designed to address these issues because large-scale emigration could be a source, or a symptom, of an apparent decline in the sustainability of agropastoral systems (see below).

The structure of the Bolivian project at SJL followed a common SR-CRSP format. Key disciplines were each represented by US institutions. Economics was in the domain of Winrock International (WI), a PVO located in Arkansas. Range animal nutrition and production was in the domain of Texas Tech University (TTU). Sociology was in the domain of the University of Missouri-Columbia (UM). Range ecology and management was in the domain of Utah State University (USU). Each of these institutions had a US-based principal investigator (PI). The role of each PI was to administer funds and provide disciplinary research leadership. It was also intended that each institution have an internationally recruited resident scientist on the ground at all times in Bolivia to oversee disciplinary research activities. One resident scientist was also appointed to serve as an overall project representative. On the Bolivian side, resident scientists were to be matched with a disciplinary counterpart (or co-investigator) from IBTA. Field work was largely carried out by 27 Bolivian students enrolled at four Bolivian universities. The Bolivian students were typically senior undergraduates who were required to conduct research and defend theses to fulfill requirements for graduation. Theses often resembled a masters (MA or MS) thesis at a US university. The Bolivian students each had a university supervisory committee, but field work was largely conceived, designed and supervised by IBTA/SR-CRSP scientists. The research priorities for the first group of students in 1991 were related to system description and problem diagnosis at SJL. After these topics were covered more attention was subsequently given to aspects of technology evaluation and experimentation in animal nutrition and forage agronomy. In terms of a disciplinary breakdown, seven Bolivian students studied range livestock nutrition, foraging ecology and animal production, five studied sociology or anthropology, five studied economics and 10 studied range ecology (including soils and water resources). Several American students also participated directly or indirectly in the project. These included one undergraduate (Harvard), three master's candidates (Michigan State, UM and USU) and one PhD candidate (USU). See the introductory materials, *Primary contributors and collaborators*, for details. Plate 1.2 depicts team members at an early stage of the project.

The IBTA/SR-CRSP project established a main office in La Paz. The vast majority of student research activities were undertaken at the SJL site. At least in the first couple of years of the project the Bolivian students lived in the main barrio (town or settlement) of the cantón and therefore were able to immerse themselves in the daily lives and seasonal routines of the resident campesinos.

It is critical to note that the primary objective of the first few years of research was gaining knowledge of how the agropastoral production system worked and what factors, if any, most threatened sustainability of current and future productivity. This was essentially a farming systems research approach (Harwood 1979). Given the short time-frame for the project, a high reliance had to be made on interviews with campesinos to provide critical insights concerning system function and generate and confirm hypotheses relevant to longer-term system dynamics. Social science thus had a co-dominant role with technical disciplines such as animal production, animal nutrition and range and forage ecology. In this regard the IBTA/SR-CRSP activity was unusual for Bolivia. Rather than embracing community-based approaches for problem identification and analysis, traditions of Bolivian agricultural research institutions have tended to be based more on classical experimental approaches on research stations (Yazman 1995; see Section 8.3: *Recommendations*).

We have observed many positive outcomes of the IBTA/SR-CRSP collaboration, but one of the most important and enduring is probably the investment in disciplinary and interdisciplinary training for 27 young Bolivian scientists. As one consequence of their experience on the project, these students have gained an intimate knowledge of campesino problems on the Altiplano. This will shape their attitudes and professional choices for years to come. This training effort, in concert with other initiatives, will hopefully help move Bolivia further in the direction of community-based approaches for problem identification, technology generation and formulation of more effective agricultural policies (see Section 8.3: *Recommendations*).

Plate 1.2 *Some student researchers, resident scientists and support staff of the Bolivian SR-CRSP in 1992.* Photograph: D. Layne Coppock

1.4 Background of the SR-CRSP on the Bolivian Altiplano

1.4.1 Research setting

It has been estimated that Andean peoples and their native camelids (i.e., llama and alpaca) have roamed the Altiplano for at least 7000 years BP (Browman 1974). It is thus a region with a very long history of herbivory, and consequently it has been speculated that the dominant plant communities had become adapted to the peculiar grazing pressures imposed by camelid production systems (Flores 1988). With the arrival of the Spanish conquistadors in 1535, however, came new livestock species such as sheep, cattle, horses and donkeys. The breeds of these livestock which adapted to high elevations became known as Criollo. Criollo animals gradually became accessible to indigenous peoples on the Altiplano. Where new urban markets flourished and alternative forms of transport became available starting in the early stages of the Republican Era in the 1800s, native species of livestock (i.e., camelids) and cereals (i.e., *quinoa, cañawa, oca*) slowly gave way to encroachment by exotics, especially in those parts of the Altiplano which had more moderate climate regimes (see Section 2.3.2: *Regional historical highlights*). The gradual predominance of sheep grazing, in particular, has been blamed for the apparent widespread environmental degradation of rangelands on the Altiplano (LeBaron et al 1979). It has been proposed, for example, that the grazing behaviour and hoof action of sheep have been detrimental to plant communities which evolved under different (i.e., more moderate) pressures from camelids (Flores 1988).

The Altiplano has also endured marked changes in climate, which in some cases could confound long-term effects of grazing. The Altiplano is essentially an alluvial plain that contains a series of remnant, endoreic lakes, the largest of which is Lake Titicaca. Studies of historical lake levels and other indicators have been interpreted to suggest that we are currently in a dry period which has persisted for hundreds of years (Dr. H. Alzérreca, rangeland ecologist, personal communication). The point is that persistent aridity alone can lead to reductions in cover and productivity of rangeland vegetation and facilitate change-over of entire plant communities from domination by grasses to domination by woody plants (Archer 1989). The postulated increase in aridity of the Altiplano could exacerbate effects of grazing and accelerate vegetation change in some cases. The Altiplano is also a region characterised by pervasive salinity, frost and drought which affect grazing resources. Increased salinisation of the Altiplano appears to be an inevitable consequence of erosion of the Cordilleras and closed hydrological cycles (see Section 2.3.1: *Regional highlights of physical geography and environment*). In contrast, however, there is little or no hard evidence of other environmental trends which could be affecting grazing resources.

Gaining an appreciation for possible climate trends, climate cycles and interactions of climate with grazing on the Altiplano is important. The role of climate versus grazing in determining vegetation dynamics has become a subject of recent debate (reviewed in Ellis 1992). In some cases, arid systems having <400 mm of annual precipitation are characterised by high annual variation in precipitation with coefficients of variation exceeding 50%. These systems may reportedly be governed more by climate fluctuations than biotic interactions. Sharp changes in precipitation can result in unpredictable, catastrophic rates of animal losses and rarely allow herbivores to reach densities at which they can markedly affect vegetation composition or productivity. Plant-animal interactions in such systems may therefore be only loosely coupled; this would be further exacerbated where plant communities are naturally dominated by herbaceous annuals and soil substrates are less susceptible to erosive forces (Coppock 1993). Hence, the role of heavy grazing in shifting vegetation composition and causing degradation (i.e., erosion) in such systems may be hard to prove, since climate plays such a pervasive role in ecosystem change. Prescriptions to destock such systems, with the goal of improving sustainable productivity of the environment, may therefore be ineffectual in ecological terms and inappropriate in terms of the undue economic penalties imposed on herding societies (Ellis and Swift 1988; Behnke and Scoones 1993). In contrast to arid systems, semi-arid systems may exhibit more of the classical features of grazing-mediated vegetation change and pose more scope for environmental degradation. Semi-arid systems are often defined as having a lower limit of 450 mm of precipitation per annum (Coppock 1993). Annual variability in precipitation tends to be less in semi-arid systems compared to arid systems. Drought frequency may also be reduced in semi-arid systems, herbaceous plant communities are more commonly dominated by perennial species, and there is more consistent opportunity for more tightly coupled interaction between plants and herbivores. Herbivores can more regularly achieve stocking rates which alter plant communities (Coppock 1993). In this type of system carrying capacity concepts become more relevant and periodic destocking could promote some objectives pertaining to sustainable resource use. Where the Altiplano could fit on such a continuum was unclear.

Besides climate fluctuations and large-scale shifts in herbivore species on the Altiplano, there has also been a pronounced human dynamic which affects natural resources. During the 1700 and 1800s the human population on the Altiplano remained relatively low, largely related to lingering effects of massive depopulation during the early colonial period, routine epidemics and high rates of child mortality (Klein 1995). The human population on the rural Altiplano began to steadily grow from the early 1900s up through the 1960s, afterwhich time a decline in some rural populations has been evident, especially in the drier central and southern portions of the Altiplano. This population depletion is largely attributable to a rural exodus to the vicinity of large urban locales (see Section 2.3.2: *Regional historical highlights*; Plate 1.3). Large urban markets have grown in this century, affecting the types of animals and crops produced as well as placing pressure on other resources such as water, soils and fuelwood. Markets can be very dynamic. For example, the campesinos at our study area reported that the 1960s and 1990s were times when the profitability was highest for potato production and dairying, respectively (see Chapter 7: *Patterns of technology adoption at San José Llanga*), which suggests that shifts in demand for key commodities occur. Land tenure systems have periodically changed on the Altiplano. A popular revolution in the early 1950s finally eliminated the last vestiges of the hacienda system and initiated various land reforms. One outcome was that many campesino communities regained legal ownership of their lands. Policies to better distribute tax wealth to rural areas, and privatise lands that have been communally owned in recent times are other issues currently under debate that will affect natural resource dynamics (see Section 2.4.2: *Local society*).

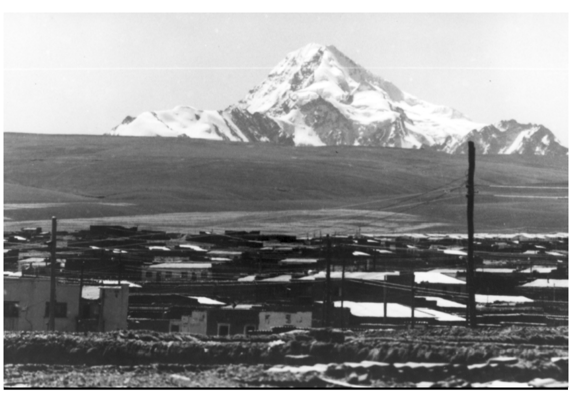

Plate 1.3 *Panorama that captures important contemporary elements of the Bolivian Altiplano. Rapid urbanisation is represented by the outskirts of the city of El Alto, a large suburb of La Paz. Immigrants come to El Alto from the semi-arid rangelands in the distance.* Photograph: Courtesy of *Presensia* (La Paz)

1.4.2 Project framework and initial research questions

1.4.2.1 Focus on role of small ruminants in system sustainability and drought management

The SR-CRSP project in Bolivia was initially guided by one overall research question (Gilles and Malechek 1990), namely: “What is the role of small ruminants in sustaining agropastoralism on the Altiplano, and can this role be strengthened or otherwise improved through better use of technology, management or policy?”

This question is interdisciplinary and oriented towards farming systems analysis (Grove 1992) rather than a disciplinary approach. This question was also strongly oriented towards improving the role of small ruminants in mitigating negative effects of drought. Drought was increasingly recognised as a pervasive influence that appeared to be crippling whole societies in the developing world (Dr. D.L. Coppock, IBTA/SR-CRSP, personal observation). To answer the initial question requires that the role of small ruminants be understood in the context of the structure and function of an aggregated and dynamic crop-livestock system. Despite the core focus of the project on the Altiplano, it was hoped that generalisable insights could be obtained that would be relevant to better understanding problems of agropastoral systems worldwide. Small ruminants were to be the hub of our analyses in Bolivia since they are the target commodity of the SR-CRSP.

1.4.2.2 Our context of sustainability

Sustainability of agriculture is a problematic concept subject to several interpretations (NRC 1989; Francis and Youngberg 1990). Here we adopt a conceptual framework of Dr. D.L. Coppock (IBTA/SR-CRSP, unpublished). The focus of this framework is the sustained output—or at least potential capacity for sustained output—of commodities a, b, c, etc., or their aggregates from a given locale. In this context sustainability refers to the process of maintaining a level of output. A distinction can be drawn between this use of the verb “sustaining” versus the phrase “sustainable agriculture”. A sustainable agriculture in the United States has been defined as agricultural practices which share three common features, namely: (1) social acceptability (both to farmers and society at large); (2) economic viability; and (3) environmental soundness (Dr. D.L. Coppock, IBTA/SR-CRSP, personal observation). Our use of the word “sustaining”, in contrast, focuses more on the optimal combinations of inputs required to sustain or maintain a commodity output.

Any given commodity is produced as a function of basic inputs including land, labour, management and capital, all under various degrees of control by producers. This can be shown as a Venn diagram in which the central intersection of three spheres yields optimal combinations of inputs needed to sustain output of a given commodity (Figure 1.1). Change in any given input may be negative or positive, reversible or irreversible, etc. The currency in which output is evaluated varies with the analytical objective. For example, aggregate income per household per year, aggregate caloric yield of agropastoral products per household per year, or some grand total figure that integrates income and consumption value of commodity production could be used. This currency would be graphed as a time series. The overall Venn diagram in Figure 1.1, here representing some aggregate system feature, could also be broken out into other Venn diagrams representing a grazing livestock subsystem or a crop agriculture subsystem. Outputs of key animal products or crops could be portrayed as time series with their own specific factors of production. Each Venn diagram thus could have value in providing an inventory from which source(s) of change in commodity output could occur. For example, a long-term decline in output of a food crop such as *quinoa* for a household could be traced to proximal changes in management, capital investment, loss of labour, increased environmental degradation of crop land (human-induced or abiotic), and/or a long-term drop in precipitation. Potential causes for a decline in the output of marketed sheep per household could be similarly depicted and analysed. The Venn diagrams can also be identified as to household, community or regional levels of resolution. Factors affecting inputs would change as scale of resolution changes. Aggregate Venn diagrams also permit depiction of feedback loops between crop and livestock components. Finally, it is notable that the land, labour and capital components are divisible among households and within households, as will be shown, this impacts both management choices as well as household well-being.

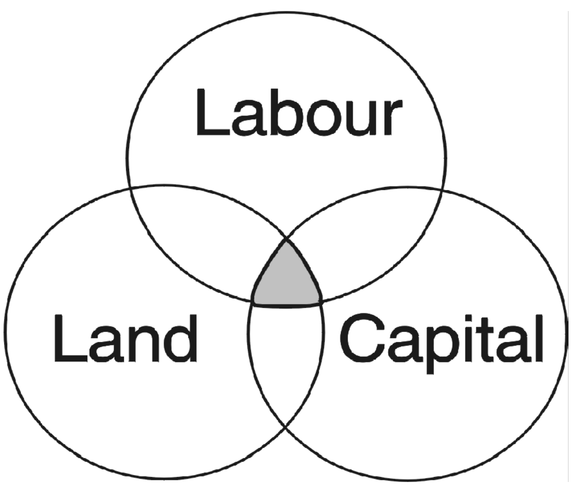

Figure 1.1. *Conceptual diagram of how inputs of land, labour and capital are related to sustaining output from a production system. The shaded intersection of the three circles represents a zone of optimal combinations of inputs. Deviations of a system outside of the shaded area implies suboptimal combinations of inputs that could undermine system productivity and sustainability. The diagram can be viewed as representing an agropastoral system in aggregate or viewed as representing cropping and rangeland components in isolation. Capital is assumed to include the livestock component.* Source: Dr. D. L. Coppock (IBTA/SR-CRSP, unpublished)

1.4.2.3 Features of agropastoral systems

Agropastoral systems are often characterised according to the nature of their crop-livestock interactions. Agropastoral systems are defined based on the mix of animal and plant products produced at the household level on an annual basis. Jahnke (1982, 66-110) reviewed general features of pastoral and agropastoral systems. Pastoral systems are those in which livestock products provide the mainstay of the economy and grain is either obtained through barter or irregularly cultivated on a very small scale. In contrast, an agropastoral system is one in which livestock products and home-grown crops are co-dominant in household economies.

Well-balanced agropastoral systems should be superior in terms of their stability and resilience features compared to pure pastoral or pure cropping systems, especially in marginal environments. In this context stability refers to the ability of a component to maintain productivity in the face of perturbation. Resilience refers to the ability of a component to regain its original productivity following a perturbation; a less resilient component takes more time to recover. Because crop production is intimately linked to rainfall it tends to be unstable, yet crop production also confers the potential for rapid recovery (i.e., high resilience) from prolonged drought because all that is required is one good rainy season to produce a good crop. In contrast, livestock production tends to be more stable under perturbation because several consecutive rainfall failures are often required to decimate herds or flocks. Despite the greater stability of livestock in response to drought compared to crops, once livestock populations have been reduced by a severe perturbation it takes a longer period of time for them to recover once the perturbation has ceased. This is particularly true for larger livestock such as cattle, which may require over a decade to achieve pre-drought levels of productivity (Dahl and Hjort 1976; Cossins and Upton 1988). Small ruminants are notable for often being more stable under drought perturbation than cattle; small ruminants are also more resilient than cattle by virtue of their rapid rates of reproduction and flock recovery (Mace and Houston 1989).

Agropastoral systems often have complex crop-livestock interactions, and these interactions tend to be more loosely coupled as aridity increases (McIntire and Gryseels 1987). There are several reasons for weaker crop-livestock interactions in the more arid locales. In some cases increasing aridity simply means a greater likelihood of regular crop failure. In other cases crop production is pursued as a means to compensate for decreased productivity of livestock following a prolonged drought. Crop production therefore is pursued when livestock production is less viable and vice versa, leading to a lack of tight integration (Coppock 1994, 122-5). There are four major crop-livestock interactions. These include:

(1) Use of livestock manure as a fertiliser for cultivated fields. In parts of the agropastoral Sahel having nutrient-poor soils, for example, it has been proposed that livestock manure is required for crop production to be viable. In this case rangelands have been shown to be critical sources of extensively harvested nutrients which are ultimately concentrated and transported by animals (Williams et al 1993). Manuring fields can occur in several ways. In some cases it can result from animals directly depositing dung on fields when they graze on crop residues (Powell 1986; Williams et al 1993). Where animals are corralled at night people may supply labour to transport manure from livestock corrals to cultivated fields (Coppock 1994);

(2) Use of crop residues for animal feed, either as cut-and-carry forage or for grazing. Crop residues become available in dry seasons and can provide a critical nutritional boost for livestock. Much research has been devoted to quantifying effects of various species and varieties of crops and crop management practices on the nutritive value of crop residues (Little and Said 1987; Reed et al 1988). Crop residues are also used to supplement diets of grazing animals to improve conversion efficiency for grazed portions of diets;

(3) Use of animal draft power for tillage (Starkey and Faye 1990). Use of cattle and equines for ploughing can replace human labour and increase yields by expanding acreage under cultivation (Quiroga 1992, 149); and

(4) Animals are often sold to provide strategic cash flows for crop production inputs such as tools, seeds and fertilisers (Jahnke 1982, 55).

For the Altiplano it was likely that at least three of the major interactions above would be directly relevant to understanding the role of small ruminants in sustaining agropastoralism. Sheep and camelids are corralled on the Altiplano, and thus manure is known as a common input for cultivated fields (Quiroga 1992, 150), crop residues are often an important feed source for livestock (Alzérreca 1992, 191), and since sheep are an important form of capital storage and income generation (Quiroga 1992, 150), some revenue from sheep sales would be expected to be diverted into crop production. To the extent that revenue from sheep sales helps support draft cattle, sheep could also indirectly underpin the tillage interaction as well.

We postulate that an agropastoral system is adequately functioning in a biological, ecological and economic sense when: (1) cultivated fields are receiving an adequate amount of manure; (2) crop residues are harvested and utilised by animals at a high rate of efficiency; (3) tillage of fields occurs to the desired extent each year and timing of tillage is optimal; and (4) capital for purchasing the traditional, routine inputs for cultivation via animal sales is not limiting. What could thus weaken or undermine the traditional role of small ruminants in sustaining agropastoralism? Anything that detracted from the four features of an adequately functioning system above is a candidate. Lack of sufficient labour, animals and reliable markets would be prominent.

1.4.2.4 Sustainability and environmental degradation

Under the banner of the overall research question given at the beginning of this section, there are several lower-order questions which dealt more directly with the interactions of small ruminants with their environment; these questions relate to the role of humans and livestock in directing range ecosystem dynamics reviewed earlier in this chapter (see Ellis and Swift 1988; Ellis 1992; Behnke and Scoones 1993). These have been interpreted from the original project proposal (Gilles and Malechek 1990):

(1) Has heavy grazing by small ruminants degraded Altiplano rangelands? If so, has this degradation occurred in distant times, recent times, or both?
(2) If environmental degradation is found, is it instead more attributable to abiotic or other unmanageable factors unrelated to human or livestock activity? For example, is drought or natural salinisation a cause of more environmental problems than heavy grazing per se?
(3) Are there discernible interactions between abiotic and biotic factors which result in environmental degradation?, and
(4) If biotic factors are important in environmental degradation, are there realistic changes in range management, development of new range technology, or economic policy which could ameliorate negative effects?

The prevailing view of Andean technical agencies is that over-grazing of the Altiplano is pervasive and that populations of small ruminants and humans are unsustainable, in part because of past degradation of rangelands which limits productive output today (Flores 1988; Alzérreca 1992). In some cases the emigration of campesinos from the rural Altiplano to large urban areas in recent years could reflect a permanent degradation of their agroecosystems; on the other hand it could reflect changing social aspirations (C. Jetté, IBTA/SR-CRSP, personal communication; see Section 4.3.1.2: *Living standards, household structure and human population dynamics*). In the official view there are several possible solutions. One is to encourage campesinos to leave the Altiplano and take up potentially more profitable agriculture in the tropical lowlands, where government investments in infrastructure and technology have recently occurred (see Section 2.2.2.3: *National highlights of social history: 1951 to 1996).* Other solutions would be to prescribe technical or policy interventions to either help arrest degradation and/or rehabilitate degraded sites (Alzérreca 1992).

Compared to the small ruminant/rangeland grazing component, the original proposal by Gilles and Malechek (1990) did not focus as much on the cultivation component of the agropastoral system given this was to be a "small ruminant project." We subsequently further developed the cultivation component to embrace a whole-systems perspective. Inclusion of the cultivation component allowed us to consider another suite of questions as follows:

(1) Is there a declining output of products for the agropastoral system as a whole? If this is the case, which component is becoming less productive, the rangeland component or the crop component?; and
(2) If the crop component is becoming less productive, what could be the cause(s) of this trend? Is the cause primarily human (management) related, abiotic, or an interaction between the two?

The inclusion of the crop component has thus allowed us to come full circle. We can again use Figure 1.1 as a point of reference. The full inclusion of a cropland component also allowed us to address another pervasive issue, namely the contention that inappropriate dry-land cultivation, not over-grazing, is the main source of environmental degradation in the arid and semi-arid areas of the Altiplano and elsewhere in the world (Alzérreca 1992, 189; Pimentel et al 1995).

As we consider the attributes of a dynamic agropastoral system, it is pertinent to recall that our field presence was limited to less than four years; i.e., 1991-5. This is a narrow window of observation. Material reviewed earlier in this chapter indicated that social, economic and ecological contexts on the Altiplano are ever-changing; some change much more rapidly than others. Our short period of observation would thus coincide with one particular combination of social, economic and ecological events. For example, it was noted earlier that the campesinos at SJL reported that the 1960s were a time of higher market demand for sheep, while more recently there has been a higher market demand for dairy products. Such shifts should alter household motivations in terms of resource use and strategies for income generation. Marginal returns to investment for various enterprises would consequently change over time. What this means is that our ability to extrapolate our results to a future scenario at SJL would be highly problematic. This could simply be due to shifts in markets, regardless of a larger dynamic of climate or ecological change.

1.4.2.5 Other sustainability factors: Community leadership, new technology and urban markets

Work expanded to include other system components besides those strongly related to small ruminants. Dairy cattle and food crop production were thus gradually incorporated. Research questions expanded to include more social science topics such as: (1) Clarifying the role of human capital (i.e., leadership, entrepreneurial activity, etc.) in community development; (2) noting how changing aspirations of residents influence rates of out-migration and hence labour availability and sustainability of the production system; (3) the role of crops, livestock and wage employment in promoting food security (Fafchamps 1992; Webb et al 1992); (4) documenting patterns of gender and wealth bias in technology adoption (Biggs and Clay 1988; Pfaffenberger 1992); and (5) economic development theory, specifically whether technology adoption favours economic diversification or specialisation (Bromley and Chavas 1989; Shucksmith 1993) and the extent that non-market (i.e., social) relations augment market relations to better-manage risk (Alberti and Mayer 1974).

1.5 Literature cited

Alberti G. y Mayer E. 1974. *Reciprocidad e Intercambio en los Andes peruanos.* Instituto de Estudios Peruanos (IEP), Lima, Perú.

Alzérreca H. 1992. Overview of small ruminant research in the Bolivian Andean zone. In: Valdivia C. (ed), *Sustainable Crop-Livestock Systems for the Bolivian Highlands. Proceedings of an SR-CRSP (Small Ruminant Collaborative Research Support Program) Workshop held at Lubbock, Texas, USA, 14-17 May 1991.* University of Missouri, Columbia, Missouri, USA. pp. 165-208.

Archer S. 1989. Have southern Texas savannas been converted to woodlands in recent history? *American Naturalist* 134(4): 545-561.

Behnke R. and Scoones I. 1993. Rethinking range ecology: Implications for rangeland management in Africa. In: Behnke R., Scoones I. and Kerven C. (eds), *Range Ecology at Disequilibrium: New Models of Natural Variability and Pastoral Adaptation in African Savannahs. Proceedings of a Workshop held at Woburn, UK, 19-21 November 1990.* The Commonwealth Secretariat and the Overseas Development Institute, London, UK. pp. 1-30.

Biggs S. and Clay E. 1988. Generation and diffusion of agricultural technology: Theories and experiences. In: Ahmed I. and Ruttan V. (eds), *Generation and Diffusion of Agricultural Innovation: The Role of Institutional Factors*. Gower, Brookfield, USA. pp. 19-67.

Bromley D. and Chavas J.P. 1989. On risk, transactions and economic development in the semi-arid tropics. *Economic Development and Cultural Change* 3:719-736.

Browman D. 1974. Pastoral nomadism in the Andes. *Current Anthropology* 15: 188-196.

Buttolph L. 1998. *Rangeland Dynamics and Pastoral Development in the High Andes: The Camelid Herders of Cosapa, Bolivia.* PhD dissertation. Utah State University, Logan, Utah, USA. 286 pp.

Coppock D.L. 1993. Vegetation and pastoral dynamics in the southern Ethiopian rangelands: Implications for theory and management. In: Behnke R., Scoones I. and Kerven C. (eds), *Range Ecology at Disequilibrium: New Models of Natural Variability and Pastoral Adaptation in African Savannahs. Proceedings of a Workshop held at Woburn, UK, 19-21 November 1990.* The Commonwealth Secretariat and the Overseas Development Institute, London, UK. pp. 42-61.

Coppock D.L. 1994. *The Borana Plateau of Southern Ethiopia: Synthesis of Pastoral Research, Development and Change, 1980-91*. Systems Study No. 5. ILCA (International Livestock Centre for Africa), Addis Ababa, Ethiopia. 374 pp.

Cossins N. and Upton M. 1988. The impact of climatic variation on the Borana pastoral system. *Agricultural Systems* 27:117-135.

Dahl G. and Hjort A. 1976. *Having Herds: Pastoral Herd Growth and Household Economy.* Stockholm Studies in Social Anthropology, University of Stockholm, Sweden. 335 pp.

Ellis J.E. 1992. Recent advances in arid land ecology: Relevance to agropastoral research in the Small Ruminant CRSP. In: Valdivia C. (ed), *Sustainable Crop-Livestock Systems for the Bolivian Highlands. Proceedings of an SR-CRSP (Small Ruminant Collaborative Research Support Program) Workshop held at Lubbock, Texas, USA, 14-17 May 1991*. University of Missouri, Columbia, Missouri, USA. pp. 1-14.

Ellis J.E. and D.M. Swift. 1988. Stability of African pastoral ecosystems: Alternate paradigms and implications for development. *Journal of Range Management* 41: 450-459.

Fafchamps M. 1992. Cash crop production, food price volatility, and rural market integration in the third world. *American Journal of Agricultural Economics* 74:90-99.

Flores J. 1988. *Llamichos y Paqocheros: Pastores de Llamas y Alpacas*. CONCYTEC, Cuzco, Peru.

Francis C.A. and Youngberg G. 1990. Sustainable agriculture: An overview. In: Francis C., Flora C. and King L. (eds), *Sustainable Agriculture in Temperate Zones*. John Wiley & Sons Inc., New York, New York, USA. pp. 1-24.

Gilles J. and Malechek J.C. 1990. *Sustainable Agropastoral Systems on Marginal Lands: SR-CRSP Request for Extension, 1990-1995.* Unpublished proposal. SR-CRSP (Small Ruminant Collaborative Research Support Program), University of California. Davis, California, USA. 106 pp.

Grove T. and Edwards C. 1992. Agroecological perspectives on agricultural research and development. In: Valdivia C. (ed), *Sustainable Crop-Livestock Systems for the Bolivian Highlands. Proceedings of an SR-CRSP (Small Ruminant Collaborative Research Support Program) Workshop held at Lubbock, Texas, USA, 14-17 May 1991.* University of Missouri, Columbia, Missouri, USA. pp. 15-37.

Harwood R. 1979. *Small Farm Development: Understanding and Improving Farming Systems in the Humid Tropics.* Westview Press, Boulder, Colorado, USA. 160 pp.

Jahnke H. 1982. *Livestock Production Systems and Livestock Development in Tropical Africa*. Kieler Wissenschaftsverlag Vauk. Kiel, Federal Republic of Germany. 253 pp.

Johnson S. (ed). 1994. *SR-CRSP Annual Report 1994.* The Management Entity, SR-CRSP (Small Ruminant Collaborative Research Support Program), University of California, Davis, California, USA. 165 pp.

Johnson S. (ed). 1997. *SR/GL-CRSP Annual Report 1997*. The Management Entity, SR/GL-CRSP (Small Ruminant/Global Livestock Collaborative Research Support Program), University of California, Davis, California, USA. 341 pp.

Klein 1995. *Haciendas y* Allyus *en Bolivia, ss. XVIII y XIX*. Instituto de Estudios Peruanos, Lima, Perú. 236 pp.

LeBaron A., Bond L., Aitken P. and Michaelsen L. 1979. An explanation of the Bolivian highlands grazing--erosion syndrome. *Journal of Range Management* 32(3): 201-208.

Little D. and Said A. (eds). 1987. *Utilisation of Agricultural By-Products as Livestock Feeds in Africa*. Proceedings of a Workshop Held in Blantyre, Malawi, September 1986. ARNAB/ILCA (African Research Network for Agricultural By-Products/International Livestock Centre for Africa), Addis Ababa, Ethiopia. 179 pp.

Luna D. 1994. *Caracterizacion de Associaciones Vegetales de la Comunidad Altoandina "Aguas Calientes"* (Provincia Pacajes del Departmento de La Paz). MS tesis, Universidad Tecnica de Oruro. Oruro, Bolivia. 128 pp.

Mace R. and Houston A. 1989. Pastoralist strategies for survival in unpredictable environments: A model of herd composition that maximises household viability. *Agricultural Systems* 31: 185-204.

McIntire J. and Gryseels G. 1987. Crop-livestock interactions in sub-Saharan Africa and their implications for farming systems research. *Experimental Agriculture* 23: 235-243.

NRC (National Research Council). 1989. *Alternative Agriculture*. National Academy Press, Washington DC, USA. 448 pp.

Pfaffenberger B. 1992. Social anthropology of technology. *Annual Review of Anthropology* 21:491-516.

Pimentel D., Harvey C., Resosudarmo P., Sinclair K., Kurtz D., McNair M., Crist S., Spritz L., Fitton L., Saffouri R. and Blair R. 1995. Environmental and economic costs of soil erosion and conservation benefits. *Science* 267:1117-1123.

Powell J.M. 1986. Manure for cropping: A case study from central Nigeria. *Experimental Agriculture* 22: 15-24.

Quiroga M. 1992. Agroecological characterization of the Bolivian Altiplano. In: Valdivia C. (ed), *Sustainable Crop-Livestock Systems for the Bolivian Highlands. Proceedings of an SR-CRSP (Small Ruminant Collaborative Research Support Program) Workshop held at Lubbock, Texas, USA, 14-17 May 1991.* University of Missouri, Columbia, Missouri, USA. pp. 123-164.

Reed J., Capper B. and Neate P. (eds). 1988. *Plant Breeding and the Nutritive Value of Crop Residues. Proceedings of a Workshop Held at Addis Ababa, Ethiopia, 7-10 December 1987.* ILCA (International Livestock Centre for Africa), Addis Ababa, Ethiopia. 334 pp.

Shucksmith M. 1993. Farm household behavior and the transition to post-productionism. *Journal of Agricultural Economics* 44(3):466-478.

Starkey P. and Faye A. (eds). 1990. *Animal Traction for Agricultural Development. Proceedings of the Third Workshop of the West Africa Animal Traction Network held at Saly, Senegal, 7-12 July 1988.* Technical Centre for Agricultural and Rural Cooperation, Ede-Wageningen, The Netherlands. 475 pp.

Yazman J. 1995. *Informe Final*. IBTA/SR-CRSP (Instituto Boliviano de Tecnología Agropecuria/ Small Ruminant Collaborative Research Support Program). La Paz, Bolivia. 58 pp.

Webb, P., von Braun J. and Yisehac Yohannes. 1992. *Famine in Ethiopia: Policy Implications of Coping Failure at National and Household Levels*. Research Report 92. IFPRI (International Food Policy Research Institute), Washington DC, USA. 167 pp.

Williams T., Powell J. and Fernandez-Rivera S. 1993. Manure utilisation, drought cycles and herd dynamics in the Sahel: Implications for cropland productivity. In: Powell J., Fernandez-Rivera S., Williams T. and Renard C. (eds), *Livestock and Sustainable Nutrient Cycling in Mixed Farming Systems of Sub-Saharan Africa, Volume II. Proceedings of an ILCA (International Livestock Centre for Africa) Conference Held at Addis Ababa, Ethiopia, 22-26 November 1993.* ILCA, Addis Ababa, Ethiopia. pp. 393-410.

Chapter 2

National, regional and local context
Contexto nacional, regional y local

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Summary

As a prelude to reviewing site-specific studies undertaken by IBTA and the SR-CRSP, this chapter provides a broad overview of secondary information pertaining to the diverse physical and social geography of Bolivia. Bolivia contains ecosystems ranging from the tropical Amazon Basin to cold, arid Andean mountain ranges, and thus has a great diversity of climatic regimes, natural resources and agroecosystems. Bolivia also has a diverse cultural heritage involving interactions among many indigenous and colonial powers. Today, Bolivia is making strides towards democracy, social equity and economic stability. With a review of environment and social history as cornerstones, this chapter gradually sharpens the focus from a national to a regional (Andean) and local (San José Llanga) scale of resolution. San José Llanga (SJL) is an *Aymara* Indian community which has existed on the semi-arid Altiplano of the Andes for at least 500 years. This chapter therefore helps set the larger environmental, social and political context within which our project operated.

Bolivia is South America's poorest nation with a Gross Domestic Product (GDP) of USD 710 per person per year. About 17% of GDP is provided from use of natural resources. Although during most of Bolivia's history the majority of people have resided in the rural, high-elevation Andean zone (27% of the national land area), the current population of 6.9 million is about evenly divided between urban and rural dwellers. Rural populations in the Andes are now either exhibiting slow rates of growth or are shrinking due to high emigration to urban areas. Urban populations are growing by 4% per annum, with a doubling time of 16 years. This rural/urban dichotomy has materialised in the past 40 years. As one case-in-point, El Alto, a suburb of La Paz, grew from 50 000 residents in 1976 to over 400 000 residents by 1992. The national population is numerically dominated by indigenous Andean peoples such as the *Aymara* and *Quechua*-speaking Indians. Although European (e.g., Criollo Spanish) and racially mixed (e.g., Mestizo) cultures have been ethnic minorities, they have variously dominated the national economy and political system since colonial times. Recently the Bolivian government has encouraged rural Bolivians to relocate from the Andean zone to the tropical lowlands, but 70% of the national population still resides in urban or rural locales of the Andean highlands.

The ultimate source of much of the ecological diversity in Bolivia is the Cordilleras of the Andes, which is a massive, parallel chain of mountains in the western quarter of the country. The steep slopes of the Cordilleras contain a great diversity of ecosystems including the Yungas and High Valleys, which offer favourable climates for production of a wide variety of agricultural commodities. The Cordilleras also bound a central plateau called the Altiplano. At an average elevation of 3800 m and about 800 km in length and an average of 130 km in width, the Altiplano has climates which vary from sub-humid to hyper-arid. Prior to Spanish contact the *Aymara* Indians and other indigenous peoples commonly used a vertically integrated system of resource use. This system incorporated grazing by camelids [i.e., llama (*Llama glama*), alpaca (*L. pacos*), vicuña (*Vicugna vicugna*) and probably guanaco (*L. guanicoe*)] and production of frost-resistant crops [i.e., potato (*Solanum spp*), *quinoa* (*Chenopodium quinoa*) and cañawa (*C. palidicaule*)] on the Altiplano along with production of maize (*Zea mays*) and coca leaf (*Erythroxylum coca*) in the High Valleys and Yungas, respectively. Among the *Aymara* such regional agroecological networks of kinship-based communities were referred to as *ayllus*. Camelid pastoralism, with crop cultivation as an ancillary subsistence activity, is thought to have occurred on the Altiplano for about 7000 years BP.

Aymara kingdoms dominated what is now the Bolivian Andean region until the second half of the fifteenth century, and comprised a total population of perhaps one to two million people. At this time the *Aymara* were conquered by the *Quechua*-

speaking Inca who expanded south from what is now Peru. A highly developed *Aymara-Quechua* society emerged as a result, but this was short-lived. Spanish conquistadors arrived by the mid-1500s and gradually destroyed the traditional Andean ways of life. The Spanish used indigenous peoples as slave labour in Andean silver mines and broke-up the *ayllus* by establishing the hacienda system in the Yungas, High Valleys and on the best lands of the Altiplano. The Spanish also introduced cattle, sheep, equines and various cultivated crops (i.e., barley, wheat, oats, clovers) and the iron plough to the region, but these were mostly confined to haciendas in the more productive environments. Indigenous populations plummeted during the first century of the Spanish Conquest as a result of exotic diseases, warfare and substandard working conditions. Some free communities of *Aymara*, however, persisted on the less-productive lands on the Altiplano. By 1824 about one-third of lands formerly under indigenous tenure were controlled by the haciendas.

Despite achieving national independence in 1825, and the subsequent social and political upheavals, the hacienda system and other forms of institutionalised discrimination against indigenous Andean peoples by social elites persisted in Bolivia in various forms until the early 1950s when the Movimiento Nationalista Revolucionario (MNR) seized power. The MNR set a new agenda to empower the indigenous peasantry (or campesinos) in Bolivia. One aspect of change was the Land Reform Act of 1953 in which land ownership in the Andean zone was returned to indigenous peoples and the hacienda system was dismantled. This also served to eliminate the traditional rural elite (Mestiza) class and freed-up and diversified regional marketing channels for agriculture. The new agenda also included expansion of access to primary education in rural areas and increased investment in agricultural research and extension. One outcome of these policies was a gradual increase in the availability of fertilizers, mechanised farm equipment, new varieties of seeds and improved livestock breeds for campesino households.

This diffusion of technology has subsequently led to a mixture of traditional and imported methods for crop and livestock production. Some traditional Andean crops have become marginalised by modernisation. Frost-resistant (bitter) potato, *cañawa* and *quinoa* have all been under threat from purchased products such as rice, wheat and pasta that are often more convenient to cook. The llama, once relied upon for production of meat, fibre and as a means of portage, has been replaced by sheep, equines and mechanised transport. While the new policies of the MNR increased investment in Bolivian agriculture, this tended to emphasise export crops in the tropical lowlands. Traditional staples of the Andean highlands tended to be ignored. Andean campesinos were also encouraged to migrate to new settlements in the tropical lowlands. Campesinos often settled, however, in the humid Yungas where they began growing coca leaf in response to high international demand by the late 1970s.

Recession and hyperinflation characterised the Bolivian economy of the early 1980s; this was spurred by low prices for key Bolivian exports, fiscal mismanagement and natural disasters like flooding in the lowlands and drought in the highlands. Since the mid-1980s the top priorities of Bolivian governments have been to facilitate economic stability by exerting tighter control on government finance, abolishing public sector interventions, and opening the country to more foreign trade and investment. Large amounts of foreign aid have also played a key role; in 1992 foreign aid was around USD 100 per capita. Despite making substantial strides towards multi-party democracy and economic stability since the mid-1980s, however, the negative decline for agriculture in general, and highland agriculture in particular, has continued. The downward trends are related to a combination of factors including poor performance of tropical agriculture despite increased inputs, inadequate marketing channels and marketing policies, depression of food prices due to large quantities of food aid, importation of cheap food, pervasive technical constraints in Andean agriculture posed by the harsh climate, and depletion of much of the rural Andean labour force due to urban migration. The Bolivian government has taken further steps to try to remedy the decline of agriculture and promote sustainable rural development. It issued a decree in 1990 to modernise the national agricultural research entity called Instituto Boliviano de Tecnología Agropecuaria (IBTA) by promoting a shift in focus to include more efforts for technology generation and technology transfer. In 1994 a Popular Participation Act was passed which provides legal status for campesino communities and redistributes 20% of national tax revenues back to such communities on the basis of population size. Only in the past few years has total government spending on the Altiplano exceeded 10% of total revenues. Recently, an all-weather road was completed connecting La Paz and Patacamaya with Arica on the Chilean coast. This will have large implications for international trade.

In terms of environment, the Altiplano is a closed hydrological system having high levels of endogenous salinity. The low levels of fresh water inputs from precipitation and glacial run-off are insufficient to allow any salts to effectively leach out of the system. The Altiplano is a lacustro-alluvial plain represented by a series of inter-linked lake basins and tributaries. Ecologically distinct sub-regions have been created by various types of geomorphic barriers. Characteristic features of the Altiplano include Lake Titicaca, Lake Poopó and the extensive salt flats of Coipasa and Uyuni; all are remnants of ancient lakes. The central alluvial plain is often where significant soil deposition has occurred; the slopes of the Cordilleras largely remain covered with unweathered rock. Because the Altiplano is located in the southern hemisphere, a cooler, drier winter occurs from June to August while a warmer, wetter summer occurs from December through February. There is a large daily variation in air temperature. Frost risk is pervasive, especially in winter. Most precipitation occurs as rain from November through March or April. The overall physiognomy of Altiplano vegetation is open with small- and medium-sized plants and little, if any, tree cover. This physiognomy is generally referred to as puna. The shrub-like plants are more common on better-drained soils such as those found on mountain footslopes or terraces. Bunchgrasses occur more at intermediate elevations, while short grasses and halophytes (i.e., salt-tolerant species) occur more at the lowest elevations such as plains or dried lake basins having high water tables.

The Altiplano can be divided into several agroecological regions defined by moisture regimes. The sub-humid region comprises about 6% of the Altiplano and is where the most extensive cultivation occurs. This is largely the environs of Lake Titicaca. The frost risk is very low and annual precipitation varies from 600 to 900 mm. The human population density averages 25 to 37 persons per km^2. Mixed farming systems prevail in the sub-humid region; it has been recently observed that sheep production has declined, but dairying and production of barley, alfalfa and beef cattle have increased. The semi-arid region comprises about 54% of the Altiplano. Annual precipitation ranges from 400 to 600 mm. The human population density varies from two to 15 persons per km^2. There is some dairying and beef production in the semi-arid region, but this remains the centre for sheep production and agropastoralism. The arid region comprises about 23% of the Altiplano. Annual precipitation ranges from 200 to 400 mm. There is typically less than one person per km^2. Cultivation is limited and dominated by hardy indigenous taxa such as *quinoa*; livestock are dominated by camelids and sheep. Salt is harvested for market in some locales. The native vegetation of the arid zone is similar to that of the semi-arid zone, but the former is more patchy and more dominated by shrubby species. The hyper-arid puna comprises about 14% of the Altiplano, with annual precipitation typically <200 mm. There is some rearing of camelids in this zone, but it is largely uninhabited. Finally, about 3% of the Altiplano consists of barren salt flats.

Our study site of San José Llanga (SJL) is located in the semi-arid region on the east-central Altiplano about 120 km southeast of La Paz and El Alto. The main barrio (settlement) of SJL is located about 17 km south of the regionally important town of Patacamaya on the Pan-American highway. The Cantón of SJL is 7200 ha in size and varies from 3725 to 3786 m in elevation. It is located near the middle of the alluvial plain of the Altiplano in the Patacamaya Basin and is thus distant from the foothills of the Cordilleras. The Patacamaya Basin is essentially a flat, extensive fluvio-lacustrine plain largely defined by the environs of the saline, perennial Desaguadero River which runs 15 km to the southeast of SJL. The mean annual precipitation at SJL is about 407 mm. The Cantón of SJL is home to about 100 campesino households distributed among six settlements, loosely organised according to kinship. The people grow food and forage crops on alluvial surfaces and do not have access to hillside cultivation systems common elsewhere. The people also raise sheep, beef cattle, dairy cattle and donkeys. People of SJL are part of a traditional *ayllu* called Llanga, but this (like many *ayllus*) was fragmented and permanently disrupted during the Spanish colonial period. The people of SJL, however, remained relatively free from colonial domination. The ability of the SJL residents to remain free was due in part to their association with a larger indigenous group called *Umala* renowned for its fierce opposition to encroachment by the Spanish. In 1953 SJL received a collective (*pro indiviso*) title to the lands they occupied. Land was then divided among resident households by action of local committees. Higher value (crop) lands were assigned to households under private tenure except for some restrictions on future sale or transfer; this largely meant that crop lands could only be sold to someone outside of SJL upon approval by a SJL council. Despite that croplands in general were put under private tenure, there was still variation in who could access certain plots and when. For example, although plots which are currently in production are under private control, once they have been harvested or left to fallow they are available for communal grazing. The native grazing lands at SJL tend to be under communal tenure, but higher value parcels may be subject to *de facto* private control, especially if the parcels are located near households which use them regularly.

Like most Andean campesinos this century, the people of SJL have typically been a low priority in the economic development plans of Bolivia. There has been some recent development activity at SJL, however, which is altering the traditional campesino way of life. A dirt road between the main barrio of SJL and the town of Patacamaya was completed in 1988 and has stimulated commerce, including development of smallholder dairying as early as 1989. A 23-km irrigation canal was completed in 1984 linking some potential croplands at SJL with water from the Desaguadero River. The passage of the Popular Participation Act in 1994 will probably also affect SJL through redistribution of tax monies to needy communities and by shifting regional centers of political power.

Overall, it is concluded that recent policy shifts of the Bolivian government offer some chance for people like the *Aymara* to improve their economic status. It is also evident that our study site at SJL has key attributes in terms of landscape position and access to markets and technology that make it an important place to conduct research. The primary exploitation of alluvial plains rather than hillsides makes SJL more of a resource “sink” where nutrients, salts and water collect. The proximity to urban markets and access to new technology via the Patacamaya Research Station make SJL a “living laboratory” in which one can observe effects of market integration and technology diffusion on rural development processes.

Resumen

Como preludio a la revisión de los estudios puntuales efectuados por el SR-CRSP y el IBTA, este capítulo presenta un panorama general de información secundaria referida a la diversidad física y social en la geografía de Bolivia. Bolivia está constituido por diversos ecosistemas que van desde el tropical Amazona hasta las frías y áridas montañas Andinas, debido a ésto existe una gran diversidad de regimenes climáticos, recursos naturales, y sistemas agrícolas. Bolivia tiene una herencia cultural diversa, incluyendo interacciones entre numerosos poderes indígenas y los invasores colonizadores. En la actualidad, Bolivia está haciendo esfuerzos hacia una democracia en un marco de equidad social y estabilidad económica. Con la revisión de características medioambientales e historia social como elementos principales, este capítulo gradualmente enfoca su interés desde una escala nacional, hacia una regional (Andes) y local (San José Llanga, SJL) de resolución. San José Llanga es una comunidad indígena *Aymara* la cual ha existido en el Altiplano semi-árido de los Andes por lo menos por 500 años. Este capítulo, por lo tanto, ayuda a establecer un amplio contexto medioambiental, social y político dentro del cual nuestro proyecto ha operado.

Bolivia es la nación más pobre en Sudamérica con un producto interno bruto (PIB) de USD 710 por persona por año. Aproximadamente el 17% del PIB proviene del uso de los recursos naturales. Aunque en gran parte de la historia de Bolivia la mayoría de la gente residió en las zonas rurales de las tierras altas de los Andes (27% de la superficie total nacional), la población actual de 6.9 millones de habitantes está casi igualmente distribuida entre las zonas rurales y urbanas. Las poblaciones rurales en los Andes actualmente presentan grados lentos de crecimiento o éste está decreciendo debido a la alta emigración a áreas urbanas. Las poblaciones urbanas están creciendo en 4% por año, lo que implica la duplicación de la población en 16 años. Esta dicotomía urbana/rural se ha materializado en los pasados 40 años. Como un caso puntual se tiene a El Alto, un suburbio de La Paz, que ha crecido de 50.000 residentes en 1976 hasta cerca de 400.000 en 1992. La población nacional está numéricamente dominada por gente indígena andina, principalmente de habla *Aymara* y *Quechua*. Aunque la cultura de los europeos (p.e. criollo español) y de gente racialmente mezclada (p.e. mestizo) han sido minorías étnicas, ellas han dominado en varias formas la economía nacional y el sistema político desde tiempos coloniales.

Recientemente el gobierno de Bolivia ha promovido la movilización de la gente desde las áreas rurales de la zona Andina a las zonas bajas tropicales, pero el 70% de la población nacional todavía reside en localidades rurales y urbanas de los Andes.

El origen primario de gran parte de la diversidad ecológica de Bolivia es la cordillera de los Andes, la cual presenta cadenas montañosa masivas y paralelas que ocupan una cuarta parte del país. Las pendientes pronunciadas de estas cordilleras contienen una gran diversidad de ecosistemas incluyendo los Yungas y Valles Altos, los que ofrecen climas favorables para la producción de una gran variedad de productos agrícolas. Las cordilleras también encierran una planicie central llamada Altiplano. El Altiplano con una altura promedio de 3800 m, cerca de 800 km de largo, y 130 km de ancho en promedio, con climas que varían desde sub-húmedo hasta hiper-árido. Antes de la conquista española, los indígenas *Aymaras* y otras poblaciones locales comúnmente usaban un sistema vertical integrado de uso de los recursos. Este sistema incorporaba pastoreo de camélidos [p.e. llama (*Lama glama*), alpaca (*L. pacos*) y utilización dirigida de camélidos silvestres p.e. vicuña, (*Vicugna vicugna*) y probablemente *guanaco* (*L. guanicoe*)] y la producción de cultivos resistentes a heladas [p.e. papa (*Solanum* spp), *quinua* (*Chenopodium quinoa*) y *cañahua* (*C. palidicaule*)] en el Altiplano al igual que maíz (*Zea mays*) y hojas de coca (*Erythroxylon coca*) en los Valles Altos y los Yungas, respectivamente. Entre los *Aymaras*, estas redes agroecológicas regionales, de comunidades relacionadas por parentesco, fueron conocidas como *ayllus*. Se piensa que el pastoralismo de camélidos acompañado por cultivos agrícolas como una actividad complementaria de subsistencia ha ocurrido en el Altiplano desde hace 7000 años AC.

Los reinos *Aymaras* dominaron lo que es actualmente la región Andina de Bolivia hasta la segunda mitad del siglo quince. Se estima que en esta época una población total de uno a dos millones de habitantes podrían encontrarse en la región. Hacia esta época los *Aymaras* fueron conquistados por los Inca *Quechua*-parlantes, quienes se expandieron desde el sur, lo que es ahora el Perú. Como resultado se generó una sociedad *Quechua-Aymara* altamente desarrollada, aunque de corta vida. Los conquistadores Españoles arribaron en la mitad de los 1500s y gradualmente destruyeron los sistemas tradicionales de vida de los Andes. Los Españoles usaron a los indígenas como mano de obra esclava para el trabajo en las minas de plata y desintegraron los *Ayllus* con el establecimiento del sistema de hacienda en los Yungas, Valles Altos y en las mejores tierras agrícolas del Altiplano. Los Españoles también introdujeron en la región vacas, ovejas, equinos, varios cultivos (p.e. cebada, trigo, avena, trébol) y el arado de hierro, aunque estas introducciones ocurrieron principalmente en las haciendas y en los medio ambientes más productivos. La difusión gradual de estas nuevas tecnologías ocurrió a lo largo de centenares de años que siguieron a su introducción. La población indígena se redujo drásticamente durante el primer siglo de la conquista española como resultado de enfermedades exóticas, guerras y condiciones de trabajo infrahumanas. Varias comunidades libres *Aymaras*, sin embargo, persistieron en las tierras menos productivas en el Altiplano. En 1824 cerca de un tercio de tierras originalmente controlada por los indígenas pasaron a ser controladas por las haciendas.

A pesar de alcanzar la independencia nacional en 1825, y subsecuentes reformas sociales y políticas, el sistema de hacienda y otras formas de discriminación institucionalizada contra las poblaciones indígenas de los Andes por las élites sociales locales, persistieron en Bolivia en varias formas hasta los primeros años de 1950, cuando el Movimiento Nacionalista Revolucionario (MNR) subió al poder. El MNR estableció una nueva agenda para verdaderamente otorgar poder a los agricultores o campesinos en Bolivia. Un aspecto de este cambio fue el Decreto de Reforma Agraria de 1953, por el cual la propiedad de la tierra en la zona Andina fue devuelta a la población indígena y el sistema de hacienda fue desmantelado. Esto también sirvió para eliminar las clases rurales tradicionales de élite (mestiza), además para abrir y diversificar canales regionales de mercadeo para productos agrícolas. La nueva agenda también incluyó la ampliación del acceso a la educación primaria en el área rural y se incremento la inversión en investigación y extensión agrícola. Un resultado de éstas políticas fue el incremento gradual en la disponibilidad de fertilizantes, maquinaria, equipo agrícola, nuevas variedades de semillas y razas mejoradas de ganado para los productores campesinos.

Esta difusión de tecnología resultó subsecuentemente en el desarrollo de nuevos métodos mixtos de tecnología con componentes tradicionales e importados para la producción agrícola y ganadera. Algunos cultivos tradicionales andinos resultaron marginalizados por la modernización. La papa amarga resistente a heladas, la *cañahua* y la *quinua* han sido amenazadas por productos de fácil disponibilidad en el comercio local como arroz, trigo y pasta que son por lo general más convenientes. Por otra parte, la llama, de la cual por mucho tiempo se dependió como productora de carne, fibra y como medio de transporte de productos, ha sido remplazada por la oveja, equinos y trasporte mecanizado. Mientras que las nuevas políticas del MNR incrementaron la inversión en la agricultura boliviana, estas políticas tendieron a enfatizar la producción de cultivos para exportación en las tierras bajas tropicales y los cultivos tradicionales de las tierras altas andinas tendieron a ser ignorados. Los campesinos de los Andes fueron también concientizados a migrar a nuevas áreas de colonización en las tierras bajas. Los campesinos a menudo terminaron en los Yungas húmedos donde empezaron a cultivar hoja de coca en respuesta a la alta demanda internacional a fines de 1970.

La recesión e hiperinflación caracterizaron la economía de Bolivia en los primeros años de la década de los ochenta; ésto fue favorecido por los bajos precios de los productos claves de exportación de Bolivia, la disminución de los préstamos internacionales, manejo fiscal ineficiente y desastres naturales tales como inundaciones en las tierras bajas y sequía en las tierras altas de los Andes. Desde mediados de 1980, una de las prioridades máximas del gobierno de Bolivia ha sido facilitar la estabilidad económica mediante un severo control de las finanzas del gobierno, eliminar la participación del sector fiscal y abrir el país a las inversiones y mercado extranjero. Los altos montos de ayuda extranjera también jugaron un papel clave. En 1992 la ayuda extranjera fue de alrededor de USD 100 per cápita. A pesar de intentos substanciales para lograr una democracia multipartidaria y estabilidad económica desde mediados de los 80, el crecimiento negativo de la agricultura en general , y la agricultura de la zona andina en particular ha continuado. Estas tendencias decrecientes están relacionadas a una combinación de factores que incluyen el pobre comportamiento de la agricultura tropical a pesar del incremento de insumos, canales y políticas de mercadeo inadecuados, la baja de los precios de alimentos, los constantes problemas técnicos en la agricultura andina debido a factores climáticos negativos, y la falta de disponibilidad de la mayoría de la fuerza de trabajo rural debido a la migración urbana. El gobierno de Bolivia ha tratado otras medidas para tratar de corregir la disminución en la producción agrícola y promover el desarrollo rural sostenible. En 1990, el gobierno promulgó un Decreto para modernizar la entidad nacional de investigación agrícola llamada Instituto Boliviano de Tecnología Agropecuaria (IBTA) con un cambio de enfoque que incluiría mayores esfuerzos en la generación y transferencia de tecnología. En 1994 se promulgó la Ley de Participación Popular, la que confiere status legal a las municipalidades rurales y redistribuye el 20% de los ingresos de impuestos de regreso a las comunidades en base al tamaño de población. Solo recientemente el gasto total del gobierno en las áreas rurales Andinas ha excedido el 10% del total de los ingresos. Recientemente se terminó de construir una carretera de circulación permanente entre La Paz, Patacamaya, Tambo Quemado y Arica, en la costa chilena, que tendrá amplias implicaciones para el comercio internacional en los Andes.

En términos medioambientales, el Altiplano es un sistema hidrológico cerrado con altos niveles endógenos de salinidad. Los bajos niveles de agua fresca incorporados por la precipitación y provenientes de los glaciales son insuficientes para eliminar esta salinidad fuera del sistema. El Altiplano es una planicie lacustre-aluvial caracterizada por la presencia de una serie de tributarios y cuencas con lagos intercomunicados. Ecologicamente, varios tipos de barreras geomorfológicas han influído para la formación de distintas sub-regiones. La característica más relevante del Altiplano incluye el Lago Titicaca, el Lago Poopo y los extensos salares de Coipasa y Uyuni; ambos salares son residuos de lagos antiguos. La planicie central aluvial es frecuentemente la zona más importante donde han ocurrido depósitos significativos de suelos, las laderas de las cordilleras permanecen cubiertas por rocas que resistieron el desgaste por factores climáticos. Debido a que el Altiplano esta localizado en el hemisferio sur, el invierno, de Junio a Agosto, es frío y seco, mientras que el verano, de Diciembre a Marzo, es caliente y húmedo. La temperatura del aire presenta una amplia variación térmica diaria, y el riesgo de helada es constante, especialmente en invierno. La mayoría de la precipitación ocurre como lluvia desde Noviembre hasta Marzo o Abril. En general, la fisionomía de la vegetación del Altiplano por lo general es abierta, con plantas de tamaño pequeño y mediano, con muy poco o ausencia de arboles. Esta fisionomía es generalmente conocida como puna. Las plantas arbustivas son más comunes sobre suelos de mejor drenaje tales como en los pies de laderas y terrazas. Los pastos amacollados ocurren con mayor frecuencia en elevaciones intermedias del paisaje, mientras que los pastos cortos y halófilas (p.e. especies tolerantes a sal) ocurren por lo general en zonas bajas, tales como planicies o cuencas secas de lagos con aguas subterráneas superficiales.

El Altiplano puede ser dividido en varias regiones agroecológicas definidas de acuerdo al régimen húmedo. La región sub-humeda abarca cerca del 6% del Altiplano y es allí donde la mayoría de los cultivos ocurren. Esta zona ocupa mayormente los medio ambientes influenciados por el Lago Titicaca. El riesgo de heladas es bajo y la precipitación anual varía desde 600 hasta 900 mm. La densidad de la población humana varía en promedio de 25 a 37 personas por km^2. Recientemente se ha observado que en los sistemas agrícolas mixtos de la zona sub-húmeda la producción de ovejas está declinando, pero la producción de leche, cebada, alfalfa y ganadería de carne se está incrementando. La puna semi-árida abarca cerca del 54% del Altiplano. La precipitación anual en la zona varía entre 400 y 600 mm. La densidad de la población humana varía entre 2 a 15 personas por km^2. En ésta zona existe algo de producción lechera y de carne de vacuno, sin embargo, esta región se destaca como el centro de la producción ovina y agropastoralismo. La región árida abarca casi un 23% del Altiplano. El rango de la precipitación anual en la zona árida varía entre 200 y 400 mm. Típicamente, para esta zona se registra menos de 1 persona por km^2. El cultivo es limitado y restringido a cultivos indígenas rústicos tales como la *quinua*, en tanto que la ganadería está dominada por los camélidos y ovinos. También se extrae sal para mercadeo en algunos mercados locales. La vegetación nativa de la puna árida es similar a la de la puna semi-árida, pero en la zona árida la vegetación es más fragmentada y dominada por especies arbustivas. La puna hiper-árida abarca cerca del 14% de el altiplano, con una precipitación anual de <200 mm. En la zona se crían algunos camélidos, pero en su mayor parte está deshabitada. Por último, cerca de un 3% del Altiplano está cubierto por áreas planas desnudas saladas.

Nuestro sitio de estudio de San José Llanga (SJL) está localizado en la puna semi-árida del Altiplano central-este, a una distancia de cerca de 120 km al sudeste de La Paz y El Alto. El barrio mayor de SJL está localizado aproximadamente a 17 km al sur del regionalmente importante pueblo de Patacamaya sobre la carretera panamericana. El cantón SJL tiene 7200 ha en tamaño y su elevación varía desde 3725 hasta 3786 m. San José Llanga está localizada en el centro de una planicie aluvial del Altiplano en la cuenca de Patacamaya y está por lo tanto lejos de las pendientes de la cordilleras. La cuenca de Patacamaya es esencialmente una extensa planicie fluvio-lacustre largamente definida por el medio ambiente salino del permanente río Desaguadero. Este río se encuentra a 15 km al sudeste de SJL. La precipitación anual media de SJL es alrededor de 407 mm. El Cantón de SJL se encuentran aproximadamente 100 familias campesinas distribuidas entre seis localidades, libremente organizadas de acuerdo a lazos familiares. La gente cultiva alimentos y forrajes en superficies aluviales y no tiene acceso a sistemas de cultivo en laderas comunes en otras partes de los Andes. Los habitantes de SJL también crían ovejas, vacunos para carne, vacunos para leche y burros. La gente de SJL fueron parte del tradicional *ayllu* llamado Llanga, pero este (al igual que muchos *ayllus*) fue fragmentado y constantemente alterado durante el período colonial español. La gente de SJL, sin embargo, permaneció relativamente libre de la dominación colonial. La habilidad de los residentes de SJL para permanecer libres se debió en parte a su asociación con un grupo indígena más grande de la región de *Umala* y conocido por su tenaz oposición a la dominación local por los españoles. Gracias a la Reforma Agraría de 1953, SJL recibió una titulo colectivo (*pro-indiviso*) de las tierras que ocupaban. La tierra fue entonces dividida entre las familias residentes a través de la acción de los comites locales. Tierras de alto valor (agrícolas) fueron entregadas a familias bajo la condición de tenencia privada, excepto por algunas restricciones sobre la venta futura o transferencia; esto significaba que las tierras agrícolas podrían ser vendidas solamente a personas ajenas a la comunidad solo después de la aprobación de un consejo de SJL. En general, a pesar que las tierras agrícolas fueron puestas bajo la propiedad privada, el acceso, uso y quién puede usar tales tierras es variable. Por ejemplo, aunque algunas parcelas están siendo usadas para el cultivo bajo el control privado, una vez que han sido cosechadas o puestas en descanso, éstas tierras pasan al uso de pastoreo comunal. En tanto que los campos de pastoreo nativos en SJL tienden a estar bajo la tutela común, ciertas parcelas, de mayor valor, pudieran estar sujetas al control privado *de facto*, especialmente si éstas se ubican cerca de casas de familias que usan éstas tierras a menudo.

Al igual que la mayoría de los campesinos andinos en este siglo, la gente de SJL típicamente ha tenido baja prioridad para el desarrollo económico de Bolivia. Planes recientes de desarrollo en SJL están alterando la forma tradicional de vida del campesino. Podemos citar algunos ejemplos; un camino ripiado se terminó en 1988 ha estimulado el comercio local incluyendo el desarrollo de pequeños productores de leche desde 1989. Por otro lado, en 1984 se terminó de construir un canal de irrigación de 23 km que une mediante riego con agua del río Desaguadero algunas áreas agrícolas potenciales de SJL. La promulgación de la ley de participación popular en 1994 incluye la redistribución de dinero de los impuestos a comunidades necesitadas y dado el cambio de los centros regionales de poder político probablemente también afectarán a SJL.

Por lo general se ha concluido que los recientes cambios en el gobierno Boliviano ofrecerá oportunidades a la gente, como los *Aymara*, para mejorar su calidad económica. Por otro lado es indudable que nuestro estudio en la comuna de SJL tiene sus características en cuanto a términos de ubicación de las tierras y su acceso a los mercados y disponibilidad de tecnología, que la convierten en un lugar importante para la investigación. La explotación primaria de las planicies aluviales en vez de las laderas hacen de SJL un “pozo” de recursos en donde tanto los nutrientes, sales y agua se acumulan. La próximidad a los mercados urbanos y el acceso a nueva tecnología a través de la Estación Experimental de Patacamaya hacen de SJL un “laboratorio vivo” en el cual se pueden observar los efectos de la integración del mercado y la difusión de las tecnologías en los procesos de desarrollo rural.

2.1 Introduction

To better understand today’s constraints and opportunities for improving small ruminant production systems on the Bolivian Altiplano, it is important to first consider the broader contexts of environment and social history. This chapter provides an introductory overview of secondary information concerning major ecological regions of Bolivia, constituent agroecosystems and how ecological regions are interrelated in terms of climate, geography, macro-economics and agricultural policy. Key aspects of cultural change and political history are also reviewed. These are important because present-day values and behaviours of Andean campesinos, as well as their use of agricultural technologies, have been profoundly shaped by forces including the indigenous *Aymara* culture, Incan occupation, Spanish colonialism, the initial Republican Period and contemporary policies of the Bolivian government.

2.2 National overview of Bolivia

Bolivia encompasses a total area of 1 098 591 km^2 (or 424 164 square miles), located in the geographic centre of the South American continent bordered by Argentina, Brazil, Chile, Paraguay and Peru. The country is governed as a democratic republic and administered as nine departments with the legal capital (judicial branch) at Sucre and seat of government (legislative and executive branches) in La Paz (Figure 2.1). As the largest city in Bolivia with over a million inhabitants, La Paz is nestled at 3650 masl near the Altiplano (Plate 2.1).

In 1995 Bolivia had a population of about 6.9 million with a population growth rate of 2.1%; roughly 50% of the people live in rural areas with the remainder urban dwellers (GDRU 1994). Thirty-nine percent of the population is under 14 years of age. The ethnic composition of the population is approximately 30% *Quechua* Indian, 25% *Aymara* Indian, 5% other native groups and 40% Mestizo (mixed European and Indian ancestry) and European. Ninety-five percent of the population are Roman Catholics (SR-CRSP 1994). About 80% of citizens over the age of 15 years can read and write. Agriculture (including forestry and fisheries) accounts for about 17% of Gross Domestic Product (GDP); principal agricultural commodities include soybeans, coffee, cotton, corn, sugarcane, rice, potatoes, coca leaf (*Erythroxylum*

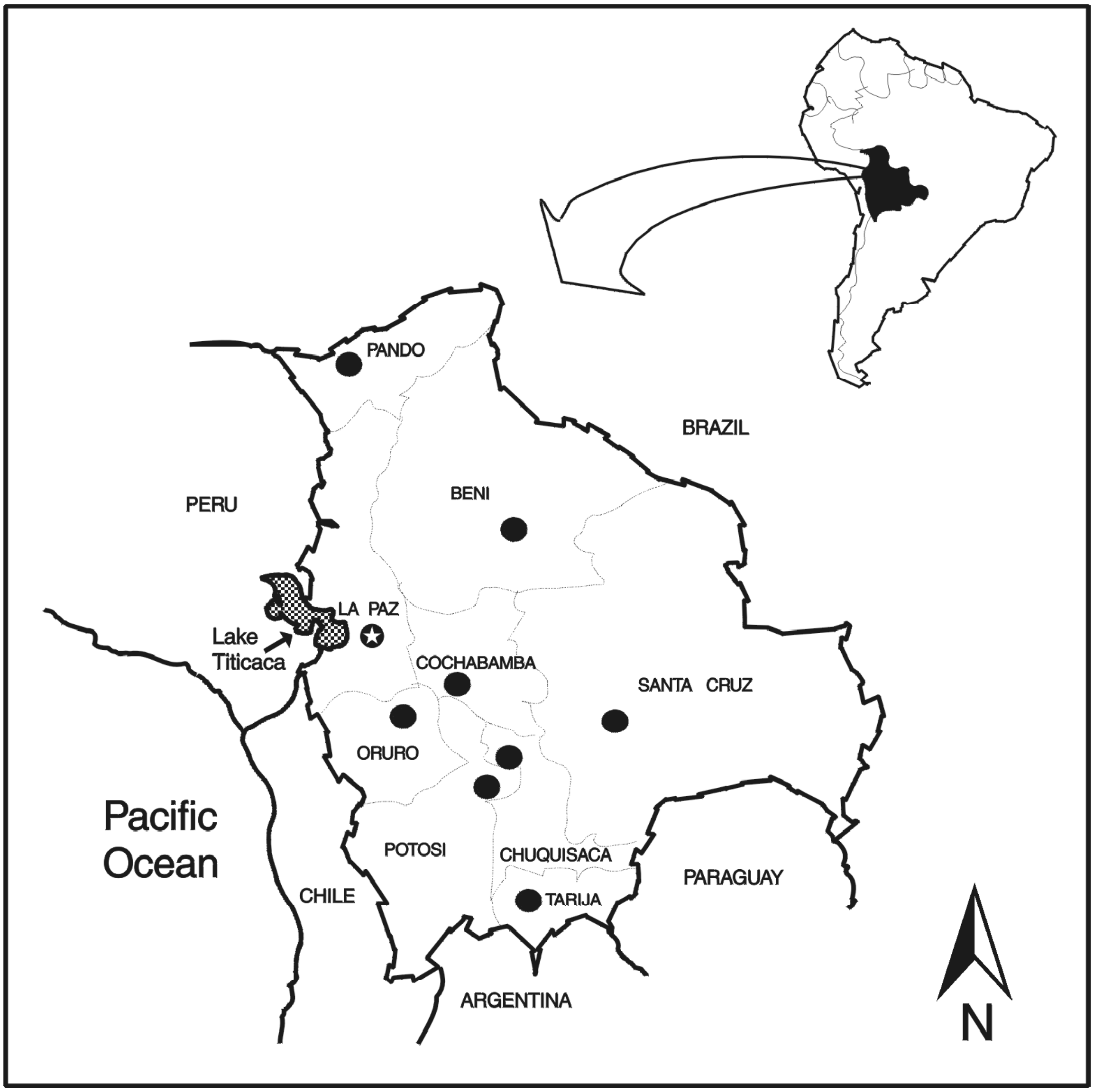

Figure 2.1. *Location of Bolivia in South America and depiction of Bolivian regional administrative departments and placement of major cities.* Source: C. Jetté (IBTA/SR-CRSP, unpublished)

coca) and timber. The remainder of GDP is largely provided from commerce, transport, finance, administration and services (45%), manufacturing and construction (20%), metals, petroleum, and natural gas (10%), and indirect taxes (8%). Exports include mainly metals, natural gas, jewelry, soybeans and timber (GDRU 1994). In 1993, per capita GDP was USD 710 per annum (GASO 1995, 35), placing Bolivia near the bottom for Latin America. According to a Human Development Index from PNUD (1994), Bolivia is also regarded as the least developed country in South America.

2.2.1 National highlights of physical geography and environment

Bolivia is a country of great physiographic and ecological diversity with ecosystems ranging from hot, tropical lowlands to cold, arid highlands. The most pervasive influences on climate are exerted by two mountain chains that run north to south and occupy the western portion of the country. These mountain chains are called the Cordilleras (Figure 2.2; Plate 2.2). The Cordilleras are part of the Andean mountain complex; some peaks in the

Plate 2.1. *Vista of the city of La Paz. La Paz is nestled at the edge of the Altiplano at an elevation of 3650 masl.* Photograph: Lita Buttolph

Cordilleras exceed 6000-m elevation (Muñoz-Reyes 1982). The western Cordillera comprises a physically continuous chain of mountains, while the eastern Cordillera is a more fragmented sequence of parallel ranges, oriented along a northwest to southeast direction, that yield a diverse series of inter-mountain locales. The two chains of the Cordilleras are combined into one unit in much of Peru, but throughout southern Peru and western Bolivia they are separated and enclose a central highland plateau called the Altiplano. The eastern and western Cordilleras are rejoined into one unit to the south in Argentina and consequently the Altiplano ends. The Altiplano averages an elevation of 3800 m and is a region of dry, temperate ecosystems (see Section 2.3.1.2: *Regional environment*). Together the Cordilleras and Altiplano above 2000-m elevation comprise 27% of the total land area of Bolivia. The Bolivian lowlands oc-

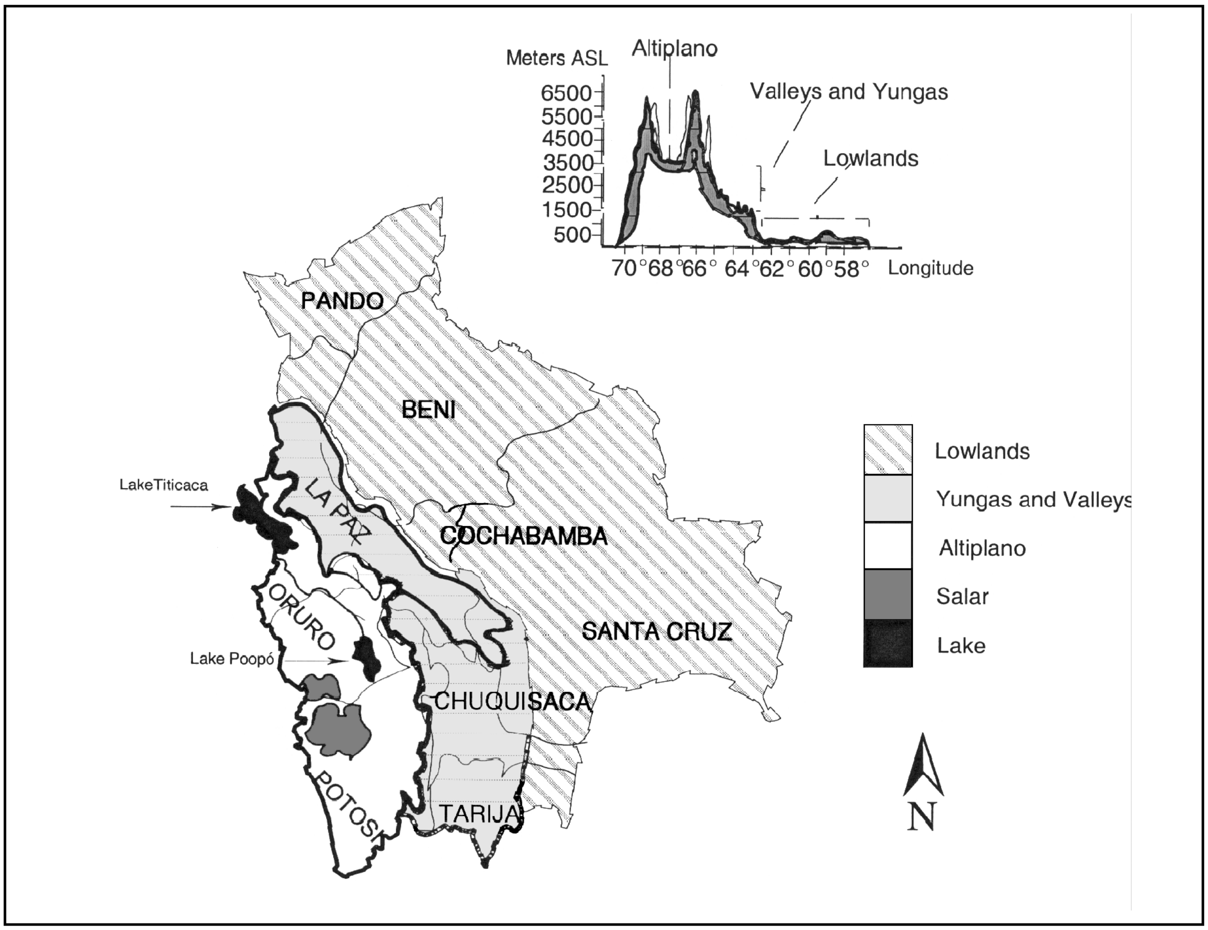

Figure 2.2. *Elevational cross-section (in masl or meters above sea level) of Bolivia and location of generalised agroecological zones with respect to regional administrative departments in Bolivia.* Sources: Adapted from Freeman et al (1980) and Ellenberg (1981)

Plate 2.2. *Vista of the Altiplano situated between the two chains of the Cordilleras.* Photograph: D. Layne Coppock

cur outside of the Andean zone and primarily consist of tropical rainforest and tropical savanna to the north and northeast. Lowlands to the east and southeast include the subtropical Gran Chaco savanna plains and forests. To the north, as one descends the slopes of the eastern Cordilleras, there is a steep gradient of increasing precipitation and ambient temperature. This transitional region occurs between 500- to 2500-m elevation and is referred to as the Yungas (Figure 2.2). The Yungas are humid, narrow valleys with steep slopes suitable for growing tropical crops like coffee and coca leaf. Similarly, to the south as one descends the eastern Cordilleras there is a gradient of increasing ambient temperature with variable precipitation; this transitional region occurs between 1000- to 3000- m elevation and is referred to as the Valleys (Figure 2.2). The Valleys consist of more semi-arid and sub-humid locations suitable for growing crops such as corn and wheat. Both the Yungas and Valleys have been very important to Bolivian agriculture. The Valleys located at higher elevations near the Altiplano (i.e., the High Valleys) and the Yungas were also traditionally exploited by highland peoples as part of a vertically integrated pattern of herding and farming (see Section 2.3.2: *Regional historical highlights*). At the base of the east-facing slopes of the eastern Cordilleras emerges Bolivia's largest hydrological system, the Amazon Basin, which fans out and extends into Brazil (Figure 2.2). The second largest hydrological system is the Rio de la Plata Basin to the south and southeast. The third hydrological system is the closed (e.g., endorheic) basin of the Altiplano where water inputs occur as precipitation and glacial runoff, and water losses occur via evaporation. By virtue of their distinct ecosystem features the Andean, transitional and lowland zones have equally varied histories of human occupation and resource use, some of which will be referred to later in this chapter. Readers interested in a detailed treatment of physical geography and environment at a national scale for Bolivia are referred to Muñoz-Reyes (1982), Brockmann (1986) and Montes de Oca (1989).

2.2.2 National highlights of social history

2.2.2.1 1400 to 1824

In the early 1400s the region of what is now western Bolivia was populated by the indigenous *Aymara* and other minority ethnic groups such as the *Pukinas* and the *Uru-Chipaya* speaking peoples. These groups were dominated by the *Aymara* who occupied the Altiplano and transitional Andean zones (Klein 1984). Despite the well-organised socio-political and economic structures of the *Aymara* kingdoms, they were conquered by the Incas, a *Quechua*-speaking people originating near Lima in what is now Peru, in the second half of the fifteenth century. The Incan occupation, however, fundamentally changed few aspects of *Aymara* society. By the early 1500s a highly developed *Aymara-Quechua* society had emerged in what is today the Bolivian Andean zone; this society was administered as one of four divisions of the Incan Empire called *Kollasuyo* [Moseley (1992) cited by Kolata (1993)]. One attribute of the *Aymara-Quechua* society was the integrated utilization of different agroecosystems along spatial and altitudinal gradients. The economy was based on agropastoral production systems with extensive grazing occurring more at higher elevations or in semi-arid and arid areas (the semi-arid Altiplano) and intensive farming in areas more favourable for agricultural production in the Altiplano (the Lake Titicaca Basin) and at lower elevations (Yungas and High Valleys). Important changes in *Aymara* agriculture that resulted from Incan influence included, for example, construction of complex terracing systems on Andean mountainsides and development of warehouses to store foodstuffs (Klein 1984).

In contrast to the Andean highlands and transitional zones, the remaining two-thirds of what is now Bolivia was inhabited by less-sophisticated cultures including hunter-gatherers and village-based agriculturalists. Some small, well-organised "states" for these peoples occurred in the lowlands.

These included the Chiriguanos in the Chaco region. Despite a lower level of organisation and cultural development compared to the *Aymara-Quechua* society, the lowlanders were successful in blocking attempts at encroachment and thus excluded highlanders from the Amazon Basin and Chaco region (Klein 1984).

The first Spanish conquistadors entered what is now Bolivia in 1535 and initiated a long period of colonialism which persisted until 1825 when Bolivia achieved national independence. Initially, the Spanish gave little attention to the Andean highlands (then referred to as the Upper Peru), but this dramatically changed with discovery of rich veins of silver at Porco and Potosí (Klein 1984). The Spanish began to exploit the mineral wealth of the highlands on a large scale by 1545. The indigenous people were forced to serve as slave labour in the silver mines. Loss of life due to poor working conditions in mines, in addition to that caused by imported diseases and military resistance against the Spanish, contributed to a marked population decline among indigenous groups. In some Upper Peru provinces it is estimated that about 90% of the indigenous people disappeared within 50 years of initial Spanish contact (Kolata 1993). Priorities of mining development included establishment of administrative centres at La Paz, Potosí and Charcas (now called Sucre), along with networks for agriculture and communication. Mineral export routes went to the Pacific Coast. Agriculture in the drier and colder highland systems subsequently evolved to incorporate mixes of indigenous and Spanish technology and management. Agriculture in the Valleys, however, developed more under the influence of Spanish innovations (see Section 2.3.2: *Regional historical highlights*).

Another important dimension of colonialism by the second half of the sixteenth century was the hacienda system, which involved numerous, private agricultural operations located on the best lands in a variety of agroecological regions of the Andean zone. During the colonial period haciendas were owned and managed by the Spanish and their descendants. These owners/managers were called hacendados. Hacendados used cheap indigenous labour from a landless worker class (about one-third of the peasant population) that had been created as a result of a breakdown of traditional indigenous communities. In parallel to the haciendas, however, were free Indian communities which maintained themselves on lower-quality lands. The free Indian communities comprised the other two-thirds of the indigenous population and emerged to become the dominant form of traditional organisations in the highlands (Klein 1984). Despite revolutions and other dramatic social and political changes in subsequent centuries, it is noteworthy that the hacienda system managed to persist in various forms until 1952.

During the Spanish colonial period economic and political power was held by an elite class of mine owners, church leaders, hacendados and government officials. The latter were called corregidores and they collected tributes and taxes from the Indians. This elite class was initially comprised of a small minority of Spanish peninsulares (or Spanish-born) persons. The Criollos (members of new generations of ethnic Spanish born in the New World) began to gain economic power in mining and agriculture by the late 1700s. Another group emerged somewhat later, namely the Mestizos of mixed Spanish-Indian descent. The Mestizos tended to be merchants and artisans with little political power, who remained socially associated with the indigenous peoples and gradually became an important ethnic group by the early 1800s (Klein 1984). Increasing resentment by Criollo and Mestizo groups against Spanish government policies in the New World (i.e., trade barriers, upper-level administrative positions reserved for peninsulares, etc.), and influences of the French and American revolutions, led Criollos and Mestizos to rebel against the Spanish crown by the early 1800s. The indigenous people, on the other hand, were in constant rebellion against the Spanish. More than 100 such revolts instigated by indigenous people occurred in what is now Bolivia and Peru during the 1700s (Klein 1984).

Bolivia achieved independence through the efforts of several popularly supported caudillos (i.e., local leaders from Criollo and Mestizo ethnic groups) in conjunction with military campaigns led by people such as Simón Bolívar and José A. Sucre. A 15-year war for independence preceded establishment of the Bolivian Republic in August, 1825.

2.2.2.2 1825 to 1950

After independence in 1825 until about 1840, a sequence of Bolivian governments helped organise a strong and cohesive state which played an important role in regional geopolitics (Hudson and Hanratty 1989). In 1846 the first national census was carried out and indicated a population of 1.25 million in the Andean region (with 89% as rural dwellers), and another 150 000 inhabitants in the lowlands for a total national population of 1.4 million (Klein 1984). By the mid-nineteenth century the mining sector of Bolivia had begun to stagnate, and this contributed to a chaotic period of rule by the military caudillos (non-elected leaders). Political instability persisted until the 1880s and was ameliorated by recovery of the mining economy in the western and southern parts of the country and a strong agricultural presence in the Valleys of Cochabamba and Chuquisaca. Agricultural development was based on an expansion of the hacienda system; new generations of hacienda owners were Criollos and Mestizos. The hacienda system continued to grow and become more diverse (Klein 1995). This increase was in many instances achieved by hacendados (backed by the military elite) taking over the best remaining lands held by indigenous communities. Native peoples gradually lost ownership of their traditional lands and were forced to live in increasingly marginal areas. This growth in the hacienda system was accompanied by an increasing influence of Criollo and Mestizo populations in rural areas. Bolivia lost its access to the sea as a result of the Pacific War with Chile (1879-83); this conflict also reduced the power of the Bolivian military elite and initiated a period of modern, parliamentary-style government dominated by civilians. This parliamentary regime, however, was characterized by limited participation. Indeed, to have the right to vote and to hold public office one had to own real estate and be able to read and write (Malloy 1970).

Although mining shifted from silver to tin exploitation during the late 1800s, mining remained the most important economic activity in Bolivia, and was largely under the control of the private sector with very little government involvement. From 1932-5 Bolivia was engaged in the Chaco War with Paraguay, which Bolivia ultimately lost. As a result of instability created by the Chaco War, the following years were characterised by the alternation of traditional governments supported by the military establishment with experiments of “military socialism” spurred by officials who had come back from the Chaco with a reinforced sense of Bolivian nationalism (Lopéz 1993) Government involvement subsequently increased in the mining sector and emerging petroleum industry. The Chaco War also altered conventional wisdom to allow the Indian majority and lower economic classes (i.e., peasants, miners, etc.) representation in the central government. At the same time the rural labourers began to organise trade unions in some of the oldest haciendas in the Valleys (Klein 1984). This widened opposition to the land owners from the traditional base of the remaining free indigenous communities.

Net growth of the national population was low between 1900 and 1950, with an annual rate on the order of 1.1% (Dr. José Castro, demographer, Instituto Nacional de Estadísticas, personal communication). By 1950 over 85% of the total population of Bolivia was still located in the Andean zone, and over 70% of Andean residents remained rural dwellers (GDRU 1994; 52). Most livelihoods in the Andes were still based on traditional agriculture. Management practices and types of domesticated plants (i.e., tubers, cereals, vegetables, fruits) and animals (i.e., camelids, sheep, cattle) still represented a blend of prehispanic and early colonial influences (Dollfus 1981; Dandler 1984). Rural land tenure continued to be dichotomous in nature, with haciendas on one hand and remnant, free communities of native peasants on the other. With few exceptions, the indigenous people still had no access to formal education and were thus effectively excluded from national politics (Malloy 1970). This disenfranchisement, combined with other elements of social and economic inequality and an upsurge in Bolivian nationalism, helped foment a new revolutionary climate by the 1940s and early 1950s.

2.2.2.3 1951 to 1996

The labour class, mainly comprised of miners and campesinos (introduced as a more contemporary term for rural peasants), provided a constituency for the MNR (Movimento Nationalista Revolucionario or National Revolutionary Movement). The MNR, primarily a middle-class political party led by Victor Paz Estenssoro, prevailed in the general elections in 1951 but was stymied by a last-minute military coup. The MNR, however, succeeded in overthrowing the military government on April 9, 1952. The National Revolution led to a number of popular political reforms and socio-economic changes during the 1950s and 1960s, prominently including full nationalisation of the larger mining and petroleum enterprises. Another outcome was the Land Reform Decree of August, 1953, in which land ownership in the Andean zone was returned to peasant communities and campesinos were released from lingering obligations to provide free labour for haciendas. This liberation had been preceded by an intense period of conflict between hacendados and campesinos that started after the April Revolution (Malloy 1970; Klein 1984). The revolutionary government expanded rural access to primary education and began to invest in agricultural research and extension.

Although many of these new initiatives held promise for rural Bolivians in general, the traditional agriculture of the Andean zone was still largely ignored (Urioste 1992). In contrast, most public investment in agriculture was targeted towards increasing production of cash crops in the tropical lowlands for domestic consumption and export; important target commodities included improved beef cattle, rice, sugar cane, cotton and soy bean. Investments for the lowlands occurred in the form of road construction, land donations, subsidised credit and building state-owned processing industries. A new class of private owners of large estates benefited from these policies, especially under the conservative military regimes that typically ran the country between 1964 and 1982 (Urioste 1992).

Andean campesinos were encouraged to migrate to the new settlement frontiers in the lowlands, but they commonly found opportunities restricted to seasonal harvests on large estates or marginal lands far from main roads and urban centres. These settlers often ended up in the humid Yungas of La Paz and Chapare to grow coffee, rice and tropical fruit. By the end of the 1970s, however, in response to an increasing international demand for narcotic drugs, many settlers switched to coca leaf production on a large scale. In 1990, coca leaf production comprised 8% of the agricultural GDP in Bolivia (GDRU 1994, 26).

The dramatic rise in production of coca leaf by the early 1980s also corresponded with a period of national economic stress induced by recession and hyperinflation. Hyperinflation was rooted in the accumulation of large fiscal deficits between 1975-81, financed with foreign loans, in a context where mining and natural gas represented more than 90% of total export revenues and 70% of state revenues. The initial driving factors at the beginning of the 1980s included declines in prices for key Bolivian exports and a decreasing productivity in the public mining sector, a sharp rise in international interest rates, and a fall in foreign lending in the wake of a regional debt crisis. The United States also withheld support because of an evaluation that the Bolivian government was failing to take action against drug trafficking. The value of the currency plummeted as a result of successive exchange rate devaluations and excessive issuance of money by the Central Bank to finance the public sector deficits. Trade unions strongly resisted real depreciation in salaries and a wage/price spiral which exacerbated inflation (Morales 1991; Morales et al 1995). There were also natural disasters occurring at the same time. The Andean highlands endured a severe drought in 1982-3, while the tropical lowlands suffered from extensive flooding. These ecological calamities were related to disruption of climate along the Pacific coast as one outcome of El Niño (INTECSA 1993).

Between 1950 and 1992 the net growth rate for the national population began to accelerate and reached 2.1% per annum (GDRU 1994, 52). It is during these 42 years that a dichotomy between rural and urban population growth became most apparent. Rural populations have grown at an average of only 0.75% per annum while those in urban areas have grown 4% per annum, the latter having a doubling time of 16 years. The reduction in net growth of rural populations is even more evident when the time frame is broken up into smaller segments. Between 1950 and 1976, for example, rural populations grew by 1.15% per annum, yet between 1976 and 1992 this dramatically dropped to 0.1% per annum (GDRU 1994, 52). According to results of the 1992 Bolivian National Census (INE 1993), rural dwellers represented 42.5% (or 2.7 million) of the total national population of 6.4 million. This estimate of the percentage of urban dwellers is probably biased high because of greater difficulties enumerating rural people. For example, Albó (1995, 2-4) believed census figures underestimate rural people on the order of 7 to 15%. Despite economic incentives to populate the tropical lowlands, the highlands remain as home for the bulk (70%) of the national rural population. The transition zones (i.e., Yungas and Valleys) are home to 10%, while about 20% reside in the tropical lowlands [C. Jetté, IBTA/SR-CRSP, unpublished data based on census information in Montes de Oca (1989, 169-72)].

Since the mid-1980s the top priorities of Bolivian governments have been to facilitate economic stability by exerting tighter control on government finance, abolishing many public-sector interventions, and opening the country to foreign trade and investment (GASO 1995). For example, in 1985 the newly elected government of Victor Paz Estenssoro (his fourth term since 1952) implemented a strict economic adjustment and stabilisation programme that was successful in controlling inflation and promoting moderate economic growth. These policies have persisted during the governments of Jaime Paz Zamora and Gonzalo Sánchez de Lozada to the present. The main elements of the programme have consisted of exchange rate stability; the liberalisation of trade and capital accounts including the elimination of import prohibitions and the legalisation of dollar deposits; the shutdown (especially in the mining sector) or the privatisation of public enterprises and the reduction of public employment; the elimination of wage indexing; increase of gasoline price to international levels; and the implementation of a value-added tax that is now the main source of fiscal revenue (Morales 1991). The adjustment and stabilisation programme has benefited from strong support of international financial institutions; in 1992, for example, foreign aid equalled more than USD 100 per capita (GASO 1995, 1). International credit has been commonly used to improve roads, both for domestic networks as well as export corridors. Efforts to attract foreign investment and technology to expand and modernize the energy and mining sectors have also been successful in recent years. It was foreseen that Bolivia would start to export large quantities of natural gas to Sao Paulo, Brazil, by 1999 (SIPFE 1996).

National highlights of the agricultural sector (1980-96). Despite fiscal successes since the mid-1980s, the adjustment and stabilisation programme has not reversed a long-term decline in rate of growth, and terms of trade, for Bolivian agriculture in general and campesino highland agriculture in particular (CEPAL 1982; Morales 1990; Healy 1991; Morales 1991, 15; Zeballos 1993, 30). There are several reasons for this. Prominent is the relatively low rate of return from large investments in the tropical lowlands. For example, large-scale, lowland enterprises have only yielded sustained increases in exports of soy bean, and this has been achieved through extensification rather than intensification (GDRU 1994, 166). Total production of important products from the Andean and transitional zones like potato, corn and barley have also decreased or stagnated, especially after 1985. This trend is alarming given that campesinos of the highlands, Valleys and Yungas have traditionally produced more than 30% and 90%, respectively, of domestic supplies of meat and plant-derived staples (Morales 1990, 21). The campesino economy has probably been negatively impacted by restriction in urban demand for food staples and recent increases in food imports, as well as increased interest rates and road transport costs (Morales 1991). The adjustment and stabilisation programme has indirectly affected these aspects through reduction of wages and salaried employees, and tight fiscal and monetary policy designed to attract capital deposits and reduce public deficits. Food subsidies have also come in the form of food aid (largely wheat donations), which has probably depressed prices of some traditional Andean commodities. Food aid increased as a result of the ecological disasters of 1982-3 (Prudencio 1993). Although cause and effect relations remain open to debate, depopulation of rural Andean communities (above) has likely resulted in losses of labor that have affected crop production (Painter 1992). The shift of many campesinos from a focus on food crop production to more profitable coca leaf also cannot be ignored (Pérez-Crespo 1991; Painter 1992).

Recent government administrations have attempted to spur productivity and growth in both traditional (e.g., campesino highland) and modern (e.g., entrepreneurial lowland) sectors. According to public statements, the main obstacles to development of campesino highland agriculture are thought to include the harsh Andean climate, poor quality and limited extent of arable highland soils, continued reliance on indigenous technology, low levels of formal education among campesinos, lack of irrigation infrastructure, and excessive fragmentation of agricultural land in more densely populated areas due to land tenure problems and ineffective policies for agricultural marketing (C. Jetté, IBTA/SR-CRSP, personal observations). Problems of entrepreneurial lowland agriculture include continued reliance on outdated technology, a shortage of well-trained people, lack of security for land tenure and high transportation costs associated with a deficient infrastructure (MACA 1990a; SNAG 1993; SIPFE 1996).

Some measures have been taken to alleviate constraints in the agricultural sector, but positive impact remains limited. Noteworthy to this end is a 1990 government decree to strengthen and modernise IBTA (Instituto Boliviano de Tecnología Agropecuria or Bolivian Institute of Agricultural Technology) which has been the national entity responsible for agricultural research. The decree re-focused the IBTA mandate to centre on technology generation, technology transfer and marketing to benefit low-income, rural producers (MACA 1990b, 10). The impetus to re-focus and re-organise IBTA involved a World Bank project conducted from 1992-7 which included funding to augment professional salaries, rehabilitate field stations, enhance capacity for technology transfer and restructure the central administration (MACA/IBTA 1992).

Other agricultural initiatives include the Fondo de Desarrollo Campesino (FDC or Peasant Development Fund) which has been created to provide subsidies for infrastructure improvements and production credit under national money-market conditions to benefit economic development projects for rural communities in general, and formal associations of campesinos in particular. The FDC programme remains limited in scope because of low levels of funding and an inefficient bureaucracy (Marconi 1996, 35-37).

Perhaps the most significant of all recent policy changes has been the 1994 passage of the Ley de Participación Popular (or Popular Participation Act) by the Bolivian Congress. This Act provides legal status for campesino communities, creates rural municipalities and institutes a redistribution of 20% of total national tax revenues among such municipalities based on numbers of inhabitants (*Gaceta Oficial de Bolivia* 1994, 2-3). The law is intended to rectify the historical inequity between urban and rural areas. It is also intended to create opportunities for rural communities to better control their destinies and be more responsible in helping manage local health care, education and infrastructure improvements. In addition, a law regulating and clarifying processes related to land ownership and tenure was enacted in October, 1996. Provisions include that lands belonging to small producers or indigenous communal entities cannot be alienated, seized or taxed. Tenancy of medium and large private estates is also guaranteed insofar as the owners pay corresponding land taxes to municipalities. Local government administrations will be allowed to redistribute large tracts of land whose owners have not paid their taxes during two years, or had obtained their titles fraudulently in the past. The law foresees a 10-year process to survey and register all land properties in the country (MDSMA 1996). While national in scope, this law should primarily serve to help resolve land-use conflicts which have mostly emerged in the tropical lowlands (C. Jetté, IBTA/SR-CRSP, personal observation).

At the beginning of 1996 the government of President Sánchez de Lozada presented a strategy for sustainable rural development to the Consultative Group of Paris (CGP), comprised of international donors. By prioritising public investments in rural areas during the next five years (1997-2002), the strategy is founded on objectives to expand and diversify agricultural exports, increase food production for domestic consumption, and raise incomes and living standards for rural producers (SIPFE 1996). The four pillars of the strategy include: (1) increased investment in human development (e.g., health and education); (2) increased emphasis on natural resource management; (3) increased investments in road and irrigation infrastructure; and (4) continued restructuring of the national system of agricultural research and technology transfer. For the last point, a significant discrepancy has been noted between the types of agricultural research typically performed and the acute needs of campesinos (SIPFE 1996). Agricultural research would be restructured to create five to seven eco-regional centres (with producer association delegates on their boards of directors) and competitive mechanisms for public fund allocation would be introduced. Government support of applied research and technology transfer activities for export commodities would be progressively privatised. The CGP has approved the new strategy in principle, but funding level remains to be determined (SIPFE 1996, 58).

2.3 Overview of the Bolivian Altiplano

2.3.1 Regional highlights of physical geography and environment

2.3.1.1 Regional physical geography and soils

The Altiplano and mountains over 2000-m elevation represent about 27% of Bolivia's land area and contain 34% of Bolivia's rangelands (Alzérreca 1992). About 800 km in length from north to south, and having an average width of 130 km, the Altiplano stretches from the southeast corner of Peru through western Bolivia and eastern edge of Chile and ends in northwest Argentina (Figure 2.2).

The Altiplano is essentially a large, lacustro-alluvial plain formed from sedimentary materials deposited in a series of inter-linked lake basins and tributaries (King 1962). The basins contain remnants of ancient lakes and vary in terms of soil salinity and water supply. It is notable that the central alluvial plain of the Altiplano is broken up by spurs, branches, ridges, peaks and transverse hills. These interceding barriers help diversify the Altiplano by creating subregions having varied edaphic features and climates. Sub-regions may possess their own hydrological systems depending on orientation and size of physical formations (King 1962).

The Altiplano contains several internationally recognised landmarks. One such landmark is Lake Titicaca, which occurs in the more subhumid, northern Altiplano at 3910-m elevation. With a surface area of 8600 km² (Kolata 1993), Lake Titicaca is the highest navigable body of fresh water in the world (Ambroggi 1965; Plate 2.3). Lake Titicaca is fed by several rivers that flow down the west-facing slopes of the eastern Cordilleras. It discharges into the Desaguadero River that flows some 320 km to the southeast and then empties into Lake Poopó. Lake Poopó is located in a more semi-arid portion of the Altiplano and is characterised by its shallow, saline water. To the southwest of Lake Poopó are the salt flats (salares) of Coipasa and Uyuni. The Uyuni flats comprise the largest surficial salt crust on earth (Figure 2.3).

Salinity of soils and water is a critical constraint for agriculture on the Altiplano; in some cases salinisation is entirely an endogenous (geomorphic or hydrological) process that cannot be appreciably altered by management, while in others management may play a role in lessening negative effects, especially in cropping systems (see Chapter 3: *Ecology and natural resources of San José Llanga*).

Still youthful in geological terms, the Andean region was once ocean floor and thus subject to high salt accumulation during bedrock formation. Today, the salinity of Altiplano soils is a function of the high concentrations of salts in soil parent materials and salinity level is locally exacerbated by soil deposition processes and features of the hydrologic cycle (Ambroggi 1965). For example, erosion is continually moving fresh, saline rock from mountain slopes towards the floor of the Altiplano where it will become part of the soil. The dry climate drives high rates of evapotranspiration of surface water, which increases salt concentrations in water bodies. High evapotranspiration also increases salinity in top soil through capillary action of subsurface water. Because the Altipano is a closed basin, there is no chance for precipitation to leach salts out of the system. Additions of fresh water from rainfall, snow and glacial melt are insufficient to compensate for water loss to evapotranspiration and thus mitigate salinity of water bodies (Ambroggi 1965). Various regions of the Altiplano differ in degree of salinisation and, over a long period of time, large areas of the Altiplano are enduring decreases in vegetation cover due to increases in soil and water salinity (Salm and Gehler 1987; Lorini 1995).

Plate 2.3. *Vista of Lake Titicaca. Note cultivated terraces near the lake shore.* Photograph: Lita Buttolph

Lake Titicaca, Lake Poopó, and the salares are remnants, respectively, of ancient lakes named Ballivian, Minchin and Tauca [Servant and Fontes (1978) cited in Kolata (1993)]. Lake Ballivian is the oldest of the lakes, but the precise ages are unknown. Lake Titicaca represents about 50% of the original area covered by Lake Ballivian. Extinct Lake Minchin existed over 29 000 years BP. Extinct Lake Tauca occurred between 11 000 and 17 000 years BP. These lakes covered large portions of the Altiplano during the Quaternary Period, when the earth's climate was characterised by alternating periods of glaciation and inter-glaciation [Servant and Fontes (1978) cited in Kolata (1993)]. The salares of Coipasa and Uyuni are an outcome of the desiccation of Lake Tauca during a period of dry climate from 10 000 to 3500 BP. Since 3500 BP the climate has been wetter, with a resulting increase in levels of contemporary lakes on the Altiplano (Coudrain-Ribstein et al 1995). In general, one can view the Uyuni salt flats as a remnant "central drain" at the lowest elevation for all inter-linked basins on the Bolivian Altiplano. At a regional scale, therefore, soil salinity tends to increase, while elevation decreases, as one travels towards the Uyuni salt flats from any direction.

The Altiplano was also a region of major volcanic activity during the late Miocene and Pleistocene (King 1962). This helps explain the abundance of lava (andesite) and ash (ignimbrite) in extensive Altiplano areas bordering the Cordilleras, especially to the west (King 1962). In general, the mountain slopes of the Cordilleras are covered with unweathered rock and soil is poorly de-

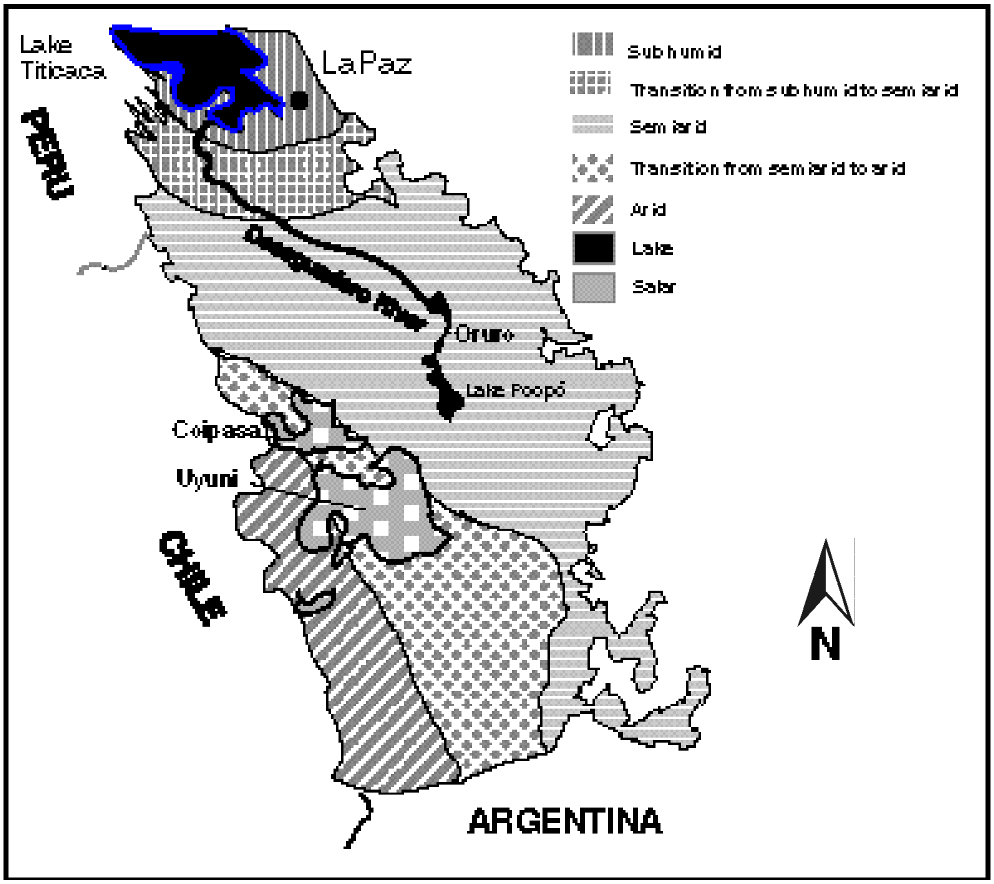

Figure 2.3. *Major ecological regions of the Bolivian Altiplano.* Source: Adapted from Beck (1988)

veloped (Ruthsatz and Fisel 1984). Foothills at lower elevations are still covered with fresh rock, but weathering has created some sandy and stony soils. Further downslope there are alluvial fans, small plateaus and gradual inclines leading to the central plains. The central plains, overall, are represented by formations such as sedimentary terraces, alluvial fans and flood plains. The central plains to the south gradually descend towards Lake Poopó and the salares. There is a concomitant textural gradient of soils from sandy-silty to clay-silty and heavy clay, with lacustrine (e.g., old lake bed) soils commonly having higher content of soluble salts (Rutsatz and Fisel 1984). There is also sandy soil resulting from aeolian (wind) deposition which is commonly found over sedimentary formations, and this has contributed to stabilised and active sand dunes throughout the Altiplano. Sand dunes increase in frequency and extent from the semi-arid zone to more arid zones in the southwest Altiplano. The composition of aeolian and fluvio-lacustrine deposits is variable, and includes conglomerates of sand, clay, silt, latites, salt and lignite (CIACER/GEOBOL 1985).

2.3.1.2 Regional environment

The climate of the Altiplano is mainly characterised by marked seasonal fluctuation in precipitation and, to a lesser extent, temperature. Given that Bolivia is in the southern hemisphere the cooler season (winter) occurs from June to August, while the warmer season (summer) occurs from December to February. The winter months are drier while summer months are wetter. There typically is a large daily variation in air temperature; daily variation is usually larger than seasonal variation and the daily spread can range from 28°to 38°C. Frost can occur anytime during the growing season (IBTA 1992). Such fluctuations pose significant challenges for production of forages and food crops.

The rainy season gradually begins in September, with most rainfall occurring from November through March or April. There is a strong gradient from the northeast to the southwest along which both mean temperature and precipitation decline (Mourguiart et al 1995). Whereas to the north the average daily temperature is 11°C and the average annual precipitation exceeds 600 mm (with 900 mm per annum along the shores of Lake Titicaca), to the southwest the average daily temperature is 7°C and annual precipitation drops to <200 mm per year. The contrast between nocturnal and diurnal temperature is also most pronounced to the southwest where a range of 36°C has been reported (Vacher et al 1992, 512-3; de Morales 1990, 76). Owing to limitations imposed by cool ambient temperatures, net primary productivity is low with slow rates of nitrogen cycling (Dollfus 1981, 22). Detailed climate diagrams for the entire Altiplano can be found in FAO (1975), Lorini (1987) and de Morales (1990).

The Altiplano has been described as the realm of the "puna". The term puna refers to an open landscape comprised of small and medium-stature plants with little tree cover (Ellenberg 1979). Vegetation physiognomy is commonly dominated by shrub-like plants along mountain footslopes, tall bunchgrasses at intermediate elevations (such as alluvial terraces), and short grasses and halophytes (e.g., salt-tolerant plants) on lower-elevation plains with higher water tables. Plant communities and vegetation cover also change according to spatial and temporal gradients of thermal and moisture regimes.

Despite high variability in local climate and soils on the Altiplano, four major ecological types of puna are commonly recognised based on degree of humidity or aridity. These include: (1) humid/sub-humid; (2) semi-arid; (3) arid; and (4) hyper-arid (Cabrera 1957, 1968; Troll 1968; Dollfus 1981; Ellenberg 1981). Altitude can also serve as a secondary factor in classification of puna. For example, over 4100-m elevation there are tundra-type plant communities consisting of small grasses, dwarf shrubs and "cushion plants"; these communities are referred to as high puna. Climatic conditions of the high puna (especially the low temperatures) exert great limitations on many forms of crop and animal agriculture. In the Cordilleras and in the Altiplano, however, there are patches of perennial and ephemeral wetlands (natural and man-made) called bofedales that are critical for camelid production systems (Caro 1992; Genin and Alzérreca 1995).

A more-crude categorisation of puna as sub-humid, semi-arid and arid roughly corresponds to latitudinal and administrative divisions commonly used in Bolivia to demarcate northern, central and southern regions of the Altiplano, respectively (Figure 2.3). This division, however, does not take into account effects of the northwest to southeast climate gradient (described above) which can lead to erroneous generalisations. For example, although the central Altiplano is typically referred to as uniform semi-arid puna, some areas are more representative of arid puna due to local effects of the climate gradient. Similarly, several municipalities of the Ingavi and Pacajes provinces to the north near Lake Titicaca are categorised as sub-humid, but in fact are semi-arid. For a general quantification based on Figure 2.3, the sub-humid area is about 6% of the Bolivian Altiplano. The semi-arid, arid and hyper-arid areas are about 54, 23 and 14%, respectively. The saltflats are about 3% of the surface area.

The sub-humid puna corresponds mainly to the general area encompassing Lake Titicaca. This is a region where cultivation occurs more extensively, especially near the lake shores where risk of frost is almost nil and precipitation is elevated compared to surrounding areas. Annual precipitation ranges from 600 to 900 mm and very little occurs as snow. Favourable influences of the lake on local climate are restricted, however, to within one kilometer of the shoreline (Vacher et al 1992, 513-4). Throughout the rest of the Altiplano the risk of frost increases and cultivation strategies are modified accordingly.

Important vegetation of different climate zones has been described by Tosi et al (1975), Lara and Alzérreca (1986) and Beck (1988). Aquatic and emergent vegetation associated with the shallows of Lake Titicaca include important forages such as *totora* (from *Quechua* vernacular; *Schenoplectus tatora*), *totorilla* (*Scirpus rigidus*), *Miriophyllum* spp. and *Elodea* spp. Criollo cattle submerge and feed on this aquatic vegetation, otherwise vegetation is harvested via cut-and-carry methods to storage facilities on shore (Dr. H. Alzérreca, rangeland ecologist, personal observation). On rain-fed, semi-humid sites near the lake, vegetation on deeper alluvial soils is dominated by *chilligua* (*Festuca dolichophylla*) while *ichu* (*Stipa ichu*) occurs more on drier and shallower soils associated with hillslopes. Scattered shrubs of the genera *Colletia*, *Cassia* and *Satureja* are found on the plains, slopes and foothills of the sub-humid Altiplano. There are a few introduced tree species established on more favourable sites, including *Eucalyptus*, *Pinus* and *Cupressus* spp.

The semi-arid puna coincides with the environs of the Desaguadero River and Lake Poopó and also includes regions north of Potosí province below 4100-m elevation (Figure 2.3). The semi-arid puna is characterised by an annual precipitation from about 400 to 600 mm. The agropastoral peasant community of San José Llanga, the main subject of this volume, occurs in semi-arid puna with about 400 mm average annual precipitation (see Chapter 3: *Ecology and natural resources of San José Llanga*). Extensive areas of the semi-arid puna, mainly on foothills and mountain slopes less prone to frost, have endured cultivation for centuries (Plate 2.4a,b). Fallow fields on these sites have been important for livestock grazing. Native vegetation has been appreciably altered as a result; often only inaccessible relict sites offer indications of original plant species composition and diversity (Ellenberg 1979; Ruthsatz and Fisel 1984). Across much of the uncultivated, semi-arid puna vegetation physiognomy is dominated by small-stature, shrubby taxa; communities have mixtures of shrubs and grasses referred to as shrub-steppe. Shrubs include important indigenous species such as *Parastrephia lepidophylla* (*thola* in the *Aymara* vernacular), *Adesmia spinosissima*, *Baccharis microphylla*, *Satureja parvifolia*, *Junellia minima* and *Tetraglochin cristatum* on well-drained soils. Halophytes such as *Suaeda foliosa*, *Atriplex* spp, *Anthobrium triandrum*, *Salicornia peruviana* and *Parastrephia phylicaeformis* are common on medium to heavy-textured soils with variable salinity. Short-grass (i.e., *gramadal*) and tall-grass (i.e., *pajonal*) vegetation types are also common in semi-arid sites. Key tall-grass species on well-drained soils include *Stipa ichu*, *S. depauperata*, *Nasella pubiflora*, *Festuca orthophylla* and *Aristida asplundii*. Key tall-grass species on medium-textured soils include *Festuca dolichophylla*, *Bromus uniloides*, *Hordeum muticum*, *Calamagrostis vicunarun* and *C. curvula*. Short grasses like *Distichlis humilis* and *Mulhenbergia fastigiata* are common on medium to heavy-textured soils with higher water tables and elevated site salinity. Hydrophytes such as *Carex* spp, *Scirpus atacamencis*, *Arenaria* sp, *Patomogeton* spp and *Miriophyllum* sp are present in wetlands (e.g., bofedales) and along shorelines of rivers, springs, lakes and ponds. Extent of vegetation cover greatly varies according to proximity to rivers, grazing managment, depth to the water table, salinity of water and soil, and other physical and chemical soil features (see Chapter 3: *Ecology and natural resources of San José Llanga*). Cultivation in the semi-arid puna is performed under high risks of failure due to drought and frost. For example, Le Tacon et al (1992) determined that risk of potato plants being negatively affected by frost ranges from probabilities of 0.15 to 0.90 in the semi-arid puna depending on local conditions.

The arid puna has an average annual precipitation from 200 to 400 mm and includes portions of the western and southern Altiplano (Figure 2.3). Cultivation is restricted to small areas having favourable microclimates and soils. Llama pastoralism dominates in the arid puna as the traditional agricultural activity (PSP 1992). Vegetation of the arid puna is represented more by a shrubland (i.e., *tholares*) physiognomy. The dominant shrub again is *thola* (*P. lepidophylla*) and other important shrub genera include *Baccharis*, *Fabiana* and *Tetraglochin*. Tall-grass communities (*pajonal*) are more rare than in the semi-arid puna,

a

b

Plate 2.4 (a,b). *(a) Vista of foothills terrain associated with the semi-arid puna at the edge of the Cordilleras and (b) typical foothill production system of the semi-arid puna with hillside cultivation, grazing land in the valley bottoms and a settlement in-between.* Photographs: (a) D. Layne Coppock and (b) Brien E. Norton but they are dominated by genera such as *Festuca* (especially *F. orthophylla*), *Stipa* and *Calamagrostis*. Halophytes continue to be common near salares, rivers and shorelines of lakes. Vegetative cover tends to be low and highly variable.

In the hyper-arid puna, with annual precipitation <200 mm, the predominant vegetation becomes more exclusively shrubby and plants tend to be more widely spaced as intensity of competition for moisture increases. The most abundant shrubs belong to the genera *Fabiana*, *Chuquiraga*, *Lampaya*, *Adesmia*, *Junellia* and *Baccharis*. Very scattered tall grasses (i.e., *Calamagrostis, Festuca, Stipa* spp.) are found adjacent to water sources and on mountainsides (Ruthsatz 1977).

It is often assumed that the rangelands of the Altiplano have been gradually degraded by overgrazing from livestock (LeBaron et al 1979; Posnansky 1982; McCorkle 1990). Some theories put more blame on introduced cattle and sheep for causing degradation due to foraging behaviour and hoof morphology adverse to fragile soils and vegetation (Posnansky 1982). Alternative theories suggest that climate fluctuations play a crucial role in determining range trend in arid lands (see Chapter 3: *Ecology and natural resources of San José Llanga*).

2.3.2 Regional historical highlights

2.3.2.1 Pre-historic times to 1524

The Altiplano is the origin for some of the most important indigenous civilisations of Bolivia. Archaeological studies have identified several sites inhabited by hunter-gatherers in the central and southern Altiplano between 10 500 and 4500 BP (Bouysse-Cassagne 1992, 480). One of the oldest sites, a relict of the Viscachani culture tentatively dated at 17 000 years BP (PNUD/AECI/MOPI-SGMA 1990), is located 25 km north of the IBTA/SR-CRSP study site at San José Llanga. It is estimated that pastoralism of llama and alpaca, with crop cultivation as a secondary activity, has existed for over 7000 years in the Andean zone (Browman 1974). Intensive agriculture was already practised in the Lake Titicaca basin around 3000 years BP (Erickson 1992), but reached a rather remarkable level of development (based on extensive irrigation systems) about 1000 years BP during the *Tiwanaku* period (Kolata 1993).

According to Bouysse-Cassagne (1992), *Aymara*-speaking groups began to expand throughout the Altiplano around 800 to 900 years BP and consolidated their control over the region around 1450 by virtue of an alliance with Incan invaders. Bouysse-Cassagne (1987, 84) estimated the total population in *Aymara* territories (including a Peruvian sector to the west of Lake Titicaca) at one to two million by the year 1500.

The *Aymara* peoples traditionally organised themselves into kinship-based groups called *ayllus*. The term *ayllu* is roughly translated as a synonym for “community,” but ayllu actually refers to more complex levels of indigenous social organisation that have progressively disappeared from the Altiplano. The basic principle for belonging to an *ayllu* was to be descended from a common male ancestor; the ancestral figure could be real or fictitious (Carter and Albó 1988).

The *Aymara* civilisation (and later the *Aymara-Quechua* civilisation) on the Altiplano was largely based on agropastoral production systems (Bouysse-Cassagne 1987). The pastoral component prominently included camelids unique to Latin America (Plate 2.5a,b). Domesticated llama (*Llama glama*) were primarily used for fibre, meat, manure and portage. Domesticated alpaca (*L. pacos*) were primarily used for production of high-value fibre and to a lesser extent, meat. Wild vicuña (*Vicugna vicugna*) were periodically rounded-up in large numbers, shorn for fibre and released (Franklin 1971). The exceedingly fine vicuña fibre has been the most valuable camelid product in recorded history (Walker 1984). Cultivated crops of the early *Aymara* civilisation (Plate 2.6a,b) were dominated by potatoes [*Solanum* spp.; the *Aymara* recognised over 250 varieties of tubers [La Barre (1947) cited in Bouysse-Cassagne (1987, 213)] and highly nutritious grains of the *Chenopodiaceae* family including *quinoa* (*Chenopodium quinoa*) and *cañawa* (*C. palidicaule*). Also prevalent were *oca* (*Oxalis tuberosus*) and *ullucu* (*Ullucus tuberosus*). As is the case today, drought and frost were significant risks for crop production, thus the *Aymara* tended to rely more on pastoralism for survival. Recent evidence has been interpreted to indicate that extensive irrigation systems also mitigated micro-climates for crops and thus reduced frost risks (Erickson 1986). Families often had large herds of camelids (Bouysse-Cassagne 1987; Murra 1988). Cropping plots were typically managed with two to three years in production followed by a long (i.e., two to 13-year) fallow to facilitate recovery of plot fertility under extant conditions of aridity and cold temperatures (Hervé 1994, 20). Plots were often placed

a

b

Plate 2.5 (a,b). *Common indigenous camelids of the Altiplano: (a) Llama and (b) vicuña.* Photographs: Lita Buttolph

on hillsides to mitigate against high risks of frost characteristic of the alluvial valleys.

In addition to their extensive use of the Altiplano, the *ayllus* of the *Aymara* controlled territory from the Pacific coast associated with the western Cordillera to the Valleys and Yungas associated with the eastern Cordilleras (Murra 1975, 1988). In this altitudinal gradient various crops were produced according to their ecological adaptations, such as potato and *quinoa* in the Altiplano, maize in the Valleys and coca in the Yungas (Kolata 1993). Hillside agriculture was common but required substantial labour for field preparation, terracing, weeding and additional crop production practices such as fertilisation (with llama manure, seabird guano or fish heads, depending on location), mixed cropping, fallowing, irrigation, etc. (Donkin 1979). Many of the indigenous domesticated agricultural species, technologies and management methods of the early *Aymara* civilisation, their predecessors (*Tiwuanacotas*) and later *Quechua* (Kolata 1993) proved to be ecologically, socially, culturally and economically adapted to Andean environments (van Kessel 1992). Some of these techniques are still used today in the Andes (Donkin 1979). Overall, this contributed to a pattern of vertical integration of resource use in complementary agroecological zones. This was a common risk-mitigating tradition among Andean peoples (Murra 1975, 1988; Golte 1980). Bouysse-Cassagne

a

b

Plate 2.6 (a,b). *Common indigenous plant crops of the Altiplano: (a) mixture of local and introduced potato varieties and (b)* quinoa, *an important cereal adapted to high elevations.* Photographs: Christian Jetté

(1987, 336) speculated that exploitation of multiple agroecological zones began when the *Aymara* initially colonised some High Valleys prior to contact with the Inca circa 1450; this colonisation may have been an attempt to solve problems on the Altiplano related to high population pressure. Population shifts of the *Aymara* towards the High Valleys and Yungas subsequently increased in the next 50 years, where they progressively adopted the *Quechua* language. More *Aymara* also moved to the High Valleys and Yungas as a consequence of establishment of haciendas during the Spanish conquest to escape obligation to work in the mines and avoid paying tributes to the Spanish.

2.3.2.2 1525 to 1824

As previously reviewed, one of the most dramatic outcomes of the Spanish conquest in Bolivia was the large drop in population of indigenous people like the *Aymara*. Sánchez-Albornoz (1978, 34) reported that demographic impacts resulting from the population decline persisted until the year 1700. Other outcomes of Spanish colonialism included restrictions in land access for indigenous peoples as well as changes in agricultural systems and technology.

The *Aymara* have been at least partially integrated into a cash economy since the early years of Spanish colonialism (Sebill 1989). To preserve their ownership rights and access to traditional *Aymara* lands, *ayllus* had to pay taxes and tributes to Spanish authorities. They also were forced to purchase goods from Spanish provincial rulers (corregidores) at high prices (Klein 1995, 151). *Ayllus* supplied labour to work large mines in locations like Potosí. Tributes were paid as cash and in-kind. It is notable that *ayllus* could generate sizable production surpluses during this period.

The *ayllus* elaborated various strategies to endure or avoid obligations to the Spanish. The *Aymara* often rebelled against the corregidores. The *Aymara* adapted to changing economic circumstances that were largely determined by cycles of expansion and recession of the mining sector. The *Aymara* obtained cash in innovative ways, including use of llamas to haul goods long distances, selling fuel (i.e., wood and manure) to mines and growing cities, cultivating cash crops, and by serving as temporary paid workers in mines and haciendas in some instances. In times of recession many former emigrants returned to their home areas and people tended to rely more on a barter economy (Harris et al 1987; Sebill 1989; Rivera 1992; Klein 1995).

The traditional Andean pattern of vertical integration of natural resource use involving the Altiplano, Yungas and High Valleys was gradually broken-up by Spanish colonialists, both as an outcome of active interference and as a consequence of hacienda expansion (Carter and Albó 1988). Technologies and management practices imported from Mediterranean environments of southern Europe were often well-suited for haciendas in the Yungas, Valleys, High Valleys and immediate vicinity of Lake Titicaca. By the end of the colonial period in 1825, it has been estimated that one-third of formerly communal lands held by indigenous Andean peoples had come under control of the haciendas (Carter and Albó 1988, 453). Although most of the new, imported agricultural technology was initially confined to haciendas, *Aymara* producers rapidly adopted innovations that could endure conditions on the Altiplano. Criollo breeds of sheep and cattle (Plate 2.7a,b), as well as equines (i.e., horses, donkeys), barley, wheat, oats, alfalfa and the iron plough were important innovations to arrive during the colonial period (Dollfus 1981).

2.3.2.3 1825 to 1952

Throughout the Incan occupation, Spanish colonial period and first decades of the new Republican Era, the *Aymara* had demonstrated a remarkable resilience and adapted to a wide variety of difficult social and economic circumstances. This adaptive ability, however, was severely tested again during the late 1800s (Klein 1995). An abrupt change corresponded to new heights of productivity and profitability in the mining sector, a triumph of emergent capitalism, rapid growth in populations of other ethnic groups (i.e., Criollo, Mestizo) throughout the nation, and a return to elitism, racism and other aspects of institutionalised discrimination. Privately owned property and European culture were considered attributes of “cultural progress” by 1890, and indigenous Andean peoples (referred to at this time as “Indios”) were accused of being ignorant, lazy and inefficient in their agricultural production practices. The Bolivian government declared null and void communal property titles held by *ayllus* that had been obtained from the Spanish crown, and then initiated widespread sales of such lands. The process was plagued by fraud and violence and many *ayllus* that intended to buy back their lands were ultimately dispossessed (Antezana 1992; Klein 1995). The hacienda system, never terminated at independence in 1825, suddenly expanded once


a


b

Plate 2.7 (a,b). *Livestock breeds introduced by the Spanish in the 1500s: (a) Criollo sheep and (b) Criollo cattle.* Photographs: Christian Jetté

again on the Altiplano, especially in the Department of La Paz. Land under hacienda control more than doubled by 1900 (Carter and Albó 1988, 455). These forces also tended to break up many residual elements of vertical integration and resource use across agroecological zones that were still held by a few *ayllus*. It is notable, however, that some *ayllus* were able to keep control of land in multiple agroecological zones, which has persisted until contemporary times. These *ayllus* occur north of Potosí where the Altiplano and High Valleys are contiguous (Rivera 1992).

Population size among the *Aymara* remained low throughout much of the 1800s. The population still had a low base level and was in a gradual recovery phase following the Spanish-induced decimation; there were also persistent, high rates of child mortality (Klein 1995). Epidemics continued to periodically ravage the Andean countryside despite the relatively high degree of dispersion of rural residents. A case-in-point was a widespread and deadly outbreak of typhoid fever in the mid-1800s (Medicaneli et al 1993).

The contemporary generation of hacienda owners on the Altiplano at the beginning of the 20th Century were not progressive and did not invest much in their properties. Some introduced pure-bred, exotic cattle and sheep (Cardozo 1994), but few hacendados bothered to fence off their grazing lands. Consequently, improved animals back-crossed with Criollo stock. Some hacendados owned land in different agroecological zones and managed to replicate some of the traditional risk-mitigating practices evident centuries earlier with the *Aymara* (Klein 1995). Hacendados contributed to a new wave of social strife by attempting to re-impose peasant servitude among the locals. In some cases peasants worked on haciendas as share croppers. Haciendas could generate large profits because of their ability to coerce free labour and control regional marketing of agricultural products (CEPAL 1982; Dandler 1984).

2.3.2.4 1953 to 1996

An important result of the Land Reform Act of 1953 was that the hacienda system finally ended nation-wide. On the Altiplano and in the densely populated Yungas and High Valleys the hacendados sold or transferred hacienda lands to campesino communities (Heath et al 1969; Albó 1979; Dandler 1984). Other major effects of land reform included elimination of the traditional mestizos and criollos (rural elite) class and freeing-up and diversification of regional marketing channels (Preston 1977; Dandler 1984). This all eventually assisted dissemination of new production technologies on the Altiplano including chemical fertilisers, tractors, new varieties of seeds and improved breeds of livestock (C. Jetté, IBTA/SR-CRSP, personal observation).

Campesinos have since embraced some of the innovations, and as a result a gradient of mestizo (or mixed) production systems occurs today throughout much of the Altiplano. Indigenous components of production systems (i.e., camelids, traditional cereal crops, etc.) predominate more in drier and colder locales. Introduced components tend to be more common in sub-humid agropastoral areas (especially under irrigation) and to a lesser extent in semi-arid agropastoral areas. The track record of agricultural innovations on the Altiplano is often equivocal, however, with both positive and negative aspects. Some outcomes of innovation adoption at the semi-arid site at San José Llanga are reviewed in Chapter 3: *Ecology and natural resources of San José Llanga* and Chapter 7: *Patterns of technology adoption at San José Llanga*.

There are examples where traditional Andean plant and animal products are becoming marginalised by modernisation. Staples such as the "bitter potato" (or *luk'i* in *Aymara* vernacular; regarded as frost resistant), *cañawa* and *quinoa* are being substituted in campesino diets by less nutritive, but easier to prepare, foodstuffs such as rice, wheat and pasta (Dandler 1984; Orlove 1987). For livestock, the best example of marginalisation may be the llama (Plate 2.5a; *Ayllu* Sartañäni 1992; Caro 1992; Valencia and Jetté 1995). Although it is widely recognised that the llama is the domestic ruminant best adapted to rangeland conditions of the Altiplano, llama are now almost exclusively bred only north of Potosí and in hyper-arid areas of the western and southern Altiplano. Llama have become marginalised because other means have been found to provide similar productive functions—trucks now transport goods long distances, sheep provide fiber, capital storage and more marketable meat. For the latter point, urbanites prefer beef and mutton as a source of animal protein and often have a strong prejudice against consumption of llama meat (Sammels and Markowitz 1994). In contrast to this general trend, however, there are reports of increasing demand for llama meat and alpaca wool in recent years on the western Altiplano. There the value of llama meat has risen to a level similar to that for sheep, while the value of alpaca wool has risen five-fold [Luis Ticona, president of AIGACAA (Asociación Integral de Ganaderos en Camélidos de Andes Altos), personal communication].

Although the Land Reform Act of 1953 considerably improved conditions for campesinos, the subsequent decades have been adverse for Andean agriculture. Altiplano communities have been particularly affected by a gradual deterioration in terms of trade, depression of the mining sector and a shifting attention of government towards opportunities in the tropical lowlands [see sub-section under Section 2.2.2.3: *National highlights of the agricultural sector (1980-96)*]. In general, fibre markets have also suffered declines due to an inability of the national textile sector (both industrial and craft components) to compete with high import levels of cheap fabrics (Eróstegui 1990).

The Land Reform Act of 1953 took place in a national context of accelerating population growth and increasing pressure on land. Pressure on land has been particularly evident in the High Valleys and densely populated areas around Lake Titicaca (Dandler 1984; Carter and Albó 1988). Today, the Andean zone and High Valleys of Bolivia are home to about 2.4 million people [C. Jetté, IBTA/SR-CRSP, unpublished data based on 90% of figures from the Bolivian National Census for 1992 (INE 1993)]. When only the rural Altiplano is considered, the current population is about 900 000, or 30% of all rural dwellers in Bolivia.

Land degradation and changing economic opportunities have fueled a large migration of campesinos from rural areas to urban centres since the mid to late 1970s. A good example is provided by the city of El Alto, which originally was a small suburb of La Paz; between 1976 and 1992 El Alto had a net annual population growth rate of 9.2% (Morales et al 1995, 95). The largest component of this growth has been emigrants from the rural Altiplano, consequently contributing to population declines and demographic shifts in neighbouring Altiplano districts (Figure 2.4). As a consequence, El Alto has recently become the fourth largest city in Bolivia after La Paz, Santa Cruz and Cochabamba (Franqueville and Aguilar 1988).

The recent decline in rural populations has been most evident in the arid central and southern Altiplano; population change in these areas has averaged -2% per annum (INE 1993). Effects of population loss have not been fully evaluated. We speculate, however, that declines in population probably have helped alleviate pressure on land in some instances. From another perspective, loss of large numbers of people between the ages of 15 and 45 years creates labour shortages in some communities, especially where labour is vital for sustainable production. One case in point would be maintenance of hillside cultivation systems (Painter 1992).

Human population density on the Altiplano decreases along the aforementioned climate gradient from the humid/sub-humid northeast to the arid (and colder) southwest (Muñoz-Reyes 1982; C. Jetté, IBTA/SR-CRSP, unpublished data). In the humid/sub-humid puna to the north the population density averages 25 to 37 persons per square kilometer. This is the highest population density on the Altiplano and it coincides with the greatest concentration of cultivation. Besides potato, *quinoa*, and barley, which are the main crops throughout the Altiplano, there are faba beans (*Vicia faba*), onions and other vegetables in the humid/

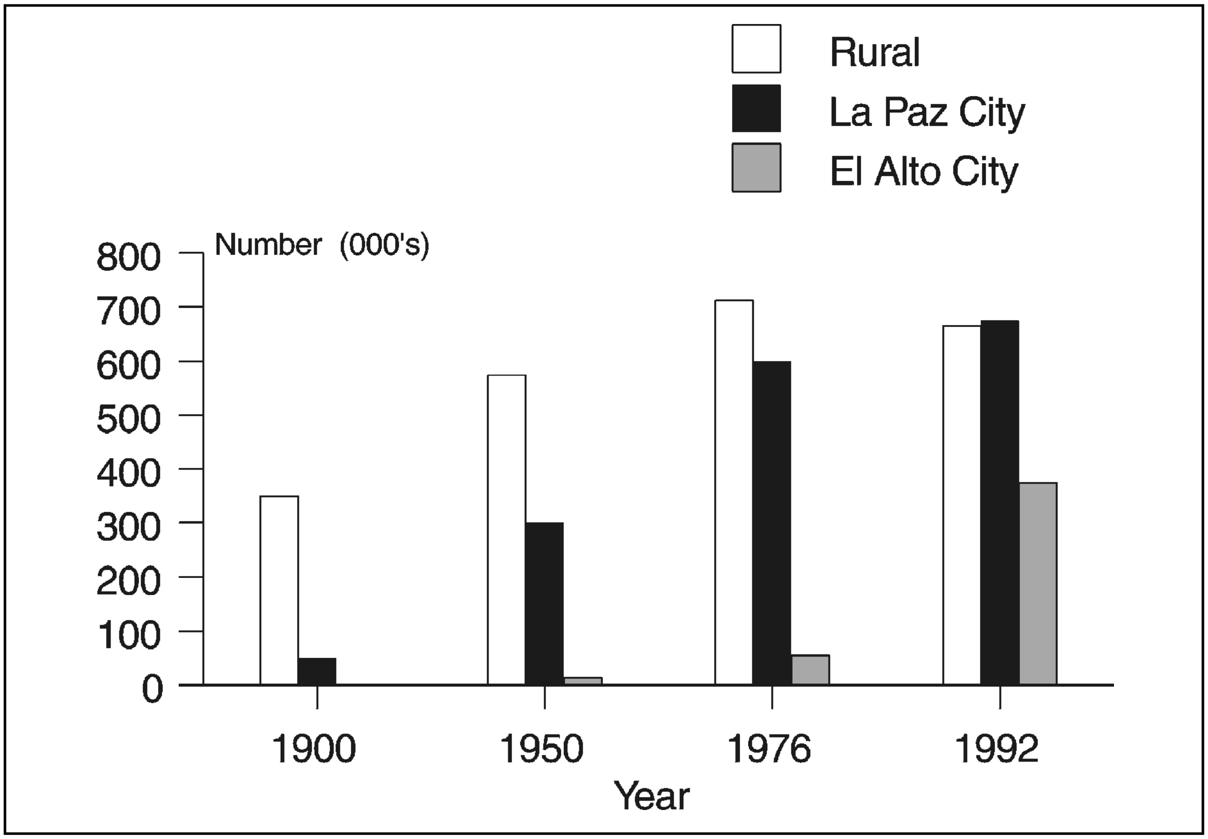

Figure 2.4. *Change in human population between urban and rural locations on the Bolivian Altiplano, Department of La Paz, 1900-92.* Sources: Created from data in Sandoval and Sostres (1991) and Municipalidad de La Paz (1995)

sub-humid north. Since the early 1980s the humid/sub-humid north has witnessed increased production of barley, alfalfa, beef cattle and dairying while sheep production has declined (Erickson 1986; PSP 1992; Paz Ballivián 1992). The majority of households manage from four to 15 cattle and 10 to 40 sheep (Paz Ballivian 1992; Castillo 1994). Hog production may also be locally significant in some of these sectors (Dr. H. Alzérreca, rangeland ecologist, personal observation).

In the semi-arid puna of the central and east-central Altiplano, human population density averages from 2 to 15 persons per square kilometer (Muñoz-Reyes 1982; Mr. C. Jetté, IBTA/SR-CRSP, unpublished data). The more densely populated sectors occur to the north of Potosí and in a wide band associated with the tarmac highway that connects La Paz with the cities of Oruro and Challapata. Population density gradually decreases towards more arid regions to the west and south. The semi-arid puna is where the largest concentrations of sheep and llama occur. In sectors closer to markets and urban areas llama tend to disappear and cattle production increases in the form of dairying and finishing beef animals. In the semi-arid provinces of Aroma and Pacajes (in the Department of La Paz) households generally possess from one to 12 cattle (average: four to seven), with sheep flocks on the order of 10 to 200 head (average: 40 to 80; Birbuet 1989; Jetté et al in press). The western sector the Department of Oruro has a population density of only two persons per square kilometer. Tichit (1995, 86) recorded the following range of livestock holdings for campesino families in Oruro: Llamas, 50 to 150; sheep, 80 to 120; and alpaca, four to 40. On the eastern side of the Altiplano in a region to the north of Potosí called Macha, the population density averages 10 to 15 persons per square kilometer (Caro 1992, 77). Caro (1992) also reported flock figures for Macha households as ranging from 75 to 400 llama and 30 to 300 sheep.

In the arid puna to the southwest human population density is very low (i.e., <1 person per square kilometer; Muñoz-Reyes 1982; C. Jetté, IBTA/SR-CRSP, unpublished data). This is a region where *quinoa* dominates cultivation. *Quinoa* is the only cereal like crop in Bolivia that can endure the low temperatures and scant precipitation characteristic of the arid puna. Campesinos breed llama and sheep and are also engaged in harvesting salt for market. Caro (1992) cites work performed in the extreme south of the arid puna in which household livestock holdings averaged around 100 llama; households having >400 llama were regarded as wealthy. In another community to the west of the salar of Uyuni, llama flocks averaged 77 head with a range of 17 to 180 head. Sheep flocks averaged 114 head with a range of 17 to 229 (PSP 1992). Even today one can encounter large caravans of llama in the arid puna transporting salt to High Valleys where herders will barter it. Many peasants also conduct such trade, however, using trucks [Molina-Rivero (1987) cited in Harris et al (1987, 607-636)].

The high puna is synonymous with alpaca-dominated systems. Roughly three-fourths of Bolivia's alpaca production tends to be concentrated in high puna either north of Lake Titicaca above 4300 elevation, or in the Sajama and Pacajes provinces of Oruro and La Paz, respectively (Tichet 1991). Alpaca flocks in the high puna range in size from 15 to 2000 animals. Families in the high puna have been documented as having average livestock holdings comprised of around 100 alpaca, 30 sheep and 40 llama (Caro 1992, 80).

The face of poverty in Bolivia, as variously measured in terms of illiteracy, child mortality and limited access to potable water, health services and adequate housing, remains pre-eminently Andean and rural (Morales 1992; UDAPSO/INE/UPP/UDAPE 1993). Despite such observations, the proportion of total public spending in the rural Andes has never exceeded 10% until very recently (Morales 1990, 25; SNAG 1993, 3). In 1991 the state-controlled Agricultural Bank of Bolivia (Banco Agrícola de Bolivia) was closed; this had been the main credit source for campesinos but it had a long history of political interference and mismanagement. Since the mid-1980s the main development agents of the rural Altiplano have been non-governmental organisations (NGOs) and various forms of international co-operation. The impact of such groups has been limited, however, by lack of co-ordination and continuity of programmes (Van Niekerk 1992).

2.4 Overview of the study area at San José Llanga

2.4.1 Local environment

Our study site at San José Llanga (henceforth referred to in this chapter as SJL) is located in the east-central Altiplano between 17 20' and 17 30' South Latitude and 67 45' and 68 00' West Longitude, approximately 120 km southeast of the cities of La Paz and El Alto and 17 km south of the locally important town of Patacamaya. In the 1990s La Paz and El Alto have attained a combined population of over 1.1 million persons, while Patacamaya had a population of about 6000 in 1992 (GDRU 1994, 57). On the political map, SJL is a cantón (or district) that is part of the Umala municipality of Aroma Province, Department of La Paz (Figure 2.5). The Aroma province was home to about 66 000 persons in 1992, with the bulk of the population <24 years of age (Figure 2.6).

The Cantón of SJL has an area of 7200 hectares at an elevation between 3725 and 3786 m. The Cantón of SJL is typified by a relatively flat landscape (Plate 2.8a-c). A main town or barrio with 245 residents consists of a town square, church, a few shops and residences augmented with earthen-walled corrals (Plate 2.9a,b). The Cantón of SJL lies in what is typically referred to as the Patacamaya Basin. This basin is a flat, extensive, fluvio-lacustrine plain largely defined by the environs of the saline, perennial Desaguadero River, which runs about 15 km to the southeast of SJL. A portion of the water from the Desaguadero River is transported by a 23-km, unlined canal to SJL for irrigation of alfalfa. This canal was built in 1984 (see material that follows later in this section and also see Chapter 3: *Ecology and natural resources of San José Llanga*).

The rain-fed, seasonal *Khora Jahuíra* River offers fresh water during the rainy season and runs directly into the Cantón of SJL near the main town or barrio. This river was diverted more than a century ago by the campesinos to irrigate crops and some of the rangelands. Another perennial river called the Kheto occurs near the eastern boundary of the Cantón of SJL, and during the rainy season the Kheto River may flood and inundate rangelands at lower elevations. For maps and further details see Figures 3.2 to 3.4 in Chapter 3 (*Ecology and natural resources of San José Llanga*).

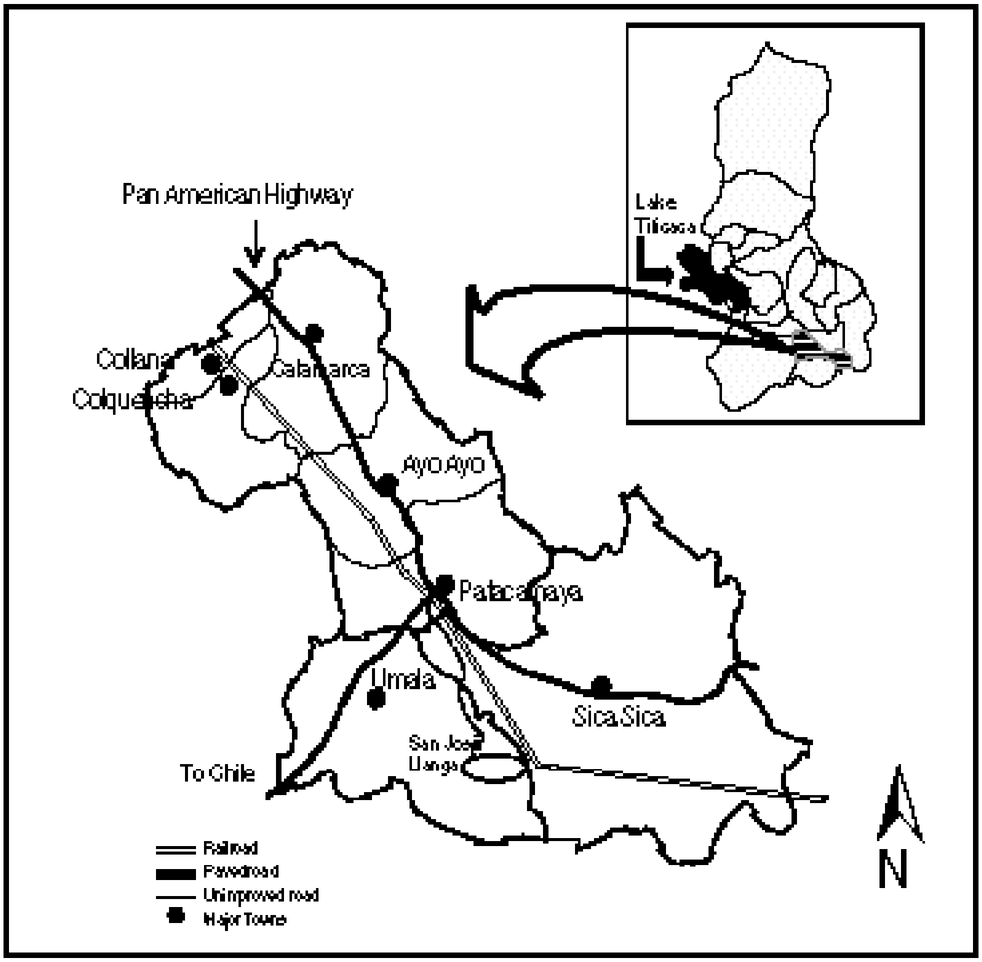

Figure 2.5. *Map of Aroma Province in the Department of La Paz on the Bolivian Altiplano.* Source: C. Jetté (IBTA/SR-CRSP, unpublished)

Climate data representing the Cantón of SJL have been collected over the past 42 years at the Patacamaya Experiment Station. This station is located 5 km to the west of the town of Patacamaya and 17 km north of the main barrio of SJL. The Patacamaya Experiment Station was established in 1958 and has been administered by IBTA. Climate data indicate that SJL is a semi-arid environment with significant risk of drought and common occurrence of crop-damaging frosts. Chapter 3 (*Ecology and natural resources of San José Llanga*) covers climate in detail.

The environment at SJL has influenced development of a complex and sophisticated agropastoral production system. The campesinos cultivate under rainfed, surface-irrigated and sub-irrigated situations. They also raise sheep and cows with improved and traditional (Criollo) breeds often mixed in the same herds. Sheep dominate livestock production, typical of the semi-arid puna. About 48% of the area of the Cantón of SJL is native rangeland (including rain-fed and sub-irrigated sites), about 36% is dedicated to rain-fed cultivation mainly on an alluvial terrace (and to a lesser extent on alluvial fans), 5% is permanent, improved pasture and 1% is for surface-irrigated cultivation (see Chapter 3: *Ecology and natural resources of San José Llanga*). Unlike other neighbouring production systems in the semi-arid puna (such as at Pumani, for example; Hervé 1994), the relatively flat landscape at SJL does not allow use of steep, hillside cultivation to mitigate severe frost risk. Some protection from frost is offered, however, by the uneven topography of the alluvial terrace (Chapter 3: *Ecology and natural resources of San José Llanga*).

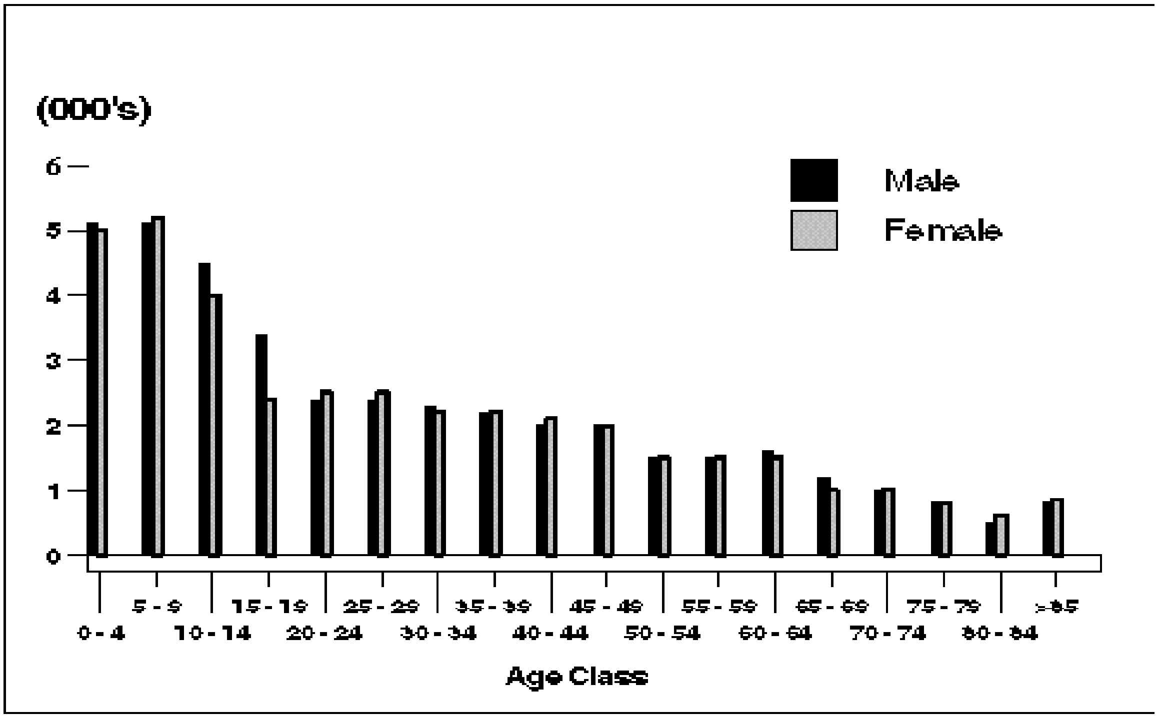

Figure 2.6. *Age distribution by gender for people inhabiting Aroma Province in the Department of La Paz on the Bolivian Altiplano in 1991.* Source: Created from data in INE (1992)

Despite the lack of hillside cultivation, the SJL site is representative of many locations on the semi-arid puna. The SJL site represents communities which tend to be closer to markets, have greater access to sub-surface water, and where beef and dairy production have emerged during the last decade in response to changing urban market opportunities and favourable government policies. The SJL community also has features which illustrate coping strategies found in more arid sectors, including the southern terminus of the Desaguadero River and the basin of Lake Poopó (Figure 2.3).

2.4.2. Local society

Centuries ago people of the San José area were part of a larger *ayllu* named Llanga that was progressively split up during the Spanish colonial era (Paredes 1984). At the end of the eighteenth century the people of SJL had thus been cut off from resources traditionally held by the Llanga *ayllu*, but they were still able to sustain themselves and maintain their independence. Even with the resurgence of hacienda domination on the Altiplano by the late 1800s (which claimed some neighbouring Indian communities) the people at SJL remained free. The residents of SJL were part of a larger indigenous group called *Umala* that was renowned for fierce defence of its lands against hacienda encroachment (Paredes 1984). Some current residents of SJL are shown in Plate 2.10(a,b).

From 1953, the Land Reform National Council typically gave free indigenous communities like SJL a collective (*pro indiviso*) title to the land they occupied. Within such communities higher-value lands (such as those used for cultivation) were assigned to households a long time ago. These households had real rights of possession except for a few restrictions on property transfer (Cala and Jetté 1994). For example, the main restriction on sale of arable land is that it can only be sold to someone from outside SJL if the prospective buyer is approved in advance by a council of community residents. With respect to rights of trespass, livestock may freely cross cultivation plots on their way to water or grazing land during times of year when potential damage to crops is minimal. Moreover, post-harvest or fallowed plots are regarded as freely accessible for

a

b

c

Plate 2.8 (a-c). *Typical scenes of the agricultural system at San José Llanga: (a) cattle and sheep grazing on unimproved rangelands, (b) potato fields prior to harvest and (c) sheep grazing on subirrigated alfalfa (also referred to as* alfalfares*). Note the contrast of the flat terrain at SJL compared to that of hillside systems in Plate 2.4.* Photographs: (a) Jim Yazman and (b,c) Christian Jetté

grazing throughout the ensuing dry season. Unlike many other indigenous communities, however, SJL does not have a communally managed system of sectoral fallowing (Orlove and Godoy 1986; Hervé 1994). What this means is that there is no collective determination of fallow duration, with each household free to cultivate its plots at any point in time. This way fallowing and cultivated plots are intermixed, which makes herding more labour intensive, as livestock feeding in fallow fields are not allowed to enter adjacent cultivated plots.

In contrast to the pattern of real ownership assigned to arable lands, it was typical that the grazing lands (of lower value compared to cropland) did not become owned by individuals but were instead communally used. In SJL these lands have been progressively divided up since

a

b

Plate 2.9 (a,b). *Typical scenes of settlements at San José Llanga: (a) Plaza of the main Barrio and (b) houses with earthen-walled corrals.* Photographs: (a) Brien E. Norton and (b) Christian Jetté


a


b

Plate 2.10 (a,b). Aymara *residents of San José Llanga: (a) Women herders and (b) men and women at a town meeting.* Photographs: (a) Lita Buttolph and (b) Christian Jetté

the 1950s among the resident households by action of local committees or leaders. Today, unlike many other communities, however, very little grazing land at SJL is truly communally used. Rather, the general pattern at SJL is one of private use of grazing plots when vegetation is abundant, and communal use of grazing during drier periods of the year (see Chapter 5: *The grazing livestock of San José Llanga*).

The differential rights and responsibilities for use of cropping and grazing lands at SJL underpin crucial aspects of stability and resilience of the agropastoral production system in response to environmental and economic perturbations. Communal authorities at SJL are responsible for enforcing rules of land use. These authorities include the *jilikata* (also called the Secretary of Justice) and two Agentes de campo (field agents), one for agriculture and the other for livestock (Cala 1994).

Today the Cantón of SJL consists of six socially distinct communities along with associated croplands and grazing lands. The six communities are defined according to factors of kinship and residence. The six communities occur either in the form of small settlements where the density of houses and other physical structures appears to increase, such as at *Callunimaya*, *Inkamaya* and *Espíritu Willq'i* with estimated populations of 45, 75 and 35 people, respectively, or as one larger settlement or main barrio [with a central square and other physical attributes of a town; Plate 2.9(a,b)]. The main barrio, however, is actually an aggregate of three social communities (i.e., *Savilani*, *Barrio* and *T'olatia*). This main barrio, again, has a total population of about 245 people (C. Jetté, IBTA/SR-CRSP, unpublished data).

The people of SJL have traditionally linked with larger neighbouring communities for market access and social activities. Until the 1960s the Cantón of SJL was most influenced by the economics and politics of the community of *Umala*, represented by a very old Mestizo town known for religious festivities and its silversmith industry. *Umala* is located about 10 km from the main barrio of SJL. Specific historical linkages between *Umala* and SJL included the obligation for SJL residents to assist the town's political and religious authorities with some services such as cleaning and communication, and to provide them with fuelwood. The SJL residents also participated actively in the celebration of the *Umala* annual religious festival, which was the occasion of an important commercial fair. The importance of *Umala* to SJL began to decline after implementation of land reform in the early 1950s. This was because, as in many other Mestizo towns in the Altiplano, the pre-revolutionary political and religious influences of *Umala* authorities was undermined. The silversmith industry declined and the town could not resist competition from new commercial fairs located closer to main roads (C. Jetté, IBTA/SR-CRSP, unpublished observations).

The Cantón of SJL started to become more influenced by the town and environs of Patacamaya in the 1950s. By the 1960s some SJL residents began to take advantage of the new Patacamaya Experiment Station, which has been previously described. Innovative campesinos gained access to extension workers and researchers based at the station, and one outcome was creation of agricultural co-operatives throughout the region, with support of the Agricultural Bank of Bolivia. One such co-operative played a leading role in introducing new technologies and management practices into the Cantón of SJL. Innovations included use of tractors, chemical fertilisers, pesticides, new potato varieties for urban markets, alfalfa and improved breeds of sheep (see Chapter 3: *Ecology and natural resources of San José Llanga*, Chapter 4: *Household economy and community dynamics at San José Llanga*, and Chapter 7: *Patterns of technology adoption at San José Llanga*).

Links between the Cantón of SJL and the town of Patacamaya greatly accelerated by the late 1980s. In 1988 a development project sponsored by the European Economic Community (EEC) resulted in construction of a 16-km gravel road from Patacamaya town to the main barrio of SJL. This road effectively severed most residual linkages between SJL and *Umala* and established strong, new ties between SJL and Patacamaya. Patacamaya is a rapidly growing town centrally located on the Pan American Highway, which connects La Paz with Oruro and now provides an export corridor between Bolivia and Arica, Chile (Figure 2.5). The town of Patacamaya provides a variety of educational and other support services for the campesinos of SJL, but the most pervasive impact is related to development of new and reliable markets for agricultural products.

Formal financial institutions occur in the region, but have undergone recent changes (Rojas 1995). The main public-finance institution in the area since the 1960s, the Agricultural Bank of Bolivia, closed in 1991. Some non-governmental orgainisations previously provided in-kind credit to be used as agricultural inputs, but these gradually failed. New private financial institutions have recently appeared, however, in Patacamaya and Lahuachaca (Rojas 1995). These institutions lend small amounts of money for a variety of objectives on a short-term basis at high rates of interest. Communal authorities or groups of neighbours are asked to guarrantee loans for individuals. Although Rojas (1995) reports that demand for such loans is increasing in the region, this has not been observed among campesino households of SJL (Dr. C. Valdivia, IBTA/SR-CRSP, personal observation). Lotteries and other informal, non-market mechanisms are employed at SJL to help residents obtain expensive livestock (e.g., dairy cattle) or secure access to land, labour, sheep and credit (Section 4.3.4: *Non-market factors in resource access*).

The inauguration of the road between SJL and Patacamaya town in 1989 encouraged a group of SJL residents to create a local association of milk producers with the support of Fomento Lechero, an extension programme financed by Danchurchaid (of Denmark). This programme assisted milk production and delivery to a milk processing plant operated by PIL (Programa de Industrialización Lechera). The PIL was originally created as a parastatal network throughout Bolivia. The PIL of the Altiplano was created to help provide a milk processing and wholesale outlet for La Paz (Sherbourne et al 1995). The PIL worked with communities to provide credit and technical assistance to farmers who wanted to get involved with small-scale dairying. This assistance has often been focussed around procurement and management of improved dairy cattle. Each community has a PIL office in the main plaza where participating households report each morning to record their milk deliveries. Locally elected or appointed officials provide administration. The PIL sends a truck to the main barrio of SJL each morning to collect milk. Payments to members occur twice per month. Recently, the PIL office at SJL has been augmented with a refrigeration unit which increases flexibility in milk collection and handling (Sherbourne et al 1995). While operating as a parastatal, the PIL offered subsidies to members. The PIL processing plants at La Paz and Cochabamba, however, were privatised in late 1996. Local associations of milk producers now own 22% of the shares of the new private enterprise called PIL Andina (C. Jetté, IBTA/SR-CRSP, personal observations). Other implications of this programme are reviewed in Chapter 6 (*Household socioeconomic diversity and coping response to a drought year at San José Llanga*) and Chapter 7 (*Patterns of technology adoption at San José Llanga*).

The construction of the 23-km irrigation canal to bring water from the Desaguadero River to SJL was vital for development of more alfalfa plots under irrigation in the southeastern portion of the cantón. The salinity of these waters, however, poses problems for longer-term sustainability for these plots (Chapter 3: *Ecology and natural resources of San José Llanga*). All communities in SJL collaborated on this project with three other surrounding communities (namely, *T'uluma*, *Wari Chullpa*, and *Wancaroma*). Some support was provided by the World Food Programme (WFP). By expanding alfalfa cultivation, this irrigation project has allowed campesinos at SJL to better support smallholder dairying and production of improved sheep breeds by providing crucial nutritional resources during the dry season. As a consequence, in less than five years the Patacamaya Basin has become one the most important milk production areas in the Department of La Paz (Illanes et al 1995).

As previously reviewed, the Popular Participation Act passed by the Bolivian congress in 1994 provides for the creation and funding of rural municipalities through national tax revenues. This law should provide a vital stimulus for development of the Altiplano, and may also contribute to a resurgence of the community of *Umala* as the seat of local government and reinvigorate connections between *Umala* and the Cantón of SJL. Indeed the first mayor elected for *Umala*, in 1995, is a resident of SJL. This result is indicative of broader political change in a country where native people, although the majority of the population, gained the right to formal citizenship just 40 years ago. Reflective of such change, in 1993 the electorate chose an *Aymara* as vice president of Bolivia, namely Mr. Victor Hugo Cárdenas, the highest public office ever held by a member of an indigenous ethnic group. The adoption of the Popular Participation Act and other legislative reforms that broaden indigenous cultural and territorial rights has contributed to important changes. Now the challenge for Bolivia is to make significant breakthroughs to improve the economic conditions of its rural inhabitants.

2.5 Conclusions

This chapter provides an overall context for the SR-CRSP project at SJL. This broad review has revealed important issues relevant to understanding social and ecological dynamics on the Altiplano. Understanding these dynamics, in turn, is important for projects which aspire to alter or improve traditional agricultural production systems.

2.5.1 Recent policy shifts

Perhaps our most important finding is that despite a long and illustrious history of the *Aymara* prior to the 1500s, only very recently have national policies been even remotely favourable for the economic advancement of the *Aymara*. It is little wonder that economic deprivation appears to be a pervasive outcome for *Aymara* communities on the Altiplano.

Recent shifts in the national and regional policy environments may have positive consequences for the *Aymara*. These include: (1) Gradual democratisation, which has resulted, for example, in the election of the first *Aymara* vice president; (2) improved fiscal management of the nation, which has created more economic opportunities in urban areas; (3) the recent Popular Participation Act provides a framework for increasing investment for community-based development on the Altiplano; (4) a re-focusing of activities for public agencies such as IBTA on technology generation and extension to better meet needs of rural communities; and (5) attempts to spur income-generating activities such as smallholder dairying on the Altiplano through parastatal organisations. Given apparent progress in this policy setting, the key is for *Aymara* communities, development agents and research entities to seize opportunities for progress now.

Some trends still appear unfavourable, however, for people like the *Aymara* on the Altiplano. These include: (1) high levels of food imports, which may depress commodity prices; (2) perceived land degradation; (3) a continued prioritisation of inputs for agriculture in the tropical lowlands at the expense of agriculture in the temperate highlands; and (4) unfavourable agricultural marketing policies.

2.5.2 General features of San José Llanga

Our research site at SJL is characterised by key features. These can be grouped according to the environment and socioeconomics. These features help define the degree to which results from the SJL study site could be extrapolated to other locations.

Like most production systems on the Altiplano, the Cantón of SJL is largely defined by its position and elevation on the landscape. It is a production system which relies on exploitation of the alluvial plains for cultivation and grazing. It therefore is not representative of production systems found in the nearby foothills of the Cordilleras. One obvious and basic consequence of landscape position is that the residents of SJL are not able to use hillside agriculture. This affects cropping and herding strategies, labour demands, risk profiles, etc. Another less-obvious consequence of landscape position is that compared to hillside production systems, the Cantón of SJL probably resembles more of a resource “sink” where nutrients, salts, soil and water slowly accumulate from surrounding areas. Unlike hillside systems, therefore, soil erosion due to heavy grazing or cultivation should be much less of an issue at SJL. Conversely, soil salinity could be more of a problem at SJL compared to that for hillside systems. All of these landscape features should have profound influences on ecological and agricultural dynamics at SJL. They also have a bearing on the debate concerning biotic versus abiotic control of land-degrading processes; this will be discussed in subsequent chapters. Finally, it is evident that the people of SJL have engaged in ambitious engineering projects to modify water delivery systems. Human modification of the landscape thus occurs.

Today, the people at SJL have reasonably good access to markets. As will be discussed, this market access has likely affected the composition of crops and livestock at SJL and is probably important to how the community is able to cope with ecological and economic stress. From a historical perspective, such coping ability at SJL has probably been greatly compromised by the parcelisation of the Llanga *ayllus* due to hacienda encroachment.

By virtue of their proximity to markets and the Patacamaya Experiment Station, the residents of SJL have reasonably good access to novel agricultural technology. A general survey of crops and livestock also suggests that SJL incorporates a Mestizo technical culture in which mixes of indigenous and Spanish innovations occur. This latter feature is fairly common on the Altiplano. The dominance of sheep is typical in this part of the semi-arid puna. Proximity to markets also means proximity to major urban centres, which points to the likelihood of other social and economic influences such as enticements which draw rural youths to emigrate.

Finally, it is important to note that, in contrast to many of their neighbours, the people of SJL largely remained free from acute internal interference from colonial powers. The people of SJL have therefore been able to exert a higher degree of self-determination compared to many neighbouring communities. This has probably manifested itself in various aspects of resource use and resource tenurial regimes at SJL. One interesting finding is that land tenure at SJL varies with quality of land; higher value croplands tend to be privately used while lower value range is communally used.

In summary, at a general level of resolution, the Cantón of SJL is a patchwork of socioeconomic and ecological attributes which make it appear unique. One could probably make the same conclusion about any site on the Altiplano. Research findings from SJL, however, would probably be most comparable to those from other sites on the semi-arid puna where (1) alluvial plains are the primary landscape type that is exploited; (2) access to markets and technology is reasonably good; and (3) indigenous culture for making resource-use decisions has been largely maintained. With regard to favourable proximity to markets and novel technology, the Cantón of SJL can serve as a “living laboratory” to observe effects of market integration and technology diffusion on an otherwise traditional campesino community.

2.6 Literature cited

Albó X. 1979. *¿Bodas de Plata? O Requiem para una Reforma Agraria*. Cuadernos de Investigación 17. CIPCA (Centro de Investigación y de Promoción del Campesino), La Paz, Bolivia. 103 pp.

Albó X. 1995. *Bolivia Plurilingüe*. Cuadernos de Investigación 44, vol. 1. UNICEF/CIPCA (Fondo de las Naciones Unidas para la Infancia/Centro de Investigación y de Promoción del Campesino), La Paz, Bolivia. 249 pp.

Alzérreca H. 1992. *Produccion y Utilizacion de los Pastizales de la Zona Andina de Bolivia*. REPAAN/IBTA (Red de Pastizales Andinos/Instituto Boliviano de Tecnología Agropecuaria). Imprenta Papiro. La Paz, Bolivia. 146 pp.

Ambroggi R. 1965. *Hidrología del Altiplano de Bolivia*. Informe preliminar del fondo especial de las Naciones Unidas, La Paz, Bolivia. 11 pp.

Antezana A. 1992. *Estructura Agraria en el Siglo XIX*. CID (Centro de Información para el Desarollo), La Paz, Bolivia. 218 pp.

Ayllu Sartañäni. 1992. P*achamamax Tipusiwa (la Pachamama se Enoja). I: Qhurqhi*. Aruwiyiri editorial. La Paz, Bolivia. 208 pp.

Beck E. 1988. Las regiones ecológicas y las unidades fitogeográficas de Bolivia. En: de Morales C. (ed), *Manual de Ecología.* Instituto de Ecología, Universidad Mayor de San Andrés, La Paz, Bolivia. pp. 233-271.

Birbuet G. 1989. *La Ganadería Campesina en Pacajes: Estudio en el rea de Caquiaviri y Comanche*. SEMTA (Servicios Múltiples de Tecnología Apropiada), La Paz, Bolivia. 134 pp.

Bouysse-Cassagne T. 1987. *La Identidad* Aymara*. Una Aproximación Histórica (Siglo XV, Siglo XVI*). HISBOL/IFEA (Instituto de Historia Social Boliviano/Insituto Francés de Estudios Andinos), La Paz, Bolivia. 443 pp.

Bouysse-Cassagne T. 1992. Past and present human populations. In: Dejoux C. and Iltis A. (eds), *Lake Titicaca. A Synthesis of Limnological Knowledge*. Kluwer Academic Publishers, Dordrecht, Holland. pp. 473-494.

Brockmann C. (ed). 1986. *Perfil Ambiental de Bolivia*. USAID/IIDE (United States Agency for International Development/Instituto Internacional Para el Desarrollo y Medio Ambiente), La Paz, Bolivia. 164 pp.

Browman D. 1974. Pastoral nomadism in the Andes. *Current Anthropology* 15:188-196.

Cabrera A. 1957. *La Vegetación de la Puna Argentina*. Revista de Investigaciones Agrícolas, Tomo XI, No. 4, Buenos Aires, Argentina. 412 pp.

Cabrera A. 1968. *Ecología Vegetal de la Puna*. Colloquium Geographicum. Ferd Dummlers Verlag, Bonn, Germany. 91 pp.

Cala E. 1994. *El Sistema de Tenencia de Tierras en la Comunidad San José Llanga*. BA tesis, Universidad Mayor de San Andrés, La Paz, Bolivia. 147 pp.

Cala E. and Jetté C. 1994. *Posesión y Control de Tierras en Una Comunidad del Altiplano Central*. IBTA/SR-CRSP (Instituto Boliviano de Tecnología Agropecuaria/ Small Ruminant Collaborative Research Support Program) IBTA 138/ Boletín Técnico 07/SR-CRSP 09, La Paz, Bolivia. 37 pp.

Cardozo A. 1994. Antecedentes de la ganadería bovina en la región Andina de Bolivia. En: Hervé D. and Rojas A. (eds), *Vias de Intensificación de la Ganadería Bovina en el Altiplano Boliviano.* ORSTOM/DANCHURCHAID (Institut Français de Recherche Scientifique pour le Développement en Coopération/Cooperación Técnica de la Iglesia Danesa), La Paz, Bolivia. pp. 15-19.

Caro D. 1992. The socioeconomic and cultural context of Andean pastoralism. In: Valdivia C. (ed), *Sustainable Crop-Livestock Systems for the Bolivian Highlands. Proceedings of an SR-CRSP (Small Ruminant Collaborative Research Support Program) Workshop held at Lubbock, Texas, USA, 14-17 May 1991.* University of Missouri, Columbia, Missouri, USA. pp. 71-92.

Carter W. y Albó X. 1988. La comunidad *Aymara*: Un mini-estado en conflicto. En: Albó X. (comp), *Raíces de América. El mundo* Aymara*.* Alianza Editorial, Madrid, España. pp. 451-492.

Castillo A. 1994. Viabilidad económica de la producción lechera en las zonas norte y centro del Altiplano. En: Hervé D. and Rojas A. (eds), *Vias de Intensificación de la Ganadería Bovina en el Altiplano Boliviano.* ORSTOM/ DANCHURCHAID (Institut Français de Recherche Scientifique Pour le Développement en Coopération/Cooperación Técnica de la Iglesia Danesa), La Paz, Bolivia. pp. 160-168.

CEPAL (Comisión Económica para América Latina). 1982. *Campesinado y Desarrollo Agrícola en Bolivia*. CEPAL (Comisión Económica para América Latina), Santiago, Chilé. 121 pp.

CIACER/GEOBOL (Centro de Investigaciones y Aplicaciones de Censores Remotos/Geología Bolivia). 1985. Suelos. In: *Estudio Integrado de los Recursos Naturales del Departamento de La Paz*. CORDEPAZ (Corporación de Desarrollo del Departamento de La Paz), La Paz, Bolivia. 222 pp.

Coudrain-Ribstein A., Pratx B., Quintanilla J., Zuppi G., Jusserand C. y Cahuaya D. 1995. La salinité de la ressource en eau souterraine de l'Altiplano central. En: Ribstein P. and Francou B. (eds), *Aguas Glaciares y Cambios Climáticos en los Andes Tropicales*. ORSTOM/UMSA/ SENAMHI/CONAPHI (Institut Français de Recherche Scientifique Pour le Développement en Coopération/Universidad Mayor de San Andrés/Servicio Nacional de Meteorología e Hidrología/Comité Nacional para el Programa Hidrólogico Internacional), La Paz, Bolivia. pp. 97-107.

Dandler J. 1984. El desarrollo de la agricultura, políticas estatales y el proceso de acumulación en Bolivia. *Estudios Rurales Latinoamericanos* 7: 81-143.

Dollfus O. 1981. *El Reto del Espacio Andino*. IEP (Instituto de Estudios Peruanos), Lima, Perú. 141 pp.

Donkin R. 1979. *Agricultural Terracing in the Aboriginal New World*. Viking Fund Publications in Anthropology, no. 56. Wenner-Gren Foundation for Anthropological Research, Inc., and The University of Arizona Press, Tucson, Arizona, USA. 196 pp.

Ellenberg H. 1979. Man's influence on tropical mountain ecosystems in South America. *Journal of Ecology* 67:401-416.

Ellenberg H. 1981. *Desarrollar Sin Destruir*. Instituto de Ecología, Universidad Mayor de San Andrés, La Paz, Bolivia. 55 pp.

Erickson C. 1986. Agricultura en camellones en la cuenca del Lago Titicaca: Aspectos técnicos y su futuro. En: de la Torre C. y Burga M. (eds). *Andenes y Camellones en el Perú Andino: Historia Presente y Futuro*. CNTC (Consejo Nacional de Ciencia y Tecnología), Lima, Perú. pp. 331-350.

Erickson C. 1992. Prehistoric landscape managment in the Andean highlands: Raised-field agriculture and its environment impact. *Population and Environment Journal* 13:285-301.

Eróstegui R. 1990. La industria textil boliviana. En: Eróstegui R. (ed), *La Industria: Problemas y Perspectivas*. ILDIS (Instituto Latinoamericano de Investigaciones Sociales), La Paz, Bolivia. pp. 151-163.

FAO (Food and Agriculture Organization). 1975. *Estudio Agroclimatólogico de la Zona Andina*. Proyecto Inter-institucional en Agroclimatología, FAO, Roma, Italia. 236 pp.

Franqueville A. y Aguilar G. 1988. *El Alto de La Paz. Migraciones y Estrategias Alimentarias en Bolivia*. INAN/ORSTOM (Institut Nacional de Alimentación y Nutrición/Institut Français de Recherche Scientifique Pour le Développement en Coopération), La Paz, Bolivia. 163 pp.

Franklin W. 1971. High, wild world of the vicuña. *National Geographic* 143:76-91.

Freeman P., Cross B., Flannery R., Harcharik D., Hartshorn G., Simmonds G. and Williams J. 1980. *Bolivia: State of the Environment and Natural Resources - a Field Study*. USAID (United States Agency for International Development) contract no. PDC-C-Q247. JRB Associates, Inc., McLean, Virginia, USA. ca. 300 pp.

Gaceta Oficial de Bolivia. 1994. *Ley de Participación Popular*. Anno XXXIV, No 1828. La Paz, Bolivia. 20 pp.

GASO (Grupo de la Agenda Social). 1995. *Bolivia. Desarrollo Diferente para un País de Cambios. Informe Final de la Misión Piloto Sobre Reforma Socio-Económica en Bolivia*. BID (Banco Interamericano de Desarrollo), La Paz, Bolivia. 274 pp.

Gastó J., Cosio F. y Panario D. 1993. *Clasificación de Ecoregiones y Determinación de Sitio y Condición: Manual de Aplicación a Municipios y Predios Rurales*. REPAAN/CIID (Red de Pastizales Andinos/Centro Internacional de Investigaciones para el Desarrollo), Santiago, Chilé. 253 pp.

GDRU (Grupo de Desarallo Rural). 1994. *Bolivia. Anuario Estadístico del Sector Rural 1994*. CID (Centro de Infomratión para el Desarrollo), La Paz, Bolivia. 331 pp.

Genin D. y Alzérreca H. 1995. Reseña de la vegetación de la zona de Turco. En: Genin D., Picht H., Lizarazu R. y Rodriguez T. (eds), *Waira pampa.Un Sistema Pastoril Camélidos - Ovinos del Altiplano rido Boliviano*. ORSTOM/CONPAC/IBTA (Institut Français de Recherche Scientifique Pour le Développement en Coopération / Programa de Autodesarrollo Campesino fase de Consolidación/Instituto Boliviano de Tecnología Agropecuria), La Paz, Bolivia. pp 35-56.

Golte J. 1980. *La Racionalidad de la Organización Andina*. IEP (Instituto de Estudios Peruanos), Lima, Peru. 124 pp.

Harris O., Larson B. y Tandeter E. (comp). 1987. *La Participación Indígena en los Mercados Surandinos. Estrategias y Reproducción Social, Siglos XVI a XX*. CERES (Centro de Estudios de la Realidad Económica y Social), La Paz, Bolivia. 768 pp.

Healy K. 1991. *Structural Adjustment, Peasant Agriculture and Coca in Bolivia*. Unpublished paper presented at the XVI International Congress of the Latin American Studies Association, Washington, DC, USA. 49 pp.

Heath D., Erasmus C. and Buechler H. 1969. *Land Reform and Social Revolution in Bolivia*. Praeger Press, New York, New York, USA. 464 pp.

Hervé D. 1994. Desarrollo Sostenible en los Andes Altos. Los sistemas de cultivo con descanso largo pastoreado. En: Hervé D., Genin D. y Rivière G. (eds), *Dinámicas del Descanso de la Tierra en los Andes*. ORSTOM/IBTA (Institut Français de Recherche Scientifique Pour le Développement en Coopération/Instituto Boliviano de Tecnología Agropecuria), La Paz, Bolivia. pp. 15-36.

Hudson A. and Hanratty D. (eds). 1989. *Bolivia: A Country Study*. Federal Research Division of the United States Library of Congress, Washington, DC, USA.

IBTA (Instituto Boliviano de Technología Agropecuria).1992. *Analisis Ex-Ante de Alternativas Tecnológicas. Proyecto Sistemas du Produccion en el Altiplano Boliviano*. IBTA Boletín Técnico no. 128, La Paz, Bolivia, 74 pp.

Illanes P., Cuesta M. y Céspedes J. 1995. *Adopción de Tecnología en la Producción Lechera. Estudio de Caso de la Comunidad San José Llanga*. IBTA/SR-CRSP (Instituto Boliviano de Tecnología Agropecuria/Small Ruminant Collaborative Research Support Program) IBTA 147/ Boletín Técnico 15/SR-CRSP 17, La Paz, Bolivia. 35 pp.

INE (Instituto Nacional de Estadísticas). 1993. *Censo 1992. Resultados Finales*. Vol. 2, 4, y 5. INE, La Paz, Bolivia. 233 pp.

INTECSA (Internacional de Igeniería y Estudios Técnicos Sociedad Anónima). 1993. *Plan Director Global Binacional de Protección-Prevención de Inundaciones y Aprovechamiento de los Recursos del Lago Titicaca, Río Desaguadero, Lago Poopó y Lago Salar de Coipasa (Sistema T.D.P.S.). Estudio de Climatología*. Republicas de Perú y Bolivia. EEC (European Economic Community), La Paz, Bolivia. 581 pp.

Jetté C., Loyza V. y Rojas R. In press. Monografía de la Provincia Aroma. Situación social y pobreza. En: CIDES/UMSA/PNUD (Centro de Evestigación para el Desarrollo/ Universidad Mayor de San Andrés/Programa de las Naciones Unidas para el Desarrollo), *Desarrollo Humano y Pobreza en las Provincias de Caranavi y Aroma*. CID (Centro de Información para el Desarrollo), La Paz, Bolivia. pp. 99-170

King L. 1962. *The Morphology of the Earth: A Study and Synthesis of World Summaries*. Hafner Publishing Company, New York, New York, USA. 699 pp.

Klein H. 1984. *Historia General de Bolivia*. Editorial Juventud, La Paz, Bolivia. 361 pp. [original title, publisher and publication date: *Bolivia: The Evolution of A Multi-Ethnic Society*. Oxford University Press, Oxford, UK, 1982.]

Klein H. 1995. Haciendas y *Ayllus* en Bolivia, ss. XVIII y XIX. Instituto de Estudios Peruanos, Lima, Peru. 236 pp. [original title, publisher, and publication date: *Haciendas &* Ayllus*. Rural Society in the Bolivian Andes in the Eighteenth and Nineteenth Centuries*. Stanford University Press, Stanford, California, USA, 1993.]

Kolata A. 1993. *The Tiwanaku: Portrait of an Andean Civilization*. Blackwell Publishers, Cambridge, Massachusettes, USA. 317 pp.

Lara R. y Alzérreca H. 1986. Pastizales. En: Brockman C. (ed), *Perfil Ambiental de Bolivia*. USAID/IIDA (United States Agency for International Development/Institut Internacional para el Desarrollo), La Paz, Bolivia. pp. 82-96.

LeBaron A., Bond L., Aitken P. and Michaelsen L. 1979. An explanation of the Bolivian highlands grazing-erosion syndrome. *Journal of Range Management* 32:201-208.

López C. 1993. *Biografia de Bolivia*. Editorial Juventud, La Paz, Bolivia. 166 pp.

Lorini J. 1987. *Climatología de la Cuenca del Lago Titicaca (Bolivia-Perú)*. Proyecto: Evaluación de los Recursos del Lago Titicaca. OLDEPESCA (Organización Latinoamericana de Pesquería), Lima, Perú. 48 pp.

Lorini J. y Libermann N. 1983. El clima de la provincia Aroma del departamento de La Paz-Bolivia. En: Comité de Redaccion del Instituto de Ecología (eds), *Ecología en Bolivia*. No. 4. Revista del Instituto de Ecología. La Paz, Bolivia. pp. 19-29.

Lorini J. 1995. El ecosistema altiplánico, situación actual. En: Tejada E. y Defilippis D. (eds), *Lineamientos de Políticas para el Desarrollo Sostenible del Recurso Camélido. Documentación del Seminario Taller Nacional.* RBPC/PRODENA/CERENA (Red Boliviana de Producción de Camélidos/Asociación Boliviana Pro-defensa de la Naturaleza/Centro de Economía y Recursos Naturales), La Paz, Bolivia. pp. 39-44.

MACA (Ministerio de Asuntos Campesinos y Agropecuarios). 1990a. *Lineamientos de Política Agropecuaria*. Internal Report. Subsecretaría de Desarrollo Agropecuario, Proyecto MACA/FAO/PNUD (Ministerio de Asuntos Campesinos y Agropecuarios/Food and Agriculture Organization/Programa de las Naciones Unidas para el Desarrollo), BOL/88/201, La Paz, Bolivia. 64 pp.

MACA (Ministerio de Asuntos Campesinos y Agropecuarios). 1990b. *Decreto Supremo No. 22565 de Fortalecimiento y Modernización del IBTA*. Serie Documentos Legales y Administrativos no. 1. MACA, La Paz, Bolivia. 20 pp.

MACA/IBTA (Ministerio de Asuntos Campesinos y Agropecuarios/ Instituto Boliviano de Tecnología Agropecuaria). 1992. *IBTA. Instituto Boliviano de Tecnología Agropecuaria*, MACA/IBTA, Imprenta papiro, La Paz, Bolivia. 36 pp.

Malloy J. 1970. *The Uncompleted Revolution.* University of Pittsburgh Press, Pittsburgh, USA. 396 pp.

Marconi R. 1996. *ONG's y Crédito Rural en Bolivia.* FINRURAL (Asociación de Instituciones Financieras para el Desarrollo Rural), La Paz, Bolivia. 74 pp.

McCorkle C. (ed). 1990. *Improving Andean Sheep and Alpaca Production: Recommendations From a Decade of Research in Peru*. SR-CRSP (Small Ruminant Collaborative Research Support Program). University of Missouri, Columbia, Missouri, USA. 220 pp.

MDSMA (Ministerio de Desarrollo Sostenible y Medio Ambiente). 1996. *Ley del Servicio Nacional de Reforma Agrario*. MDSMA, La Paz, Bolivia. 23 pp.

Medicaneli X., Jimenez R. and Quiton M. 1993. *Historia Demográfica de Aroma-Umala-San José.* Unpublished research report. IBTA/SR-CRSP (Instituto Boliviano de Tecnología Agropecuria/ Small Ruminant Collaborative Research Support Program), La Paz, Bolivia. 130 pp.

Montes de Oca I. 1989. *Geografía y Recursos Naturales de Bolivia*. Imprenta superel, La Paz, Bolivia. 574 pp.

de Morales C. 1990. *Bolivia. Medio Ambiente y Ecología Aplicada*. Instituto de Ecología, Universidad Mayor de San Andrés, La Paz, Bolivia. 318 pp.

Morales J. 1990. Impacto de los ajustes estructurales en la agricultura campesina Boliviano. En: Toranzo C. (ed), *El Impacto de la NPE (Nueva Política Económica) en el Sector Agropecuario.* COTESU/MACA/ILDIS (Cooperación Técnica Suiza/Ministerio de Asuntos Campesinos y Agropecuarios/Instituto Latinoamericano de Investigaciones Sociales), La Paz, Bolivia. pp. 9-69.

Morales R. 1991. *The Impact of the Macroeconomic Policy Reform on Poverty, Household Food Security and Nutrition in Bolivia*. Unpublished paper presented at a workshop on Economic Policy Reforms and the Poor in Latin America, held in Cali, Colombia, October 1991. Econométrica, La Paz, Bolivia. 48 pp.

Morales R. 1992. *Estudio Sobre reas de Pobreza Rural en Bolivia.* Second edition. Caritas, La Paz, Bolivia. 248 pp.

Morales R., Azero R., Szmuckler A. and Mollinedo F. 1995. *Desarrollo Humano en la Montañas. Informe del Desarrollo Humano de la Ciudad de La Paz.* GMLP/UNDP(Gobierno Municipal de La Paz/Programa de las Naciones Unidas para el Desarrollo), La Paz, Bolivia. 277 pp.

Mourguiart P., Argollo J. y Wirrmann D. 1995. Evolution paléohydrologique du bassin du lac Titicaca au cours de l'holocène. En: Ribstein P. and Francou B. (eds), *Aguas Glaciares y Cambios Climáticos en los Andes Tropicales.* ORSTOM/UMSA/SENAMHI/CONAPHI (Institut Français de Recherche Scientifique Pour le Développement en Coopération /Universidad Mayor de San Andrés/Servicio Nacional de

Meteorología e Hidrología/Comité Nacional para el Programa Hidrólogico Internacional), La Paz, Bolivia. pp. 161-169.

Muñoz-Reyes J. 1982. *Geografía y Recursos Naturales de Bolivia.* Academia Nacional de Ciencias de Bolivia, La Paz, Bolivia. 515 pp.

Murra J. 1975. El control vertical de un máximo de pisos ecológicos en la economía de las sociedades Andinas. En: Murra J. (ed), *Formaciones Económicas y Políticas del Mundo Andino.* IEP (Instituto de Estudios Peruanos), Lima, Perú. pp. 59-115.

Murra J. 1988. El *Aymara* libre de ayer. En: Albó X. (comp), *Raíces de América. El Mundo* Aymara. Alianza Editorial, Madrid, España. pp. 51-73.

Orlove B. 1987. Stability and change in highland Andean dietary patterns. In: Harris M. and Ross E. (eds), *Food and Evolution: Toward a Theory of Human Food Habits*. Temple University Press, Philadelphia, Pennsylvania, USA. pp. 481-515.

Orlove B. and Godoy R. 1986. Sectoral fallowing systems in the central Andes. *Journal of Ethnobiology* 6:169-204.

Painter M. 1992. Changes in highland land use patterns and implications for agropastoral development. In: Valdivia C. (ed), *Sustainable Crop Livestock Systems for the Bolivian Highlands. Proceedings of an SR-CRSP (Small Ruminant-Collaborative Research Support Program) Workshop held at Lubbock, Texas, USA, May 1991*. University of Missouri, Columbia, Missouri, USA. pp. 92-121.

Paredes R. 1984. *La Provincia de Sicasica*. Second edition. Isla, La Paz, Bolivia. 62 pp.

Paz Ballivián D. 1992. *Región y Desarrollo Agrario.* Vol II, Zona 01. ANCB (Academia Nacional de Ciencias de Bolivia) Secretaria Ejecutiva PL-480, La Paz, Bolivia. 88 pp.

Pérez-Crespo C. 1991. *Migration and the Breakdown of a Peasant Economy in Central Bolivia.* IDA (Institute for Development Anthropology) Working Paper Number 82. State University of New York, Binghamton, New York, USA. 39 pp.

PNUD (Programa de las Naciones Unidas para el Desarrollo). 1994. *Informe Sobre Desarrollo Humano* 1994. FCE (Fondo de Cultura Económica), México D.F. 243 pp. [original author, title and publisher: UNDP (United Nations Development Programme). 1994. *Human Development Report 1994.* Oxford University Press, New York, New York, USA].

PNUD/AECI/MOPI-SGMA (Programa de las Naciones Unidas para el Desarrollo/Agencia Española de Cooperación Internacional/Ministerio de Obras Publicas y Urbanismo/Secretaria General del Medio Ambiente). 1990. *Desarrollo y Medio Ambiente en America Latina y el Caribe:Una Vision Evolutiva*. Secretaría General Técnica-MOPU. Imp. Neografis. Madrid, España. 231 pp.

Posnansky M. 1982. Los efectos sobre la ecología del altiplano de la introducción de animales y cultivos por los españoles. En: Geyger E. y Arze C. (eds), *Ecología y Recursos Naturales en Bolivia.* Instituto de Ecología, University Mayor de San Andrés. La Paz, Bolivia.

PSP (Proyecto Sistemas de Producción). 1992. *Resultados del Sondeo de Cinco Comunidades del Altiplano Boliviano*. Publicaciones técnicas no 2. IBTA/CIID (Instituto Boliviano de Tecnología Agropecuria/Centro Internacional de Investigación para el Desarrollo), La Paz, Bolivia. 143 pp.

Preston D. 1977. *Rural-Urban Interaction and the Market Systems: The Bolivian Altiplano After Land Reform.* Working Paper No. 174. University of Leeds, Leeds, UK. 27 pp.

Prudencio J. 1993. El impacto de las donaciones alimentarias en Boliva. En: MCTH (Misión Cooperación Técnica Holandesa) (eds), *Autosuficiencia o Inseguridad Alimentaria: El Rol de los Alimentos Donados en Bolivia*. ILDIS (Instituto Latinoamericano de Investigaciones Sociales), La Paz, Bolivia. pp. 33-60.

Rivera S. 1992. Ayllus *y proyectos de desarrollo en el norte de Potosí*. Editorial Aruwiyiri, La Paz, Bolivia. 192 pp.

Rojas R. 1995. *Mercados Financieros Rurales en la Región Andina. Zona de Estudio: La Paz*. CEP (Centro de Estudios y Proyectos). La Paz, Bolivia. 35 pp.

Ruthsatz B. 1977. *Pflanzengesellschaften und Ihre Lebensbedingungen in den Andinen Halbwusten Nordwest-Argentiniens.* Dissertationes Botanica. Band 39. Vaduz, Austria. 168 p.

Ruthsatz B. and Fisel U. 1984. The utilization of natural resources by a small community in the highlands of Bolivia and its effects on vegetation cover and site conditions. In: *Erdwissenschaftliche Forschung*. Band XVIII. Franz Steiner Verlag Wiesbaden GmbH, Stuttgart, Germany. pp. 211-234.

Salm H. y Gehler E. 1987. La salinización del suelo en el altiplano central de Bolivia y su influencia sobre la cobertura vegetal. En: CRIE (Comité de Redacción de Instituto de Ecología) (eds), *Ecología en Bolivia*. Revista del Instituto de Ecología, No. 10. La Paz, Bolivia. pp. 37-48.

Sammells C. y Markowitz L. 1994. *Carne de Llama: Alta Viabilidad, Baja Visibilidad*. IBTA/SR-CRSP (Instituto Boliviano de Tecnología Agropecuria/Small Ruminant Collaborative Research Support Program) IBTA 140/Boletín Técnico 09/SR-CRSP 09, La Paz, Bolivia. 32 pp.

Sánchez-Albornoz N. 1978. *Indios y Tributos en el Alto Perú*. IEP (Instituto de Estudios Peruanos), Lima, Peru. 224 pp.

Sandoval G. y Sostres F. 1991. *La Ciudad Prometida*. ILDIS (Instituto Lantinoamericano de Investigaciones Sociales), La Paz, Bolivia. 230 pp.

Sebill N. 1989. Ayllus y *Haciendas. Dos Estudios de Caso Sobre la Agricultura Colonial en Los Andes*. HISBOL (Instituto de Historia Social Boliviana), La Paz, Bolivia. 142 pp.

Sherbourne J., Dunn E., Valdivia C. and Nolan M. 1995. *Agropastoral Production Systems, Intra-household Resource Allocation and Household Members Domains: Five Case Studies from the Community of San José Llanga.* IBTA/SR-CRSP (Instituto Boliviano de Technología Agropecuraria/ Small Ruminant Collaborative Research Support Program). IBTA 171/Boletín Técnico 39/SR-CRSP 37. 50 pp.

SIPFE (Secretaría de Inversión Pública y Financiamiento Externo). 1996. *La Estrategia para la Transformación Productiva del Agro.* Presentación del gobierno de Bolivia al Grupo Consultivo (Paris, Francia, March 1996). Ministerio de Hacienda. La Paz, Bolivia. 70 pp.

SNAG (Secretaría Nacional de Agricultura y Ganadería). 1993. *Estrategia de Desarrollo Agropecuario 1994/2003. Un Camino Contra la Pobreza*. Internal document. SNAG, La Paz, Bolivia. 159 pp.

SR-CRSP (Small Ruminant Collaborative Research Support Program). 1994. Republic of Bolivia. In: Johnson S. (ed), *SR-CRSP Annual Report 1994*. Management Entity, SR-CRSP, University of California, Davis, California, USA. pp. 1-70.

Le Tacon P., Vacher J., Eldin M. y Imaña E. 1992. Los riesgos de helada en el Altiplano Boliviano. En: Morales D. and Vacher J. (eds), *Actas del VII Congreso International Sobre Cultivos Andinos*. IBTA/ORSTOM/CIID (Instituto Boliviano de Tecnología Agropecuria/ Institut Français de Recherche Scientifique Pour le Développement en Coopération/Centro Internacional de Investigación para el Desarrollo), La Paz, Bolivia. pp. 287-291.

Tichit M. 1991. *Los Camélidos de Bolivia*. FADES (Fundación para Alternativas de Desarrollo) and Editorial EDOBOL, La Paz, Bolivia. 154 pp.

Tichit M. 1995. Diversidad de la actividad ganadera en las unidades de producción de Turco marka. En: Genin D., Picht H., Lizarazú R. y Rodriguez T. (eds), *Waira pampa. Un Sistema Pastoril Camélidos - Ovinos del Altiplano rido Boliviano*. ORSTOM/CONPAC/IBTA (Institut Français de Recherche Scientifique Pour le Développement en Coopération/Programa de Autodesarrollo Campesino fase de Consolidación/ Instituto Boliviano de Tecnología Agropecuria), La Paz, Bolivia. pp. 73-89.

Tosi J., Unzueta O., Holdridge L. y Gonzales A. 1975. *Mapa Ecológico de Bolivia*. MACA (Ministerio de Asuntos Campesinos y Agropecuarios), La Paz, Bolivia. 308 pp.

UDAPSO/INE/UPP/UDAPE (Unidad de Análisis de Políticas Sociales/Instituto Nacional de Estadísticas/Unidad de Políticas de Población/ Unidad de Análisis de Políticas Económicas). 1993. *Mapa de Pobreza. Una Guía Para la Acción Social*. UDAPSO/INE/UPP/UDAPE, La Paz, Bolivia. 389 pp.

Urioste M. 1992. *Fortalecer las Comunidades*. AIPE/PROCOM/TIERRA (Asociación de Instituciones de Promoción y Educación/ Programa de Contención Migratoria/Taller de Iniciativas Rurales y Reforma Agraria), La Paz, Bolivia. 264 pp.

Vacher J., Brasier de Thuy E. and Libermann M. 1992. Influence of the lake on littoral agriculture. In: Dejoux C. and Iltis A. (eds), *Lake Titicaca. A Synthesis of Limnological Knowledge*. Kluwer Academic Publishers, Dordrecht, Holland. pp. 511-522.

Valencia S. y Jetté C. 1995. *Estrategias de Reproducción Familiar y Tenencia de Recursos, en una Comunidad del Altiplano Occidental*. IBTA/ SR-CRSP (Instituto Boliviano de Tecnología Agropecuria/Small-Ruminant Collaborative Research Support Program) IBTA 172/Boletín Tecnico 40/SR-CRSP 38, La Paz, Bolivia, 40 pp.

Van Niekerk N. 1992. *La Cooperación Internacional y la Persistencia de la Pobreza en los Andes Bolivianos*. UNITAS/MCTH (Unión Nacional de Instituciones para el Trabajo Social/ Misión de Cooperación Técnica Holandesa), La Paz, Bolivia. 178 pp.

van Kessel J. 1992. Tecnología *Aymar*a: un enfoque cultural. En: Van Denberg H. and Schiffers N. (eds), *La Cosmovision* Aymara. HISBOL/UCB (Instituto de Historia Social Boliviana/Universidad Católica Boliviana), La Paz, Bolivia. pp. 187-219.

Walker R. 1984. *Vicuñas and Pastoralists on the Peruvian Altiplano*. Unpublished report. Range Honors Program, Department of Range Science. Utah State University, Logan, Utah, USA. 125 pp.

Zeballos H. 1993. *Agricultura y Desarrollo Económico II*. CID (Centro de Información para el Desarrollo), La Paz, Bolivia. 302 pp.

Chapter 3

Ecology and natural resources of San José Llanga

Ecología y recursos naturales de San José Llanga

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Summary

In this chapter we report on a broad inventory of natural resources and natural resource dynamics at San José Llanga (SJL). This includes analyses of climate, surficial geology, hydrology, soils and vegetation. Such studies are important because they help us identify key resources that support agropastoral production and the likely sustainability of those resources. In cases where resource use is considered unsustainable, links can be made as to whether activity of humans and livestock, or background effects of climate and geology, are primarily responsible for degradation. Natural resource studies provide a mechanistic basis for understanding risk management behaviour of campesinos and options for increased system productivity.

Secondary information was used in preliminary analyses of climate, based on 43 years of data collected at nearby Patacamaya Experiment Station. Empirical data were used in all other trials and studies, and this information was largely collected in the context of student research projects. Methods included use of transect surveys, soil pits, satellite imagery, preparation of maps using geographical information systems (GIS), chemical analyses of soil, water and forage samples, space-for-time assessments of the successional dynamics of plant communities, and clipping studies to assess seasonal patterns of net primary productivity.

The environment at SJL resembles that of a cold-desert shrubland. The average annual precipitation is 402 mm, with <5% occurring as snow or hail. Considered throughout the year, evapotranspiration is 3.5-times precipitation. The coefficient of variation (CV) for annual precipitation is 23%. The probability that a given year will be markedly drier than average (i.e., with precipitation <75% of the long-term mean) is 0.17. Annual precipitation may have a cyclic character of alternating wetter and drier periods of 11 to 13 years in duration; this was revealed from analysis of seven-year running means. Although there is no long-term statistical trend in annual precipitation, the campesinos perceive that the climate is becoming drier. Seasonality at SJL tends to be defined more by precipitation than temperature, but temperature flux is nonetheless important. Delivery of precipitation is unimodal, with 78% occuring during a five-month period from November to March. This also tends to be the warmest period of the year. This five-month period is when the growing season for crops and native range largely occurs. Crop cultivation is risky, however, due to the variation in rainfall and the occurrence of frost. The cold, dry winter of June through September is a time of ubiquitous moisture stress and prevalence of frost. Native perennial herbaceous plants tend to become dormant at this time. Net primary production and crude protein content of common herbaceous forage begin to drop by June, but this varies by species and site. June and July are the most variable months in terms of precipitation.

The topography of SJL is relatively level, with an overall elevational range of only 61 m (i.e., from 3725 to 3786 m) across 7200 ha. This absence of relief is representative of a large portion of the central Altiplano distant from the footslopes of the Cordilleras. This very modest relief at SJL is still sufficient, however, to underpin several complementary options for resource use by the campesinos. There is a high patch diversity in terms of distinct geomorphic units that vary in edaphic and hydrologic features and degree of salinisation. There are six geomorphic units at SJL, with four important to the agropastoral system. Three of the four important units have been extensively modified by human activity. In general, crop cultivation occurs more on units having non-saline water and soils, while grazing occurs more on units having saline water and soils. The four important units are described below.

An alluvial terrace is located to the west and comprises 25% (or 1800 ha) of SJL. It is elevated by 20 m relative to the rest of SJL. It is a natural formation with gently undulating topography. It is

comprised of non-saline Luvisols and Lixisols. The soil texture and physical position of the terrace is associated with enhanced drainage characteristics (i.e., non-saline ground water is inaccessible to most plants and is located 3 to 10 m below the soil surface). The slight elevation also lends to higher minimum temperatures which mitigate frost risk. The alluvial terrace is the epicenter of rain-fed production of food and forage crops (i.e., potato, *quinoa*, barley) with over 2500 cropping plots in a complex matrix of cultivated (20%) and fallowed (80%) fields. Fallowing may be up to 15 years in duration. Fallowing and the cropping sequence are probably important to help control nematode populations and promote recycling of soil nutrients under the cold, dry ambient conditions. Fallow consists of a couple successional stages. About 25% of fallow fields are in an early successional stage called *kallpas*, which are important for grazing. *Kallpas* have typically been fallowed <4 years and cover varies from near barren, sandy substrates to domination by annual herbs and young, evergreen shrubs such as *thola* (*Parastrephia lepidophylla*). A late successional stage is referred to as *tholares* and is dominated by associations of large *thola* and bunch grasses such as *Festuca orthophylla*. *Tholares* are used for grazing, but also for harvesting fuel wood from mature *thola*. The *kallpas* initially appeared to be subject to significant wind erosion, but our studies revealed that topsoil is redistributed among *kallpas* and adjacent *tholares* plots. This fortuitous situation may be related to plot size and intermixing of *kallpas* and *tholares* that creates a suitable matrix for recapture of wind-blown soil. The campesinos commonly report perceptions that crop production on the alluvial terrace is declining, but we have no hard evidence to support this contention. If crop production is indeed declining we speculate that several factors could be contributors. The best hypothesis is a lower annual rainfall associated with a dry phase in the postulated rainfall cycle. Other hypotheses include altered cultivation practices such as substitution of chemical fertilisers for manure or expanded use of tractor tillage. Substitution of chemical fertilisers for manure may save labour, but with a cost of declining soil organic matter. Tractor tillage could be contributing to soil erosion by disturbing the *kallpas/tholares* matrix.

The second unit is an alluvial fan, which is centrally located near the main settlement of SJL and comprises 15% (or 1080 ha) of the study area. This low-lying unit was created when campesinos re-directed the channel of the *Khora Jahuíra* River some 15 years ago, and is in a slow process of expansion. This highly productive unit is comprised of non-saline, medium-textured Fluvisols. Non-saline ground water occurs at a depth of 2 to 3 m below the soil surface, accessible to roots of alfalfa (*Medicago sativa*), an important perennial forage crop. The alluvial fan receives annual additions of fresh water and sediment from periodic flooding of this ephemeral, rain-fed river. Depositional processes give the fan a slight convex shape. By virtue of its use in cultivated forage production (alfalfa and barley) under flood irrigation, the alluvial fan is the critical backbone of local smallholder dairying and the production of improved sheep breeds. One risk, however, is the danger posed for crop damage due to the occasional large flood and late-season frosts.

The third unit is the deltaic deposits, located to the east, which comprises 10% (or 720 ha) of SJL. This low-lying unit is made up of slightly saline Solonchak soils. The water table occurs at 1.6 to 2.4 m below the soil surface, but the water has a moderate level of salinity and is therefore marginal for crop sub-irrigation. This unit has also been modified by humans over the past decade in that irrigation water is supplied via a 23-km canal from the saline Desaguadero River, which originates from Lake Titicaca. Alfalfa, barley, *quinoa* and potatoes are grown here under a variety of flood-irrigated and rain-fed conditions. The deltaic deposits have allowed some aspects of livestock production to expand. This contribution appears unsustainable, however, in that irrigation water from the Desaguadero River may eventually salinise crop fields and limit cultivation.

Finally, the fourth and largest unit is the fluvio-lacustrine plain, which comprises 38% of SJL (or 2736 ha) and occupies most of the remaining landscape. It is about 12 km in length along its east to west axis. Formerly a lake bed, this unit incorporates the lowest elevations in the study area. It is typically used for grazing. Compared to the other units it has been relatively free of overt modification by people, although evidence of low earthen ridges (possibly used years ago for water spreading or delineation of grazing areas) are evident in some locales. Vegetation is dominated by perennial grasses or halophytic "cushion plants," depending on location. Seasonal productivity of herbaceous communities may be more constrained by frost occurrence or salinity rather than lack of soil moisture, especially in instances where plant roots have easy access to ground water. Soils vary from hyper-saline Solonchaks (about 1061 ha or 39% of the fluvio-lacustrine plain) and moderately saline Solonchaks (1079 ha or 39%) to slightly saline Solonchaks (386 ha or 14%) and non-saline, fine-textured Fluvisols (210 ha or 8%). The fluvio-lacustrine plain is subtended by a very high water table from 0.6 to 1.5 m beneath the soil surface. Water is found in a honeycomb of often discrete and relatively small cells and varies greatly in salt content. Proliferation of hand-dug wells may ultimately help homogenise ground water. Landscape position, soil type, and to a lesser extent grazing pressure, appear to influence plant community composition on the fluvio-lacustrine plain. A grazing gradient occurs by virtue of settlements (and hence livestock corrals) being located at the western end of the fluvio-lacustrine plain. Barren zones occur in the centre. Barren zones may be saline, but it has been hypothesised that the widespread denudation is probably most related to effects of seasonal flooding. The hyper-saline Solonchaks (termed *eriales* with afloramiento salino) often appear barren except for communities of small, halophytic cushion plants of very marginal forage value (referred to as *q'auchiales* and *q'otales* in the local vernacular). Dominant species of cushion plants include *Salicornia pulvinat*a (an obligatory halophyte) and *Anthobrium triandru*m. The moderately saline Solonchaks are dominated by 280 ha of barren land (*eriales*), 450 ha of communities dominated by a tall-statured, valuable forage named *Hordeum muticum* (*yawarales*), and 350 ha of communities dominated by prostrate, low-growing forages such as *Distichlis* and *Muhlenbergia* spp. with some *H. muticum* (collectively termed *gramadales*). The *gramadales* tend to have forages of moderate feeding value and lower productivity (3.8 t DM/ha) which are commonly grazed to a high intensity; this is often due to proximity of *gramadales* to sacrifice zones of heavy livestock use near corrals. *Distichlis* tends to naturally dominate *gramadales* if salinity is higher. If salinity is lower we speculate that grazing can shift community composition from a dominance by *Hordeum* sp. to dominance by *Distichlis* and *Muhlenbergia* spp. The latter case occurs in only a small portion of the fluvio-lacustrine plain, and our view is that when *Distichlis* dominates moderately saline *gramadales*, this represents a stable, but degraded, rangeland state in relation to animal production. This is one of the few notable instances where we suspect grazing to have altered plant community composition at SJL in recent times. Non-saline soils are relatively rare on the fluvio-lacustrine plain, but the plant communities on non-saline soils tend to be more productive than those on saline soils. Fine-textured fluvisols (300 ha) support communities dominated by tall-statured *Festuca dolichopylla* (termed *chilliwares*, with a productivity of 7.6 t DM/ha) and *Calamagrostis curvula* (*p'horkeales* with a productivity of 7.9 t DM/ha); the latter sites under heavy grazing appear to have increased representation of *C. curvula* relative to *H. muticum* and others. Finally, there was evidence from studies of plant population distributions and salinity of soil and water that the hyper-saline zone has increased relative to the moderately saline zone on the fluvio-lacustrine plain in recent times. Young cohorts of *S. pulvinata* have spread into moribund stands of other species less tolerant of high salinity, this population shift appears to be correlated with sharp changes in salinity of top soil and ground water. While the extent of expansion of the hyper-saline zone may be pervasive, it could not be quantified due to the heterogenous patchiness of the central fluvio-lacustrine plain. Several hypotheses could explain migrating ecotones, but our results are interpreted to suggest that increasing salinity of patches is related to erosion of the uppermost layer of sandy/loam soil. This exposes a subtending layer of highly saline clay and silt, probably deposited when the site was repeatedly inundated as an endoreic lake. The exposed saline layer then presents a more hospitable environment for species such as *S. pulvinata.*

In conclusion, SJL exhibits signs of environmental degradation, but attention to geomorphic units and associated land use is critical in understanding degradative processes. The character of SJL is fundamentally defined by its landscape position and role as a recipient for water, soil and salt at a macro-scale.

Although the fluvio-lacustrine plains appear denuded to the casual observer as a result of contemporary over-grazing, <20% are degraded in this manner. This equates to <8% of the cantón overall. These *gramadales* and *p'horkeales* sites in sacrifice zones near settlements show altered species composition and conform to equilibrial theory for plant/herbivore interactions. In contrast, however, the vast majority of acreage on the fluvio-lacustrine plains has been denuded by flooding and salinisation. This situation conforms to non-equilibrial theory where abiotic factors overwhelm management. A mix of controls, even within geomorphic units, is thus evident. This limits generalisations regarding system-level designations of equilibrial or non-equilibrial behaviour.

Contemporary threats to sustainable resource use may occur more in the farming dimension of this system rather than the grazing dimension. The best example of human-induced degradation is the recent irrigation of the deltaic deposits with saline water. Mis-management of topsoils on the alluvial terrace remains to be verified. The people have positively affected their farming environment, however, by creating the alluvial fan.

Resumen

En este capítulo se presenta un inventario general de los recursos naturales y de su dinámica para San José Llanga. Se incluye análisis del clima, geomorfología, hidrología, suelos y vegetación. Estos estudios son importantes por que ayudan a identificar recursos claves que apoyan la producción de los sistemas agropastoriles y elaborar sobre su sostenibilidad. En casos donde el uso de los recursos se considera insostenible, referencias pueden hacerse sobre si la actividad humana y del ganado ó si los efectos subyacentes del clima y la geología son los responsables primarios de la degradación. Los estudios de los recursos naturales proporcionan los mecanismos básicos para comprender las estrategias de manejo del riesgo por los campesinos y de las opciones para incrementar la producción del sistema.

Para el análisis del clima se usó información secundaria, el análisis se basó en 43 años de datos colectados en la cercana Estación Experimental de Patacamaya. En todos los otros ensayos y estudios se usaron datos empíricos, los que fueron mayormente tomados en el contexto de proyectos de investigación de estudiantes. Los métodos incluyen: el uso de transectos de estudios, excavaciones para la descripción de perfiles de suelo, imágenes de satélite, preparación de mapas usando Sistemas Geográficos de Información (SGI), análisis químico de muestras de suelo, agua y forraje, sustitución de tiempo por espacio para determinaciones de la dinámica de la sucesión vegetal de las comunidades vegetales, y estudios de corte de fitomasa para determinar los patrones estaciónales de la productividad neta primaria.

El medioambiente de SJL recuerda el de los arbustales de desiertos fríos. La precipitación anual en SJL es de 402 mm, con <5% en forma de nieve o granizo. Considerando el periodo de un año, la evapotranspiración es 3.5 veces mayor que la precipitación. El coeficiente de variación (CV) para la precipitación anual es de 22%. La probabilidad de que un determinado año podrá ser marcadamente más seco que el promedio (p.e. con una precipitación <75% de la media) es 0.17. La precipitación anual podría tener un comportamiento cíclico con periodos alternados secos y húmedos desde 11 hasta 13 años de duración; como se evidencia del análisis de 7 años de desviaciones acumulativas anuales. Influencias de las oscilaciones de “El Niño” (ENSO) podrían tener un rol determinando los patrones cíclicos de precipitación. Aunque no se detectaron tendencias estadísticamente significativas para la precipitación anual en el largo plazo, la percepción de los campesinos es que el clima está volviéndose más seco. En SJL, las estaciones tienden a ser definidas más por la precipitación que por las variaciones de la temperatura, pero los cambios de temperatura no dejan de ser importantes. La forma de la precipitación es unimodal, con 78% de ocurrencia en un periodo de cinco meses entre Noviembre y Marzo. Este periodo tiende a ser también el periodo del año con temperaturas más elevadas. Este periodo de cinco meses es la época en el que mayormente ocurre el crecimiento de las plantas tanto cultivadas como las de los campos naturales de pastoreo. Sin embargo, la agricultura es riesgosa, debido a la variación en la precipitación pluvial y la ocurrencia de heladas. El frío y seco invierno desde Junio hasta Septiembre es un período donde el déficit de humedad y prevalecía de helada es infaltable. Las plantas herbáceas nativas tienden a entrar en dormáncia durante este período; la producción primaria y el contenido de proteína cruda de las plantas forrajeras herbáceas comunes empiezan a disminuir en Junio, aunque estos cambios pueden variar por especie y sitio. Junio y Julio son los meses más variables en términos de precipitación.

La topografía de SJL es relativamente plana, con un rango altitudinal general de solo 61 m (p.e., desde 3.725 hasta 3.786 m) a través de 7.200 ha. Esta ausencia de relieve es representativa de una amplia región del Altiplano central, alejada de los piedemontes de las Cordilleras. Este muy modesto relieve en SJL, sin embargo, es todavía suficiente para que los campesinos desarrollen varias opciones complementarias de uso de los recursos. Se presenta una alta diversidad espacial manifestada en las distintas unidades geomorfológicas que varían en términos de sus características edáficas, hidrológicas y grado de salinización. En SJL se identifican seis unidades

geomorfológicas, siendo cuatro las más importantes para el sistema agropastoril. Tres de estas cuatro unidades han sido ampliamente modificadas por la actividad humana. En general, los cultivos son más comunes en las unidades que disponen de agua y suelos no salinos, mientras que el pastoreo, es más común en las unidades que tienen agua y suelo salinos. Las cuatro unidades importantes se describen a continuación.

La *terraza aluvial* está localizada al oeste de la comunidad y abarca un 25% (ó 1.800 ha) de SJL, se encuentra 20 metros más alta con relación a las otras unidades de SJL. La terraza aluvial es una formación natural de topografía ondulante. Está formada por Luvisoles y Lixisoles no salinos. La textura del suelo y la ubicación física de esta terraza está asociada con características de buen drenaje (p.e., el agua subterránea no salina se encuentra entre 3 a 10 metros de profundidad y es inaccesible para la mayoría de las plantas). La escasa elevación también tiende a una mayor temperatura mínima, lo que mitiga el riesgo de helada. La terraza aluvial es el epicentro de la producción agrícola y de forrajes a secano (p.e. papa, *quinua* y cebada) en cerca de 2.500 parcelas de cultivo distribuidas en una compleja matriz que incluye parcelas actualmente con cultivos (20%) y en descanso (80%). El descanso puede ser hasta de 15 años, debido en parte al clima severo, y presenta un par de estados sucesionales. Cerca del 25% están en estados iniciales de sucesión y se las denomina localmente *kallpas*, estas *kallpas* típicamente están en descanso por <4 años y la cobertura vegetal varia de casi totalmente descubierta con exposición del substrato arenoso hasta dominio de hierbas anuales y arbustos jóvenes siempre verdes tal como la *thola (Parastrephia lepidophylla)*. Las *kallpas* son importantes para pastoreo. Los estados sucesionales tardíos, referidos a nosotros como *tholares* y que están dominados por asociaciones de *tholas* grandes y pastos tufosos, mayormente de *iru ichu (Festuca orthophylla)* son usados para pastoreo, pero también para extracción de leña de las plantas adultas de *thola*. Las *kallpas* al inicio del periodo de descanso, durante la época seca, aparentan estar bajo fuerte erosión por el viento, pero nuestros estudios indican que el suelo superficial estaría siendo redistribuido entre las *kallpas* y los *tholares* adyacentes. Esta situación fortuita puede estar relacionada con el tamaño de la parcela y la mezcla de *kallpas* y *tholares* que crean una matriz apropiada para la captura del suelo transportado por el viento. La percepción general entre los campesinos es que la producción de las parcelas de cultivo en la terraza aluvial está decreciendo; pero nosotros no tenemos suficiente evidencia para confirmar esta controversia. Si la producción de cultivos estuviese evidentemente disminuyendo, especulamos que varios factores podrían estar contribuyendo para que ésto ocurra. La mejor hipótesis es la disminución de la precipitación anual asociada a la fase seca del postulado ciclo de la precipitación. Otras hipótesis incluyen alteraciones en las practicas de cultivo tales como la sustitución del uso del estiércol por fertilizante químico o el incremento del uso del tractor. La substitución de estiércol por fertilizante químico puede ahorrar trabajo, pero al costo de perdida de materia orgánica del suelo. La preparación de suelos con tractor podría contribuir para la erosión del suelo debido a la alteración de la matriz *kallpas/tholares.*

La segunda unidad es el *abanico aluvial*, el que se localiza en el centro cerca de las viviendas y comprende el 15% (ó 1.080 ha) del área de estudio. Esta unidad está ubicada en la zona baja de la comunidad y fue formada cuando los campesinos cambiaron la dirección del cause del río *Khora Jahuíra* hace más o menos 15 años. Esta unidad está en un proceso lento de expansión. Esta unidad altamente productiva está conformada por suelos Fluvisoles no salinos de textura media. La napa freática se encuentra entre 2 y 3 m debajo de la superficie del suelo y es accesible para las raíces de la alfalfa (*Medicago sativa)* que se ha convertido en un importante cultivo forrajero perenne en la zona. El abanico aluvial recibe contribuciones anuales de agua fresca y sedimentos por inundaciones periódicas de este río con caudal efímero alimentado por el agua de lluvia. El proceso de deposición de sedimentos da a la llanura una forma ligeramente convexa. Debido a su uso para producción de forraje (alfalfa y cebada) con riego por inundación, la llanura aluvial constituye un componente crítico para los pequeños productores de leche y para la producción de ovejas mejoradas. Un riesgo en esta unidad, sin embargo, es el peligro que existe de daño para los cultivos debido a inundaciones severas y heladas tardías.

La tercera unidad es la de los *depósitos délticos* y está localizada al este del territorio de la comunidad. Esta unidad abarca un 10% (ó 720 ha) de SJL. Esta unidad se encuentra en la parte baja y los suelos son Solonchak ligeramente salinos. La napa freática se encuentra entre 1.6 y

2.4 m debajo de la superficie del suelo, pero el agua tiene un moderado nivel de salinidad y es por lo tanto marginal para el riego de cultivos. Esta unidad a sido también modificada por intervención humana en la última década por la construcción de un canal de riego de 23 km de largo para transportar agua salina desde el Río Desaguadero, este río se origina en el Lago Titicaca. Bajo una variedad de condiciones de riego por inundación o a secano se cultiva alfalfa, *quinua* y cebada. Los *depósitos délticos* han permitido la expansión de algunos aspectos de la producción animal. Esta contribución parece inestable, sin embargo, debido a que el riego con agua del Río Desaguadero puede eventualmente salinizar las parcelas agrícolas y limitar su cultivo.

Finalmente, la cuarta y más extensa unidad es la llanura fluvio-lacustre, la que abarca el 38% (ó 2.736 ha) y ocupa la mayor parte del área remanente de SJL. De este a oeste tiene un largo de 12 km. Originalmente un lecho de lago, esta unidad incluye las cotas más bajas del área de estudio. Es típicamente usada para pastoreo. Comparada con las otras unidades, la llanura fluvio-lacustre ha estado relativamente libre de modificaciones antrópicas, aunque, evidencias de antiguas barreras de tierra (posiblemente usadas para distribución de agua y/o delimitación de áreas de pastoreo todavía existen en algunos lugares) están presentes en algunos lugares. La vegetación dependiendo del sitio que se trate es dominada por pastos perennes ó plantas halófilas en cojín. La producción estacional de las comunidades de herbáceas podría estar limitada mas por las heladas o salinidad que por la falta de humedad en el suelo, especialmente en situaciones donde las raíces de las plantas tienen fácil acceso al agua subterránea. Los suelos varían desde Solonchaks hiper-salinos (1.079 ha ó 39 %) hasta Solonchaks moderadamente salinos (386 ha ó 14%) y Fluvisoles no salinos de textura fina (210 ha ó 8%). La llanura fluvio-lacustre esta condicionada por una napa freática muy superficial (p.e., desde 0.6 hasta 1.5 m). El agua subsuperficial no es continua y se presenta en forma de una red de depósitos que recuerdan un panel de abejas, relativamente pequeños y que varían en contenido de sales. La proliferación de la construcción manual de pozos podría ultimadamente favorecer la homogeneización del agua subterránea. La ubicación en el paisaje, el tipo de suelo y en menor medida la presión de pastoreo parece que influyen la composición botánica de la comunidad de plantas de la llanura fluvio-lacustre. En esta unidad se presenta una gradiente de pastoreo, atribuida a los patrones de uso del suelo (y por lo tanto incluye corrales de ganado), localizados en el extremo oeste de la planicie. Areas sin vegetación se presentan en la parte central de la planicie. Las áreas descubiertas de vegetación pueden ser salinas, pero nuestra hipótesis fue que la presencia abundante de áreas descubiertas está probablemente mas relacionadas a efectos de inundaciones estaciónales. Los suelos Solonchak hiper-salinos (llamados *eriales* ó afloramiento salino) parecen frecuentemente descubiertos excepto por comunidades de pequeñas plantas de halófilas acojinadas de valor forrajero marginal (referidos a nosotros como *q'auchales y q'otales* en el idioma vernácular); especies dominantes de plantas en cojín incluyen *Salicornia pulvinanata* (una halófila obligada) y *Anthobrium triandrum*. Los Solonchacks moderadamente salinos están dominados por 280 ha de suelos descubiertos de vegetación (eriales), otras 450 ha de comunidades vegetales están dominadas por el valioso pasto de mediano tamaño llamado *Hordeum muticum* (*yawarales*), y 350 ha de comunidades están dominadas por pastos cespitosos de corto crecimiento tales como *Distichilis* y *Muhlenbergia* spp. con alguna presencia de *H. muticum* (colectivamente llamados *gramadales*). Los gramadales tienden a tener forrajes de moderado valor alimenticio y de baja productividad (3.8 t/MS/ha) los cuales son generalmente pastoreados con altos niveles de intensidad; esta alta intensidad de pastoreo esta frecuentemente relacionada a la proximidad de los *gramadales* a las zonas de sacrificio bajo uso intensivo del ganado, cerca de los corrales. El *Distichilis* sp. tiende naturalmente a dominar en los gramadales si la salinidad es alta. Si la salinidad es baja nosotros creemos que el pastoreo puede cambiar la composición de la comunidad vegetal de dominada por *Hordeum muticum* a dominada por *Distichilis* y *Muhlenbergia* spp. El último caso se presenta sólo en una pequeña parte de la planicie fluvio-lacustre, y nuestra interpretación es que cuando *Distichilis* domina en gramadales moderadamente salinos, representa un estable, pero degradado estado del campo natural de pastoreo, con relación a la producción animal. Esta es una de las pocos instancias notables donde pensamos que el pastoreo habría alterado la composición de la comunidad de plantas en SJL en tiempos recientes. Suelos no-salinos son relativamente raros en la planicie fluvio-lacustre, pero las comunidades de plantas en suelos no-salinos tienden a ser más productivas que las de en suelos salinos. Los Fluvisoles de textura fina (300 ha) presentan comunidades dominadas por pastos altos de *Festuca dolichophylla* (llamados *chilliwares*, con una productividad de 7.6 t/MS/ha) y *Calamagrostis curvula* (*p'orkeales*, con una productividad de 7.9 t/MS/ha); en estos últimos sitios parecería que bajo pastoreo pesado *C. curvula* incremento su representación con relación a *H. muticum* y otras plantas. Finalmente, sobre la base de estudios de distribución de plantas con relación a la salinidad de suelos y de aguas se encontró evidencia de que la zona hiper-salina recientemente se incrementó con relación a la zona con salinidad moderada en la planicie fluvio-lacustre; ésto se evidencia por el incremento de cohortes de plantas jóvenes de *S. pulvinanata* en medio de grupos de plantas moribundas de otras especies menos tolerantes a altos niveles de salinidad y ésto está correlacionado con cambios bruscos de la salinidad del suelo y del agua superficial. A pesar de que se cree que el grado de expansión de la zona hiper-salina pueda ser constante, ésto no pudo ser cuantificado debido a la extrema heterogeneidad de las manchas en la planicie fluvio-lacustre central. Varias hipótesis podrían explicar la migración de ecotonos, pero nuestros resultados son interpretados para sugerir que el incremento de la salinidad de las manchas estaría relacionada a la erosión de la capa de suelo superficial areno/francoso. Esto expone una capa inmediatamente inferior de arcilla y limo altamente salina, probablemente resultado de depósitos cuando el sitio fue repetidamente inundado debido a su condición de lago endorreico. La capa salina expuesta presenta, un medio ambiente más favorable para especies tales como *S. pulvinata*.

En conclusión, SJL exhibe signos de degradación ambiental, pero es crítico prestar atención a las unidades geomorfológicas y al asociado uso de la tierra para comprender estos procesos de degradación. El carácter de SJL esta fundamentalmente definido por su posición en el paisaje y su rol como receptor de agua, suelo y sales a una escala macro.

Aunque, la llanura fluvio-lacustre aparenta estar descubierta de vegetación al observador casual, como resultado del sobre-pastoreo contemporáneo, sólo <20% está degradada de esta manera. Esto equivale a <8% de todo el cantón. Los *gramadales* y *p'horkeales* en las zonas de sacrificio cerca de las viviendas muestran una composición de especies alterada y se ajustan a la teoría de equilibrio para las interacciones planta/ herbívoro. Al contrario, sin embargo, la mayor parte de la llanura fluvio-lacustre la vegetación ha sido eliminada por inundación y salinización. Esta situación sigue la teoría de desequilibrio donde los factores abióticos se sobreponen a los de manejo. Una mezcla de controles, por lo tanto, es evidente, incluso dentro de las unidades geomorfológicas. Esto limita generalizaciones en relación con especificaciones de sí el nivel del sistema tiene un comportamiento en equilibrio o en desequilibrio.

Peligros contemporáneos al uso sostenible de los recursos pueden ocurrir más en la dimensión agrícola de este sistema que en la dimensión de ganadería. El mejor ejemplo de degradación inducida por humanos es la reciente irrigación de los depósitos délticos con agua salada. El manejo inapropiado del suelo superficial en la terraza aluvial permanece aun sin verificar. La gente, sin embargo, ha afectado positivamente su medioambiente agrícola a través de la formación del abanico aluvial.

3.1 Introduction

Development and change in traditional societies is strongly affected by interactions between humans and their natural environments. Management practices used by most low-input, rural societies represent an amalgamation of technologies, social rules and organisational structures that have been tested over time and found suitable for sustainable exploitation of resources. In many cases, however, changes in population, social values, market opportunities, government policies or technology alter a delicate balance between humans and sustainable resource use. Given these critical relationships, a thorough knowledge of the biophysical environment is essential to comprehend and attempt to improve low-input production systems such as SJL.

Our overall purpose in this chapter is to characterise the environment and natural resources of the Cantón of SJL. This is accomplished in two steps. First the climate, surficial geology, hydrology, soils and vegetation are described. Descriptions include brief accounts of land use (i.e., cultivation, grazing, fuel wood collection, etc.) for broadly defined geomorphic units. Second, an analysis is presented concerning selected aspects of ecosystem dynamics at various spatial and temporal scales.

All of the analyses listed above set the framework for us to begin to address some of the broad ecological questions posed in the original SR-CRSP proposal, namely: What is the status of the semi-arid environment that supports a representative agropastoral system on the central Altiplano? Is degradation evident and, if so, which landscape components are most vulnerable and why? What is the role of people and livestock in environmental degradation? Are natural processes (i.e., drought or salinisation) more important than humans and livestock in determining environmental trends? The reader should consult Chapter 1 (*Project objectives and research approach*) for a review of these and related questions.

Before delving into the details of natural resources, it is first important to note the degree to which the Cantón of SJL is an open or closed system. This helps define the boundaries of the system in an ecological sense. The answer, however, depends on which resource is considered. For example, SJL is largely a closed system with respect to grazing resources. The 5600 head of livestock that reside in SJL (see Chapter 5: *The grazing livestock of San José Llanga*) are confined within the borders of the cantón, even during severe drought. During drought the stocking rate at SJL is reduced through animal sales rather than through increased dispersal of animals that has been observed elsewhere when societies are poorly served by markets (see Chapter 6: *Household socioeconomic diversity and coping response to a drought year at San José Llanga*). Reciprocal rights of regional grazing access such as those common among neighbouring pastoralists in Africa (Solomon Bekure et al 1991; Coppock 1994) are therefore absent here at the level of the cantón. In terms of access to river water, SJL is an open system because some of the rivers affecting resources within the cantón originate elsewhere and are subject to other demands upstream (see Section 2.3.1: *Regional highlights of physical geography and environment*). For cultivation, a number of key inputs such as chemical fertilisers and mechanised power for tillage come from outside the SJL system. Livestock manure has traditionally been a key component of the agropastoral system due to its use as a crop fertiliser. Manure, however, has been commonly exported out of SJL in recent years and thus increasingly serves as a cash crop (see Chapter 4: *Household economy and community dynamics at San José Llanga*).

3.2 Methods

3.2.1 Climate and description of natural resources

Material in this chapter primarily draws upon thesis work completed by eight Bolivian undergraduates and one American master's student (see Section 3.5: *Literature cited* and Chapter 1: *Project objectives and research approach*). Thesis work was targeted to address specific topics which would contribute to an overall understanding of the structure and function of the SJL agropastoral system. Such studies were variously conceived, designed and supervised by resident scientists of the SR-CRSP with ancillary guidance and participation by Bolivian co-investigators and U.S.-based principal investigators. General methods for major studies concerning climate and descriptions of natural resources and their dynamics are given below.

Researchers of the SR-CRSP relied mostly on secondary data to describe climate at SJL. This included attributes such as frost risk, evapotranspiration (ETp) and air temperature (i.e., daily maxima and minima). Secondary climate data were collected at the nearby Patacamaya Experiment Station with standard descriptive statistics prepared by INTECSA (1993) and SENAMHI (1994). The community of SJL does not have a climate station. The Patacamaya Experiment Station is located 17 km north of the main barrio of SJL at an elevation of 3789 m slightly higher than SJL at 3725-3786 m. Original work was performed by the joint IBTA/SR-CRSP project to evaluate whether precipitation data collected at the Patacamaya Experiment Station were representative for SJL. Peña (1994) examined several decades of corrected rainfall data and concluded they were reliable and representative. Standard statistics for annual and monthly average precipitation (and variability) are presented here for the period 1951-93. A seven-year running mean was used to evaluate possible cyclic behaviour of annual precipitation; this method has been used elsewhere to detect climate patterns (Kolata 1993). Peña (1994) performed other interpolation methods to evaluate precipitation data, including an appraisal of data from Sica Sica, another community located 23 km to the east of SJL at an elevation of 3820 m. Interested readers should consult Peña (1994) for a review of this work.

Miranda (1995) mapped and characterised the landscape and soils throughout SJL according to standard procedures established by USDA (1951). Panchromatic aerial photos (scaled at 1:20 000) were examined in the laboratory with a stereoscope. Broad geomorphic units were delineated for 100% of the study area. Geomorphic units were defined by topographic features and indicate situations where predominant soils share a common genesis. After this preliminary stratification according to geomorphology, transects were walked across geomorphic units and soil samples were collected using a soil auger. These transects covered about 81% of the study area; only a locale north of the *Khora Jahuír*a River was unsurveyed for soil features (Miranda 1995). Variation in soil morphology, topography, drainage and vegetation were noted at sample points along transects. Based on this information soils were then grouped into soil units as defined by the revised legend in FAO/UNESCO/ISRIC (1988). For each soil unit at least three pits were excavated in representative locations. Soil profiles were described and sampled by genetic horizon. Soil samples from at least one profile per unit were analyzed by a commercial laboratory for organic matter, available phosphorus (P), cation exchange capacity (CEC), electrical conductivity (EC) of a 1:5 soil extract, pH, particle-size distribution and exchangeable cations. Soil analysis methods were standard. For example, soil texture was determined using the pipette method. Organic matter was determined using the method of Walkley and Black (1934). Electrical conductivity is a measure of salinity and involved use of a conductivity meter. The conductivity value for the 1:5 extract was corrected using a regression equation relating the electrical conductivity of the saturation extract (ECe) and the EC of the 1:5 suspension. The regression equation was derived from laboratory measurements. A general review of pertinent analytical methods for soils is provided in chapter 2 of Cook and Stubbendieck (1986).

Treadwell and Liebermann (1992) produced a vegetation map of SJL at a scale of 1:20 000. This map was produced using data from recent (1992) aerial photos and field surveys and covered 90% of the study area. The final map identified 27 vegetation associations crudely differentiated in terms of relative cover of dominant species. Most associations had adequate plant cover to allow categorisation, but two were virtually denuded. Treadwell and Liebermann (1992) referred to these denuded sites as either *eriales* (barren and hypersaline) or afloramiento salino (i.e., patches where salts have precipitated on the surface from capillary action of ground water). These two site types together comprised <1% of the area of SJL. The 27 associations identified by Treadwell and Liebermann (1992) were further characterised by Massy (1994) in terms of plant species cover and peak standing biomass. For the purposes of this chapter, however, much of the detail contained in the final 1:20 000 vegetation map of Treadwell and Lieberman (1992) with additional information from Massy (1994) was deemed unnecessary. The 27 associations were first consolidated into six aggregates. Another five types were added to account for cultivated crops and rain-fed fallow, giving a final total of 11. This simpler schema is more in line with land-classification schemes used by the local campesinos (Dr. J. de Queiroz, IBTA/SR-CRSP, personal observation). Other detailed information on seasonal land use for grazing is presented in Chapter 5: *The grazing livestock of San José Llanga*.

Peña (1994) performed an extensive survey of water resources at SJL. He measured depth and elevation of the water table at 137 and 40 points, respectively, and determined water quality at 19 other locations which were systematically selected. Of the 15 chemical parameters measured by Peña (1994), electrical conductivity (ECw) is most pertinent to this chapter because it gives values indicative of the salinity of water. The survey did not include analysis of ground water resources for the far western portion (about 25%) of SJL because the depth to the water table there could not be measured with available equipment. This was largely the geomorphic unit referred to later in this chapter as the alluvial terrace.

3.2.2 Dynamics of natural resources

Our studies of ecosystem dynamics examined phenomena at various spatial and temporal scales. For example, we examined seasonal and annual changes in photosynthetic activity of rangeland vegetation, plant community and population dynamics in fallow fields that occur over a span of 15 years, and spatial shifts of ecotone borders (i.e., boundaries of different associations of range vegetation) that probably occur over decades. Because of funding limitations and the relatively short period of field research, the longer-term ecological dynamics commonly had to be assessed using indirect (non-observational) methods. These methods included, for example, space-for-time substitution [see chapter 3 in Cook and Stubbendieck (1986)] and interviews of campesinos who had managed the land for many years. In some instances studies were strategically focused on tell-tale manifestations of ecosystem change. Conclusions based on such work can be risky, but in our case there was little choice if the main research questions were to be addressed. In addition, work in this chapter occasionally refers to several preliminary studies that were often lacking in statistical rigour, but still yielded potentially important insights. Methods for studies of natural resource dynamics are briefly described below.

The primary objective of work by Washington-Allen (1994) was to describe how the landscape (i.e., plant communities, cover types) of SJL changed according to season and year and to generate hypotheses as to cause(s) of change. One aspect of these studies was to describe annual dynamics of landscape change using four remotely sensed images covering the period 1972-87. Three images were from the Landsat Multispectral Scanner (MSS; 1972, 1986 and 1987) and one was a Thematic Mapper satellite image (TM; 1984). The 15-year period included the year 1983-4, generally regarded as a time of severe drought. In 1983-4 annual precipitation was 43% of the long-term annual mean, while growing season precipitation was 33% of the long-term mean (Painter 1992; this chapter). Another aspect of research was to describe seasonal dynamics of plant cover in a year having a near-average level of precipitation. Six Landsat MSS images were used for the period of August, 1986, to September, 1987, a time when annual precipitation actually tended to be higher than the long-term mean. The response variable in all analyses was the transformed normalised difference vegetation index (TNDVI), an indicator of vegetation biomass and cover that relies on detection of intensity of greenness, which in turn is an indicator of photosynthetic activity. The validity of using TNDVI is reviewed in Washington-Allen (1994, 8-9). A geographical information system (GIS) was used to produce maps of the study area for dominant plant communities and land use (i.e., largely grazing versus cultivation). Values of TNDVI were then tracked for various site types as a means of quantifying and tracking stability and resilience of green vegetation under perturbation due to precipitation dynamics, both on an inter-annual and seasonal basis.

Seasonal changes in standing crop biomass and plant productivity on the rangelands of SJL were the foci of a pilot study by Prieto and Yazman (1995). The seasonal patterns of range forage production are important in evaluating the productive potential of plant communities and stocking strategies. Prieto and Yazman (1995) set up livestock-proof exclosures made of sheep fencing and wooden posts to protect 16-m^2 plots in each of three vegetation associations at SJL. These associations were important for grazing and were variously dominated by perennial *Calamagrostis*, *Festuca* or *Distichlis/Muhlenbergia* spp. Prieto and Yazman (1995) estimated above-ground standing crop for eight months (i.e., January to August) of 1995. This period included the growing season and most of the subsequent dry season. For each exclosure they clipped three, 0.5-m^2 quadrats to ground level each month. Standing biomass was hand-separated and weighed on an oven-dried basis (i.e., 48 h at 65°C). The three quadrat subsamples were randomly selected within each exclosure; previously harvested quadrats were avoided. Estimates of aboveground net primary production (ANPP) in g/m^2/day were obtained by difference on a monthly basis for the growing season. This was done using mean weights across the three subsamples in a given exclosure on a given date in comparison with values from adjacent months. The design used by Prieto and Yazman (1995) lacked replication for associations. The results, however, have utility for this synthesis chapter.

Seasonal change in the nutrient content of forages is important in terms of understanding constraints for range animal production. It has been typically found, for example, that range plants are highest in nutritive value during and shortly after wet periods in rangeland systems. Once plants mature and a system dries out, however, plants can rapidly decline in nutritive value (Van Soest 1994). Characterisation of forage nutritive dynamics was conducted by Lopéz (1994). She collected approximately 180 samples of grass, forb and shrub materials during 1992-3. These materials were hand-plucked in an attempt to mimic bites taken by sheep, cattle and donkeys throughout the Cantón of SJL. Lopéz (1994) conducted a variety of chemical analyses on forages but here we present only her results for crude protein (CP) content, quantified using the micro-kjeldahl method (AOAC 1980). Crude protein is a general measure of plant nitrogen content because it incorporates both protein and non-protein sources of nitrogen. Crude protein, however, is a commonly accepted means to assess forage value (Van Soest 1994). Here CP content was averaged for 14-15 samples per month to provide a graphical presentation of seasonal trends.

Ecological dynamics and successional trends for cultivated lands are important in understanding structure and function of the SJL system. Traditionally, campesinos of the central Altiplano have used extended fallow periods of up to 15 years to allow crop plots to recover fertility and soil structure under constraints of low precipitation and cold temperatures (see Section 2.3.2: *Regional historical highlights*). The extended fallow is also used to reduce density of parasitic nematodes, which cause serious depredation of potato crops in the Andes (Dollfus 1982). As will be shown, cultivated lands comprise up to 50 % of SJL and provide the vast majority of calories for the campesinos each year (see Section 4.3.3: *Household production system*). Cáceres (1994) used a space-for-time method in which she characterised vegetation in 20 cultivated fields fallowed from one to six (or more) years. She collected data on plant density and cover using the PCQ (or Point-Centered-Quarter) method [chapter 3 in Cook and Stubbendieck (1986)]. Her sampling design included four replications for each age class of fallow, but this was ultimately found to be inadequate for statistical analysis. The general findings from the cover data of Cáceres (1994) are referred to here, however, because they provide a broad indication of vegetation change in fallow over time. Surveys of the succession of perennial plant species on fallow fields by Queiroz et al (1994) are also highlighted. The ecology of fallow fields was addressed in the most detail by Barrera (1994), who studied changes in species composition of perennial plants in fields that also had been under fallow for different periods. He based his selection of fields on interviews with land owners. He also scaled his sampling with respect to the changing heterogeneity in each age class of fallow by using a larger plot size (i.e., 40 m^2) for younger fields fallowed <4 years and larger types of plants, and a smaller plot size (i.e., 20 m^2) for all older fields having a less variable plant cover. Six plots were randomly located in every field; numbers of shrubs and large bunch grasses were counted throughout each sample plot. Plots were subsampled to estimate abundance of physically smaller taxa. For medium-sized species half of the plot was used. Three 0.25-m^2 quadrats were systematically placed inside plots to enumerate the smallest plant species (Queiroz et al 1994).

When a visitor comes to the cultivated fields of SJL on a windy day during the dry season, a distinct impression is that much of the sandy topsoil is being lost to wind erosion (Dr. D.L. Coppock, IBTA/SR-CRSP, personal observation). In particular the younger fallow fields in the cropland matrix appear most vulnerable to soil loss because they appear to lack sufficient perennial vegetation to hold soil in place. The campesinos do not seem to have intercrops to serve as windbreaks, or any another obvious form of landscape modification, that minimises effects of wind erosion. If soil losses to wind erosion are significant, it could greatly affect sustainability of the whole agropastoral system. Barrera (1994) therefore also investigated the possibility that fallow fields were subject to high net losses of top soil due to wind erosion. He randomly placed vertical rods in the soil of five fallow fields (ranging from two to six years of age) and measured changes in soil depth around each rod for several consecutive months in the dry season of 1993. Change in soil volume per plot was estimated using change in soil depth and approximations for bulk density of soil.

Vegetation associations identified by Treadwell and Liebermann (1992) were sometimes very distinct in terms of abrupt changes at their borders, or sometimes one association would gradually change into another across a great distance. In either case the transition zone between two or more types can be referred to as an ecotonal gradient or ecotone (Odum 1971, 157-9). Given the importance of understanding which factors allow one plant association to invade the domain of another, along with the need to gauge dynamics of salinity in the system (see Section 2.3.1.1: *Regional physical geography and soils*), an analysis of abrupt ecotones at SJL was undertaken by Garabito (1995). He focused on plant associations in the salt-affected rangelands, which comprise about 40% of the Cantón of SJL. One question he wanted to address was: Are salt-tolerant associations expanding in the area, and, if so, could this be attributable to a gradual increase in salinisation? This is an important question because plant associations tolerant of highly saline conditions are undesirable in terms of grazing value compared to vegetation under conditions of moderate to low salinity (Chapter 5: *The grazing livestock of San José Llanga*). Garabito (1995) categorised ecotones into seven types based on pairings of adjacent vegetation. For each type of ecotone he located three examples. Along transects he then systematically selected sample points and measured attributes of plants [i.e., cover and plant size of certain taxa like salt-tolerant cushion plants (e.g., *Salicornia pulvinata* and *Anthobrium triandrum*)], ground water (electrical conductivity) and soil (electrical conductivity, pH and depth). In this case he wanted to see if the cushion plants were expanding their influence and, if so, whether or not this expansion was associated with increasing salinisation.

3.3 Results and discussion

The location and physiographic setting of the Cantón of SJL (7200 ha in size) has been previously reviewed. See Section 2.4.1 (*Local environment*) for these details and a description of the semi-arid puna of the central Altiplano within which the Cantón of SJL is found.

3.3.1 Climate

3.3.1.1 Precipitation

Using various interpolation methods, Peña (1994) concluded that the mean annual precipitation at SJL is about 402 mm. Less than 5% of the annual total occurs as snow or hail; snow or hail is most likely in the months of June, July and August. This mean annual total of 402 mm is very close to that for the Patacamaya Experiment Station (i.e., 406 mm; see Table 3.1). Based largely on work by Peña (1994), we believe measurements at Patacamaya Experiment Station to be reasonably accurate estimates of the true values for climatic parameters at SJL.

Overall, the climate of SJL is representative of a cold, dry ecosystem. Influences of elevation and physical geography have dictated these climatic attributes (see Section 2.2.1: *National highlights of physical geography and environment*). A large proportion of the world's arid and semi-arid ecosystems fall into the general category represented by SJL and the semi-arid puna of Bolivia. Perhaps best described by the inclusive term "cold-desert shrubland," homologues for this extensive, semi-arid puna of South America can also be found in the Great Basin of North America and in central, northern and southwestern Asia (Stoddart et al 1975). The following discussion reviews several important aspects of climate at SJL in isolation. This is followed by an integrated presentation relevant for understanding seasonal constraints on crop cultivation and plant growth.

As is typical of arid and semi-arid systems world-wide, precipitation at SJL is seasonal. The overall pattern at SJL is a uni-modal delivery of precipitation, as 93% (or 379 mm) of annual precipitation occurs throughout eight months (September to April) with 78% (or 313 mm) concentrated across the five months regarded as the growing season for crop cultivation (November to March). Accordingly, there is a distinct dry season which is commonly four months in duration (May to August) when only 7% of total annual precipitation is received (Table 3.1). Precipitation is most variable in the wet-to-dry and dry-to-wet transition periods. October is the second most variable month for precipitation in the dry-to-wet transition period; this is illustrated in Figure 3.1. That October is highly variable in terms of precipitation is emphasised here for two reasons: (1) October is a time of critical decisions by campesinos concerning field preparations for the up-coming cropping season (Section 4.3.3: *Household production system*), and (2) October is a time when grazing livestock are likely to be in the poorest condition, and therefore most in need of a flush of nutritious, green forage stimulated by early precipitation once temperatures begin to warm-up (Chapter 5: *The grazing livestock of San José Llanga*).

The high aridity at SJL is illustrated by the fact that mean potential evapotranspiration (ETp) exceeds precipitation by nearly 3.5-fold for the entire year. On a monthly basis ETp ranges from 20-times the precipitation in July to 1.25-times the precipitation in January (Table 3.1). This implies that plants dependent on precipitation are typically under threat of moisture stress, but that this markedly varies by month.

Annual precipitation at SJL is dynamic. Since 1951 to the present there have been two years with an annual precipitation between 200 and 225 mm, while there have been four years when precipitation has exceeded 550 mm (Figure 3.2). For the 42 years of data collection overall, the coefficient of variation (CV) for annual precipitation is 23%. This figure is markedly lower than the 45 to 50% range for CVs associated with tropical, arid rangeland systems in Australia (Caughley et al 1987) or South Turkana, Kenya (Ellis 1992), where rainfall varies from 200 to 350 mm per annum. Caughley et al (1987) noted that if an ecosystem has a CV for annual precipitation >30%, it is likely to be characterised more by non-equilibrial dynamics of consumers and plants and better defined in accordance with its variability rather than by long-term means. According to these precipitation criteria, the SJL system therefore seems to reside more on the equilibrial side of the rangeland spectrum. This conclusion would be strengthened further if evapotranspiration demand was incorporated, since this greatly influences effectiveness of precipitation. For example, if the higher evapotranspiration demands of hot, arid Australia or

Table 3.1. *Monthly dynamics of key climate variables for the Patacamaya Experiment Station, 1952-92.* Sources: INTECSA (1993) and SENAMHI (1994).

	Month												
Variable[1]	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Annual[2]
Precipitation (mm)	4.1	9.6	25.2	19.9	30.2	66.6	102.4	67.1	50.1	17.8	7.8	5.5	406.3
ETp (mm)	78	109	127	142	148	145	128	120	128	101	81	73	1380
Mean Temp. (°C)	5.1	6.5	8.8	10.8	12.1	12.3	12.2	12.0	11.6	10.2	7.3	5.1	9.5
Mean Max. Temp. (°C)	15.8	16.8	18.0	20.2	21.1	20.2	19.4	19.2	19.1	18.8	17.3	15.7	18.5
Mean Min. Temp. (°C)	-5.9	-3.8	-0.5	1.4	3.0	4.4	4.8	4.7	4.1	1.3	-2.9	-5.5	0.4
Mean Frost Days	28.3	25.5	15.2	9.7	4.2	1.5	0.7	0.4	1.5	10.4	24.1	27.8	149.2
Probability of Frost	1.00	1.00	0.88	0.88	0.70	0.33	0.21	0.30	0.47	0.85	1.00	1.00	0.72

[1]Where ETp is evapotranspiration, frost days are days when frost occurs, and the probability of frost was calculated over a 30 to 31-day period per month.

[2]Annual values for precipitation, ETp and mean frost days are totals while the others are means.

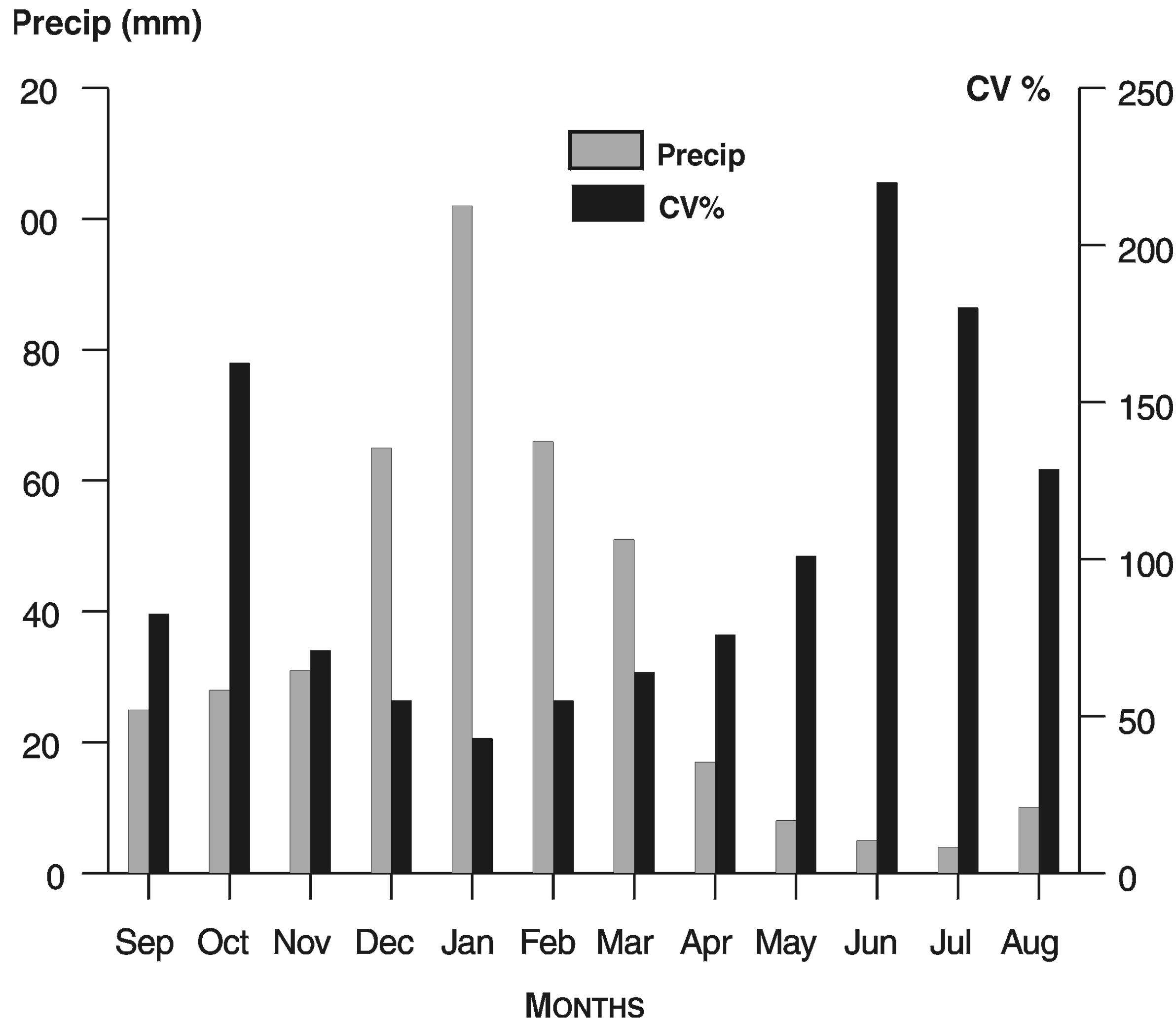


Figure 3.1. *Monthly average precipitation and their coefficients of variation (CV) for the Patacamaya Experiment Station, 1951-94.* Source: Dr. H. Alzérreca (rangeland ecologist, unpublished analysis) based on data collected by INTECSA (1993) and SENAMHI (1994).

Kenya were contrasted to the lower evapotranspiration demands of the cold altiplano, it is likely that the difference in effective moisture between the two types of systems is far greater than that indicated by comparisons based solely on precipitation. Such a crude categorisation of equilibrial versus non-equilibrial dynamics at a systems level, however, is probably too simplistic for several reasons. Evidence is provided later in this chapter to show that different geomorphic units at SJL likely vary in the degree to which precipitation controls the dynamics of plant populations. Geomorphic units, therefore, may be a more appropriate scale of resolution to ascribe equilibrial or non-equilibrial attributes. The units can then be amalgamated into an overall picture of ecosystem structure, dynamics and function.

Our 42 years of climate data are insufficient for making firm conclusions regarding variability and trends. It is interesting to note, however, that a common perception among campesinos at SJL is the the climate is becoming drier (Dr. J. de Queiroz, IBTA/SR-CRSP, personal observation). Evidence of increasing aridity comes from indications that an old and extensive lake bed at SJL holds ephemeral water much less frequently, or for a shorter period, in recent years compared to the past (see Section 3.3.2.1: *Geomorphic units*). A declining amount of standing water may be related to a medium-term variation in and/or in-

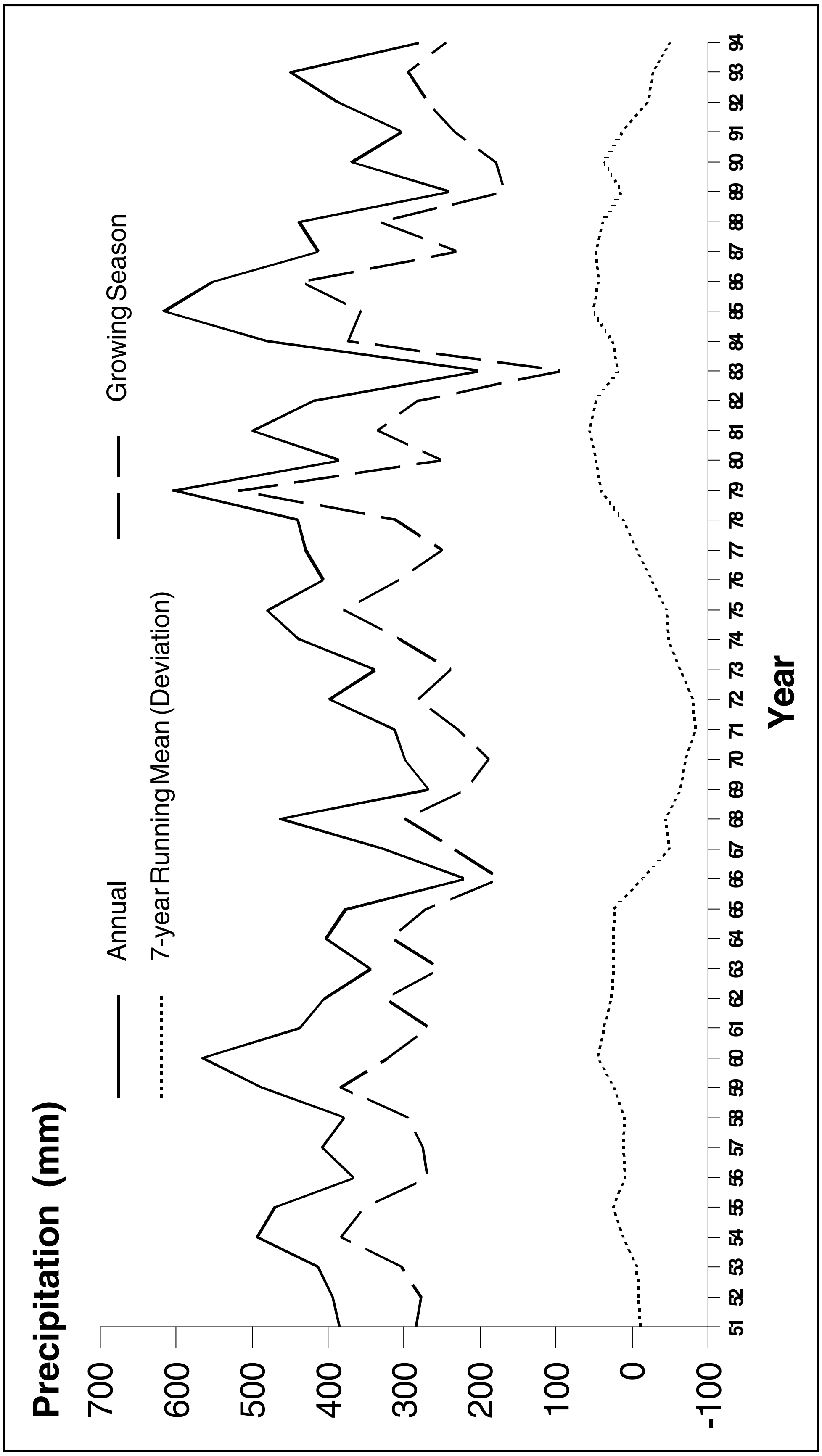


Figure 3.2. *Annual precipitation dynamics at the Patacamaya Experiment Station, 1951-94.* Source: Dr. H. Alzérreca (rangeland ecologist, unpublished analysis) based on data collected by INTECSA (1993) and SENAMHI (1994).

creased demands from upstream users on the flow of rivers that feed into SJL (see below).

If we arbitrarily define a dry year as one in which annual precipitation is <75% of the long-term mean (Cossins and Upton 1988), and a drought as the occurrence of two or more dry years in succession, then some crude probabilities can be calculated based on the 42-year time series if it is assumed that the occurrence of wet and dry years is independent. For example, the chance that a given year will be dry (i.e., with an annual precipitation <300 mm) is thus 7/42 or 0.17. The chance that two consecutive years will be dry (i.e., a two-year drought) is 0.17 x 0.17 = 0.03. Conversely, the chance that two consecutive years will both exceed 75% of the long-term mean is 0.83 x 0.83 = 0.69. The chance that one year will be dry and the other will exceed 75% of the long-term mean is 2 x (0.17 x 0.83) = 0.28. Perturbations to global climate as affected by phenomena such as the El Niño Southern Oscilation (ENSO; Ropelewski 1992) merit consideration as an influence on some patterns of local precipitation. Washington-Allen (1994) cited work interpreted to indicate that the very dry year of 1983-4 at SJL was related to El Niño activity.

If annual precipitation is not independent of that in adjacent years, then use of the probabilities above begins to lose credibility. A possible case-in-point is provided by a graphical presentation of seven-year running means at the bottom of Figure 3.2. The cyclical pattern consisting of alternating blocks of 11 to 13 years in duration can be interpreted to suggest that above-average precipitation tended to occur from 1954-65 and again in 1977-90. One irony, however, is that occurrence of a block having higher or lower rainfall does not preclude the occurrence of unusual years; one example is the very dry year of 1983 happening in the middle of the 1977-90 period of above-average rainfall (Figure 3.2). Factors associated with El Niño have been speculated to play a role in cyclic climate patterns of the Andes. Work by the Cornell University Andes Project (unpublished) has attempted to describe an apparent cycle for levels of Lake Titicaca using a data set going back to 1939. They have found that extended drops in lake levels occur at roughly 10- to 16-year intervals, and that some of these drops coincide with key activity of El Niño. Effects of El Niño have also been implicated in the heavy flooding in the transition zones and lowlands of Bolivia during the early 1980s (INTECSA 1993; see Section 2.2.2.3: *National highlights of social history:1951 to 1996*).

The high variability of annual precipitation introduces a key element of risk as campesinos plan agricultural activities. Andean campesinos mitigate climatic risk, in part, by diversifying crops and widely distributing cultivated plots across landscapes to take advantage of micro-climatic variability (see below). It is important to note, however, that while researchers have traditionally focused on inter-annual variation in precipitation as an important attribute of agroecosystems, of at least equivalent importance is the monthly or inter-seasonal variability as well as timing of precipitation events. For example, it is well-known that delays in the onset of rains in a growing season can dramatically affect crop production and survival of nursing stock in seasonal environments, even though total precipitation eventually appears "near-normal" on an annual basis (Coppock 1994). The campesinos of SJL cope with a high intra-seasonal variability of precipitation even during peak rainfall months when monthly CVs range from a low of 20% in January (the wettest month of the year at 102 mm) to 110% in June (one of the driest months at 4 mm; Figure 3.1). A comprehensive perspective also needs to include pervasive risk of frost and some losses to diseases and pests such as nematodes (Dollfus 1982; Blanco 1994). Frost risk is discussed below.

3.3.1.2 Air temperature and frost

In seasonal environments at tropical latitudes it is common that seasonality is defined more by temporal variation in precipitation rather than by temporal variation in ambient temperature. This is also the case for SJL. While monthly variation in precipitation is up to 25-fold (i.e., from 4 mm/month to 102 mm/month), monthly variation in mean daily temperature is only 2.4-fold (i.e., from 5 to 12°C). In terms of average daily temperature, May through September tend to be colder (with daily minima below freezing) while October through April tend to be warmer (Table 3.1). The variation between daily maxumum and minimum temperatures exceeds variation among monthly averages. The difference between daily maximum and minimum temperatures varies from nearly 22°C in July to 14°C in February.

In contrast to low-elevation systems in the tropics where environmental perturbations are largely defined by deficits in rainfall (Ellis 1992), frost adds another dimension of abiotic perturbation at SJL, especially when crop cultivation is considered. Frost occurs when both humidity and air temperature decline. When nights are clear and humidity is low, temperatures drop abruptly when the sun sets and this causes frost to form. Frost can severely damage crops (IBTA 1992). Frosts damage plants when ice crystals form in tissues and puncture cell membranes and organelles. Frost-resistant plants utilise several strategies. Going dormant during seasons of high risk of frost is common for perennial native forages on the Altiplano; this takes advantage of the fact that the period of highest frost risk is commonly the time of greatest moisture stress (Dr. H. Alzérreca, rangeland ecologist, personal communication). Other plants like the Andean tubers (i.e., *Solanum tuberosum*, *Ullucus tuberosum*) have their most sensitive, water-holding tissues belowground. Some perennials that have secondary compounds in cellular fluids postulated to serve as a form of "anti-freeze" (shrubs such as *P. lepidophylla*; Dr. H. Alzérreca, rangeland ecologist, personal observation). Frost has also been implicated as having direct and indirect negative effects on the nutritive value of forages, including reductions in crude protein content. Indirect effects on nutritive value occur because photosynthetic activity declines, which lowers production of enzymes and simple sugars.

Monthly incidence of frost at SJL primarily increases as a function of decreasing minimum air temperature. As mentioned above, colder months also tend to be drier. The probability of a frost occurring during a given month is highest during the coldest months when temperatures are most likely to go below freezing. As an illustration, virtually every day in a given June and July can have a frost, while December through March are almost frost-free, on average. Over a longer time frame in a probability framework, there will always be frosts each year from May through August, but nearly four out of five consecutive Januarys will not have one frost (Table 3.1). When frost conditions prevail, the extensiveness of frost on a landscape is affected by topographic location. Frosts will tend to occur more in those depressions and landscape facets where heavier (colder) air collects before sunrise. The warmer the ambient temperature, the more likely frost will be fragmented and localised. The colder the ambient temperature, the more likely that frost will be ubiquitous. Campesinos mitigate frost risk in several ways including use of frost-resistant crop varieties, widespread spatial and temporal distribution of household plots across landscapes, creating new landscapes through large-scale engineering activities, and traditional use of irrigation canals to alter micro-climates in cropping areas.

Precipitation, temperature and risk of frost are inter-related (Le Tacon et al 1992). Cloud cover associated with the rainy season also serves to increase ambient mean temperatures by trapping radiant heat that would otherwise be lost to the atmosphere. Higher ambient temperatures equate to lower risk of frost. Extending this logic further, it would be expected that drier years would have higher risk of frosts. These inter-related factors of precipitation, temperature and frost risk are important for defining the cropping season at SJL. Climate diagrams integrating monthly temperature and precipitation dynamics are presented as Figure 4.4(a-d) in Chapter 4: *Household economy and community dynamics at San José Llanga.*

It is important to note that risks for crop failure can be fairly high even during the primary rainfall months when crop establishment and early growth occurs. For example, despite that January is the wettest and second warmest month at SJL, the cumulative risks of frost or serious moisture deficits adds to a combined probability of 0.60, meaning that in six out of 10 consecutive years, January will experience one form of stress or the other.

3.3.2 Description of natural resources

3.3.2.1 Geomorphic units

Before we delve into the details of geomorphic units, it is important to note a few basic features of SJL with regards to topography. Of particular relevance is the very modest relief throughout the 7200 hectares of SJL; elevation only varies by 61 m overall (i.e., from 3725 to 3786 m). It is also notable that this is a marked contrast to some other agropastoral production systems in the semi-arid puna which incorporate access to valley bottoms for grazing and high mountainsides for cultivation across a wide range of elevation (see Section 2.3.1.2: *Regional environment*). The significance of the 61 m of relief for diversification of agropastoral production at SJL is reviewed later in this chapter.

Simply defined, landscapes are comprised of geomorphic units. Each geomorphic unit can be created differently due to varied effects of wind, water, geology, and in some cases, human activities. Geomorphic units thus have distinct physical and ecological features.

The landscape of the Cantón of SJL may be sub-divided into six basic geomorphic units, mapped in Figure 3.3. Without rigid adherence to geomorphological terminology, and for the sake of brevity, these are referred to as the: (1) Alluvial terrace; (2) alluvial fan; (3) fluvio-lacustrine plain; (4) deltaic deposits; (5) alluvial plain; and (6) eolian deposits. In general, the alluvial terrace and alluvial fan are vital for rain-fed and flood-irrigated cultivation, respectively, of food and forage crops. The fluvio-lacustrine plain is vital as a native range for grazing. The deltaic deposits have recently become important for irrigated cultivation of forage and food crops. The alluvial plain and eolian deposits are small in size and of little or no importance to the agropastoral system overall. These are all defined and described below.

Alluvial terrace. The alluvial terrace is what is left of a former flood plain. It is essentially a core standing remnant (or relict) feature that remains after erosion leveled other portions of the flood plain. The alluvial terrace consists of Luvisols and Lixisols and is situated in the western 25% (or 1800 ha) of the Cantón of SJL (Plate 3.1). The alluvial terrace is where most of the rain-fed cultivation occurs. It lies at the highest average elevation (3786 m) in the cantón, which is about 20 m above the adjacent fluvio-lacustrine plain. This positioning is fortuitous because the slightly higher elevation lowers the likelihood of hard frosts. This attribute has been reported by the campesinos, however, and has not been empirically quantified by research. The alluvial terrace has a gently undulating topography with slopes ranging from 2 to 7%. This unevenness of topography is associated with pronounced micro-climatic variation. Low-lying, concave locales are more prone to frosts than are those which are convex or at mid-slope. Households vary with respect to the distribution of cultivated plots on the alluvial terrace. Households typically have some plots in concave positions and others in convex positions or at mid-slope (C. Jetté, IBTA/SR-CRSP, personal communication).

Alluvial fan. The alluvial fan was formed by sediments deposited by flows of the intermittent, rain-fed (non-saline) *Khora Jahuíra* River as it spills over the banks. The river typically flows from November to May and probably makes "significant" deposits of sediment in most years (Dr J. de Queiroz, IBTA/SR-CRSP, personal observation). Peña (1994) found sediment levels in the river varied from 14.5 to 21.2 g/l during January and March, respectively. The *Khora Jahuíra* River originates in the northwest portion of SJL. The residents of the Cantón of SJL therefore do not have to compete with residents of other cantóns for use of this water. Given the *Khora Jahuíra* River was diverted by SJL residents during the mid-1980s, this is another example of a critical anthropogenic modification of the environment (Figure 3.3; Plate 3.2). The alluvial fan consists of medium-textured Fluvisols and occupies about 15% of the surface area (or 1080 ha) of the cantón. The alluvial fan is mostly used by the campesinos for production of flood-irrigated and sub-irrigated alfalfa (cut-and-carry as well as grazed). There are also flood-irrigated fields of barley (used for animal feed) and native forages for grazing (Chapter 5: *The grazing livestock of San José Llanga*). The overall shape of the top surface of the alluvial fan is slightly convex due to depositional processes. The slope ranges from 1 to 2%. It is important to note that the genesis of this unit is not typical for "natural" alluvial fans as defined in geology texts; purists may thus disagree with this terminological transgression. The alluvial fan at SJL is an artificial, fan-shaped land-unit formed by a man-made river channel. We could find no established geologic term to describe it any better.

Fluvio-lacustrine plain. The fluvio-lacustrine plain is the most extensive geomorphic unit in SJL, covering about 38% (or 2736 ha) of the landscape (Figure 3.3; Plate 3.3). This unit is virtually flat and occupies the lowest landscape position in the Cantón of SJL. It is essentially an old lake bed. The soils consist of Solonchaks having moderate to high levels of salinity. This unit is mostly used by the campesinos for grazing sheep, cattle and

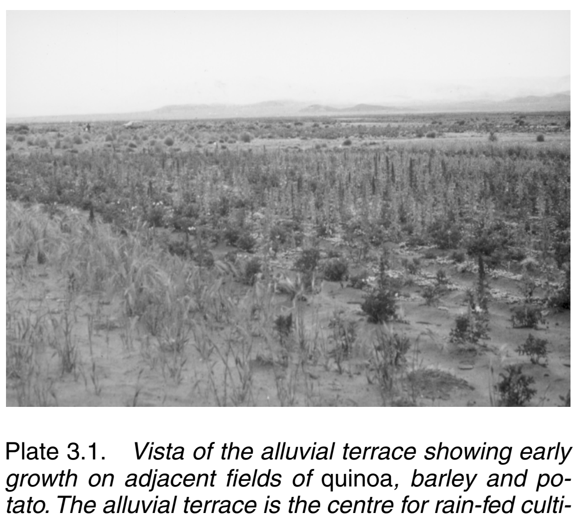


Plate 3.1. *Vista of the alluvial terrace showing early growth on adjacent fields of* quinoa*, barley and potato. The alluvial terrace is the centre for rain-fed cultivation of food crops by virtue of the fresh water supply, good drainage and other favourable soil features.*
Photograph: João S. de Queiroz

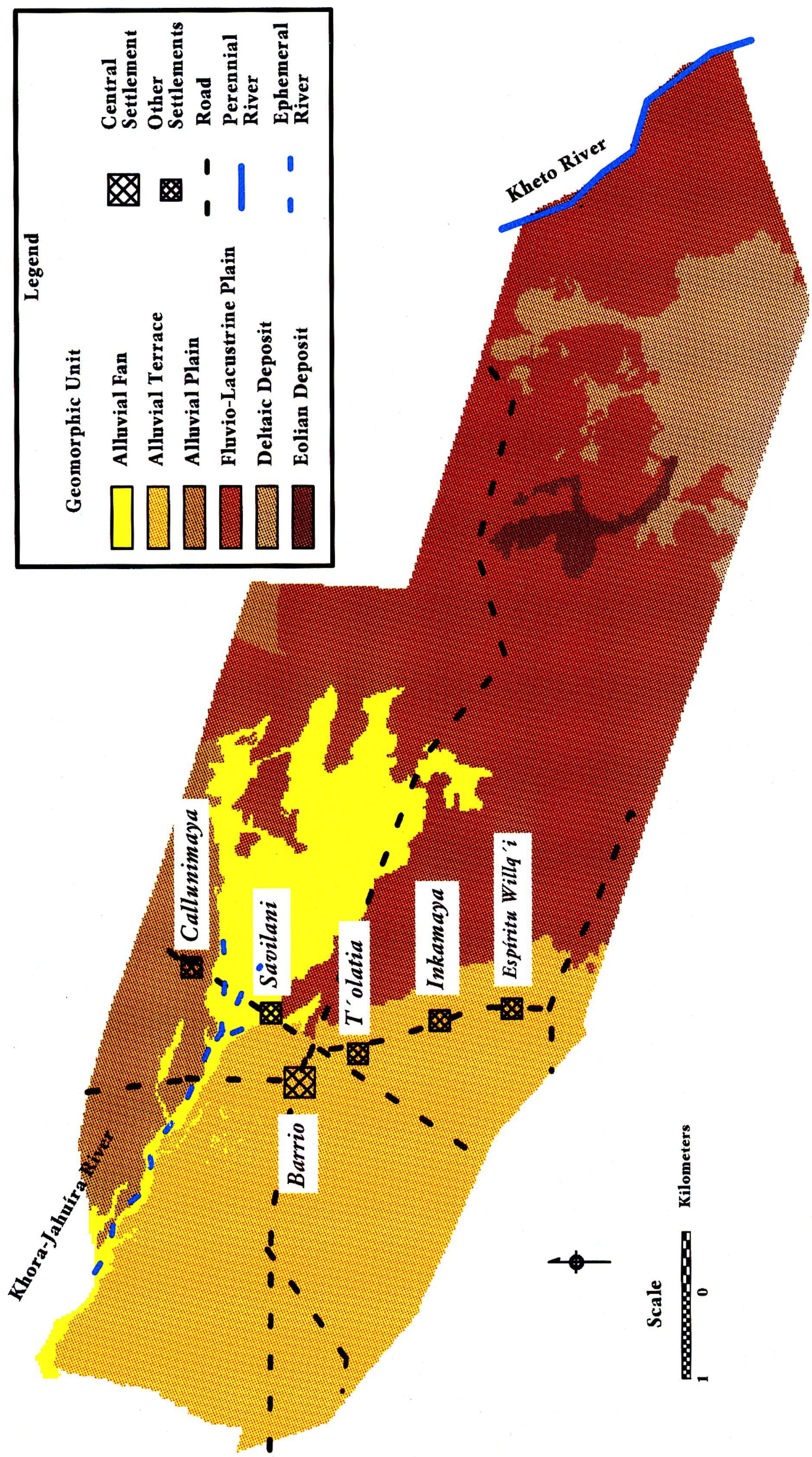


Figure 3.3. Location of six settlements in the agropastoral community of San José Llanga in relation to geomorphic units.
Source: GIS adaptation by R.A. Washington-Allen.

donkeys. Fluvio-lacustrine plains are common on the central Altiplano. They are relicts of numerous, endoreic lakes originally created in the Quaternary Period that expanded or shrank depending on climate (Servant and Fontes 1978; see Section 2.3.1: *Regional highlights of physical geography and environment*). According to campesinos of SJL, prior to the 1970s significant portions of the fluvio-lacustrine plain were commonly underwater throughout the year. This claim was corroborated by examination of aerial photographs from the dry season of 1955 (Dr. J. de Queiroz, IBTA/SR-CRSP, personal observation). Since the 1970s, however, the fluvio-lacustrine plain has not had standing water during dry seasons, according to local informants. Standing water and a high level of soil saturation are fairly common during the height of the rainy season (Chapter 5: *The grazing livestock of San José Llanga*).

Deltaic deposits. The deltaic deposits are located in the eastern quarter of the cantón and occupy about 10% (or 720 ha) of the landscape (Figure 3.3). The soils are comprised of slightly saline Solonchaks. Although the genesis of this unit is unclear, the relatively coarse soil texture, nearly flat topography, shape and stratigraphic position are congruent with those of sediments deposited by flowing water as it enters a still body of water. The deltaic deposits are used by the campesinos for flood-irrigated alfalfa using saline water from the Desaguadero River (Barrera 1994; reviewed later in this chapter). Barley, *quinoa* and potatoes are also grown on the deltaic deposits under a variety of rain-fed and irrigated conditions.

Alluvial plain and eolian deposits. The alluvial plain occupies a small portion (<9%) of the study area and is sandwiched between the alluvial fan and boundary of SJL with the Cantón Llanga Belén to the northwest (Figure 3.3). The alluvial plain was formed as a result of past flooding. The soils were not surveyed. This unit plays a very limited role in SJL production systems and was thus neglected in our investigations.

Finally, the eolian deposits occur as a small area of small, dune-like formations. They consist of fine, wind-blown sand appended to the deltaic deposits (Figure 3.3). This unit occupies <3% (or 216 ha) of the SJL landscape, and only plays a very limited role in production strategies.

3.3.2.2 Water resources

The water resources of SJL are diverse. Understanding the distribution and other attributes of water is vital to appreciating structure and function of this agroecosystem. Water resources vary in terms of location (i.e., surface versus sub-surface) and chemical quality (i.e., degree of salinity). Location and chemical quality influence the suitability of water for crop irrigation and consumption by people and livestock.

Surface water. As previously reviewed, two rivers have marked influences on the Cantón of SJL. These are the perennial and saline Desaguadero River and the ephemeral, rain-fed

Plate 3.2. *Vista of the alluvial fan showing cattle grazing and cut-and-carry alfalfa harvest. Forage and food crops are nourished by periodic over-flow of the Khora Jahuíra River and roots of alfalfa can access the high water table. The alluvial terrace is a fertile, non-saline site created by the campesinos. It expands due to depositional processes.* Photograph: João S. de Queiroz

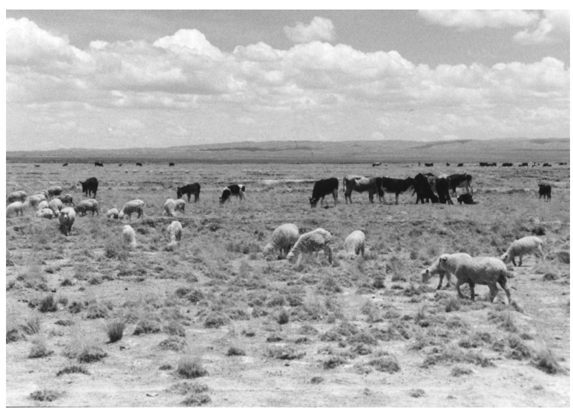


Plate 3.3. *Vista of the fluvio-lacustrine plain. This site is a former lake bottom which today is largely comprised of a matrix of various types of native range. These are often defined by variation in salinity and inundation history.* Photograph: Jim Yazman

Khora Jahuíra River. A third, the perennial Kheto River, occurs locally but only affects SJL through rare flooding on the northeastern periphery of the fluvio-lacustrine plain.

The Desaguadero River supplies irrigation to the alfalfa fields on the deltaic deposits. The 23-km, unlined canal used for irrigation was hand-dug by inhabitants of SJL and three neighbouring communities as a response to the 1983-4 drought (Peña 1994; Section 2.4: *Overview of the study area at San José Llanga*). The canal extracts 274 liters per second at its intake point on the Desaguadero River, and 35% of this volume is lost by the time it reaches SJL (Peña 1994). The high salt content of this river water, however, leaves little doubt that irrigation will salinise the deltaic deposits (Peña 1994; see Section 3.3.4.3: *Sustainability of the deltaic deposits*). The river water has a high content of sodium (457 mg/l) and chloride (924 mg/l) according to Peña (1994). Historically, flood waters from the Desaguadero River regularly contributed to the inundation of low-lying areas of SJL, such as the fluvio-lacustrine plain (Mr. Victor Marca, agropastoralist and resident of SJL, personal communication). The frequency of inundations appears to have decreased over the past few decades. The causes for this postulated change have not been established by research.

The *Khora Jahuíra* River flows in an easterly direction and follows an artificial channel that markedly deviates from its original northerly course (Mr. Don Pascual, agropastoralist and resident of SJL, personal communication). This intermittent river enters the Cantón of SJL at the northwest corner and commonly overflows its banks 4 km to the southeast. As previously noted in this chapter, the overflow deposits silt and fine sand to create a well-drained, artificial alluvial fan. Despite that this fan represents only 15% of the landscape, it is perhaps the most important parcel of land for the agropastoral economy at SJL (Section 4.3.3: *Household production system*). The regime of the *Khora Jahuíra* River consists of typically short-lived (<24 hr) periods of turbulent flow, tightly linked with rainfall, that may exceed 4800 liters per second (Peña 1994). While laden with silt and fine sand, water brought to SJL by the *Khora Jahuíra* River poses no chemical problems for plant growth because it is rain-fed (non-saline). On the other hand, there is a significant risk of flooding that can cause physical damage to crops (i.e., alfalfa, barley) on the alluvial fan. The alluvial fan is continually expanding as a result of depositional processes. This can create more acreage for critical agricultural activities such as the cultivation of alfalfa (Dr. H. Alzérreca, rangeland ecologist, personal observation).

The Kheto River forms a portion of the community's eastern boundary and contributes to flooding in the lowest portions of the fluvio-lacustrine plain (Figure 3.3). Due to its location far from the main barrio of SJL, and thus limited relevance to day-to-day activities of the campesinos, this water body was not included in our studies.

Sub-surface water. The entire Cantón of SJL is underlain by groundwater. Under the alluvial terrace where most of the rain-fed cultivation occurs, high-quality ground water of low salinity occurs at between 3 and 10 m depth, depending on topographical location and season. Most dwellings in the communities tap this resource through hand-dug wells. In late 1994 the communities installed a gravity-fed system which directly supplies water to most dwellings.

Under the alluvial fan adjacent to the *Khora Jahuíra* River, the water table is between 2 and 3 m beneath the soil surface, well within reach of alfalfa roots. The electrical conductivity of ground water (ECw) for the alluvial fan is low [i.e., <0.08 Siemens/meter (or S/m) from Peña (1994)], indicating a low degree of salinity and suitability for irrigation. Non-saline flood waters from the *Khora Jahuíra* River replenish the water table in most years. Access of roots to ground water allows perennial alfalfa to green-up in October, which is in the critical transition period between the end of the dry season and beginning of the wet season. Green-up of alfalfa is facilitated by a gradual increase in temperature, which also diminishes the likelihood of hard frosts. The nutritional status of livestock is commonly poorest at this time, and access to green alfalfa provides a critical boost (Chapter 5: *The grazing livestock of San José Llanga*). It is important to note as an aside that alfalfa, a crucial production intervention for the SJL system, has been grown at SJL for many years. Significant increases in the establishment of small-scale alfalfa fields were first noted at SJL in the 1960s when there was a push to expand production of improved sheep breeds among the campesinos. This initiative was spearheaded by staff of the Patacamaya Experiment Station in concert with consultants from Utah State University, who in turn worked under the auspices of USAID (Dr. H. Alzérreca, rangeland ecologist, personal communication). Alfalfa cultivation subsequently further expanded in the 1980s and early 1990s at SJL when smallholder dairying took hold

(Chapter 4: *Household economy and community dynamics at San José Llanga*).

The entire fluvio-lacustrine plain is underlain by perched water tables sandwiched between impervious layers of clay or silt. They are not aquifers in a technical sense and are quite small in size. The depth of the water table under the fluvio-lacustrine plain ranges from 0.6 to 1.5 m (Peña 1994) with ECw values ranging from 6.0 to 0.04 S/m (Peña 1994; Garabito 1995). The lowest ECw values occur in a small area adjacent to the alluvial fan and alluvial terrace where the bulk of the human population resides (Figure 3.3). This can be interpreted to suggest that the location of the main barrio and satellite communities has been influenced by access to potable water and proximity to the rain-fed cropping fields of the alluvial terrace. Towards the center of the fluvio-lacustrine plain the ECw values exceed 2.4 S/m, which is unsuitable for use by most plants. Out of 14 wells sampled by Peña (1994) on the fluvio-lacustrine plain in November (prior to the onset of the rainy season), 10 were either unsuitable or only marginally suitable for irrigation due to high salinity. The proportion of highly saline water samples would have probably been higher if the sample points had been selected randomly, rather than extracting samples from hand-dug wells (Dr. J. de Queiroz, IBTA/SR-CRSP, personal observation). The quality of ground water under the fluvio-lacustrine plain may also markedly change over short distances. For example, Garabito (1995) measured differences in ECw in excess of 5.5 S/m between sample points that were only 9 m apart. This phenomena occurs because pockets of sub-surface water are segregated by a honeycomb of impervious layers of silt and clay. Accordingly, quality of water from the 54 hand-dug wells across the fluvio-lacustrine plain varies tremendously (Peña 1994; Plate 3.4). Perforation of sub-surface clay and silt lenses by more hand-dug wells will result in more mixing of ground water and homogenisation of water quality over time (Dr. J. de Queiroz, IBTA/SR-CRSP, personal observation).

The depth to the water table under the deltaic deposits ranges from 1.6 to 2.4 m in depth (Peña 1994). Values for ECw range from 0.8 to 1.3 S/m, making this ground water only marginally suitable for irrigation.

3.3.2.3 Soils

About 81% of the soil resources of the Cantón of SJL were surveyed (Table 3.2). The sites that were not surveyed included those associated with the alluvial plain, a site type of very marginal significance to the production system overall.

The surveyed area was almost evenly divided into those soils which were salt-affected and those which were not. The former tend to occur at lower-elevation sites having higher water tables and periodic flooding; grazing is the most common form of land use for salt-affected soils. Soils not affected by salinity occur at slightly higher elevations, tend to have been modified by human engineering in some cases, and are well-drained; cultivation is the most common form of land use on soils not affected by salinity. This cultivation takes the form of either rain-fed or flood irrigated; the latter relies on fresh water associated with the *Khora Jahuíra* River. Some descriptions and details for constituent soil types follow.

Saline soils. Nearly 45% of the area surveyed for soil features at SJL is covered by salt-affected soils. These are called Solonchaks under the revised legend of the Soil Map of the World (FAO/UNESCO/ISRIC 1988). Guided by Garabito's (1995) study of soil-vegetation relationships, which was conducted at ecotones within salt-affected areas of SJL, we used conductivity of a saturation extract (ECe) from samples at the soil surface to sub-divide Solonchaks into three sub-types. This was required because the legend of the Soil Map of the World was inadequate to accommodate the range of salinity encountered at SJL. Thus, we defined: (1) Hyper-saline Solonchaks as soils with an ECe value for the surface horizon >2.5 S/m; (2) moderately saline Solonchaks as soils with an ECe value for the surface horizon between 0.4 and 2.4 S/m; and (3) slightly saline Solonchaks as

Plate 3.4. *Example of a hand-dug well for livestock use in a hyper-saline portion of the fluvio-lacustrine plain.* Photograph: João S. de Queiroz

Table 3.2. *Selected chemical and physical features of common surface soils at San José Llanga.* Sources: Adapted from Peña (1994) and Miranda (1995).

	Feature[1]						
Soil Type	Surface ECe ($S\ m^{-1}$)	pH	Depth of Water Table (m)	Surface Texture[2]	OM (%)	Drainage[3]	Percent of Area
Hyper-Saline Solonchaks	2.3-11.2	7.3-8.1	0.8-2.0	c, cl	0.1-0.9	poor	18.2
Moderately Saline Solonchaks	0.4-2.3	7.9-9.7	0.8-1.6	c	3.1-7.5	poor	18.5
Slightly Saline Solonchaks	<0.4	7.5-8.0	>2.0	sl	--	good	7.8
Medium-textured Fluvisols	<0.4	7.5-8.5	>2.0	ls,sl	0.6-1.4	good	11.9
Fine-textured Fluvisols	0.1-1.0	8.3-8.5	0.6-0.8	c,sil	3.2-3.4	poor	3.6
Luvisol/Lixisol association	<0.1	7.3-7.7	>3.0	s,ls	0.2-1.1	good	21.0
Other (not surveyed)	--	--	--	--	--	--	18.7

[1]Where surface ECe is conductivity (indicative of salinity), OM is organic matter, and percent of area is the approximate percentage the soil type comprised of the entire Cantón of San José Llanga.

[2]Where c=clay, cl=clay-loam, ls=loamy sand, sl=sandy loam, sil=silt-loam.

[3]Where "poor" drainage was indicated when water ponded on the soil surface for two days or more after heavy rainfall. "Good" drainage was indicated when there was no ponding of water on the soil surface after heavy rainfall.

soils with an ECe value for the surface horizon <0.4 S/m.

Hyper-saline Solonchaks covered 18% of the surveyed area (Table 3.2), but they are present only within the fluvio-lacustrine plain (Figures 3.3 and 3.4). These are fine-textured, poorly drained soils, usually subtended by a water table within 1.5 m of the soil surface (Peña 1994). Surface horizons tended to have a lower content of organic matter (OM) and a slight to moderate alkalinity (Miranda 1995). The low OM content likely occurs because these soils now support little vegetation and tend to be poorly drained. Because of extreme salinity levels and poor drainage, these soils support a restricted suite of halophytic (i.e., salt-tolerant) species with a prostrate or cushion-shaped morphology; these include *Salicornia pulvinata*, *Anthobrium triandrum* and *Atriplex nitrophylloides*. In the wet season these soils become waterlogged and are an important impediment to the movement of people and livestock in SJL. This is a factor that plays a role in grazing management decisions (see Chapter 5: *The grazing livestock of San José Llanga*).

Moderately saline Solonchaks are also restricted to the fluvio-lacustrine plain (Figures 3.3 and 3.4). These soils occupied about 18.5% of the surveyed area. They are fine-textured, poorly drained and alkaline with surface pH values reaching 9.7 when percent of exchangeable sodium is high (Table 3.2). The water table is often within 1.5 m of the surface. Surface soil horizons may have high levels of OM (Miranda 1995). Often the moderately saline Solonchaks are covered by low-growing rhizomatous and stoloniferous grasses such as *Distichlis humilis* and *Muhlenbergia fastigiata.* Where grazing pressure is relatively low, *Hordeum muticum* becomes an important component of vegetation communities. Other factors may also influence persistence of *H. muticum* in these sites (Dr. H. Alzérreca, rangeland ecologist, personal communication). Management factors aside, *H. muticum* is known as a frost-tolerant species that can grow at low temperatures, hence its highly regarded status as a forage. Considering management, grazing commonly occurs on the fluvio-lacustrine plain during dry seasons, due in part to periodic inundation or at least extreme muddiness of these sites during wet seasons (see Chapter 5: *The grazing livestock of San José Llanga*). Dry season grazing therefore defoliates plants when they are dormant, sparing the more grazing-sensitive species such as *H. muticum*. In addition, traditional practices of water spreading using low, extensive earthen walls on the fluvio-lacustrine plains may have expanded the suitable habitat for *H. muticum*. This has been the case in similar communities of the semi-arid puna (Dr. H. Alzérreca, rangeland ecologist, personal communication).

Slightly saline Solonchaks primarily occur on the deltaic deposits (Figures 3.3 and 3.4) and occupy 7.8% of the surveyed area. They are coarse-textured and well-drained soils with a water table situated >1.5 m from the soil surface (Peña 1994; Miranda 1995). The pH values for surface horizons range from slightly to moderately alkaline (Table 3.2). These soils are being used for irrigated cultivation of cereal crops (i.e., barley, *quinoa*) and alfalfa. A few campesinos have small patches of forage grasses such as *Dactylis glomerata* and *Agropyron* spp. The presence of salt-tolerant *A. triandrum* as a dominant species in fallow fields on the deltaic deposits has been interpreted as an indication of increased soil salinity due to use of irrigation water from the Desaguadero River (Peña 1994).

Non-saline soils. Medium-textured (Calcaric) Fluvisols covered about 12% of the surveyed area. These are young soils restricted to the artificially created alluvial fan (Figures 3.3 and 3.4). They are well-drained, moderately alkaline and subtended by a deep water table (Table 3.2). Surface and sub-surface textures vary from loamy sand to sandy loam. Frequent wet-season flooding by the *Khora Jahuíra* River adds sediments, moisture and nutrients which all contribute to make this patch of soil a key resource. Whereas elevated risk of frosts and floods limit potato cultivation on these soils, the presence of good quality sub-surface water, nutrients and good drainage make this site well-suited for alfalfa cultivation. Frost-tolerant annual forages such as barley also do well on these medium-textured Fluvisols (Dr. J. de Queiroz, IBTA/SR-CRSP, personal observation).

Fine-textured (Mollic) Fluvisols occur in the fluvio-lacustrine plain adjacent to the alluvial fan and near the boundary with the alluvial terrace (Figures 3.3 and 3.4). These poorly drained soils occupied 3.6% of the surveyed area. Fine-textured Fluvisols are characterised by alkalinity and a relatively high OM content irregularly distributed with depth (Miranda 1995). While mostly non-saline, some patches do exhibit saline properties as defined by the revised legend of FAO/UNESCO/ISRIC (1988). Fine-textured Fluvisols support highly productive vegetation types typified by *Calamagrostis curvula* and *Festuca dolichophylla*.

Luvisols and Lixisols covered 21% of the surveyed area. Barrera (1994) found these soils to comprise the alluvial terrace where the bulk of community production of food-crops (i.e., potatoes, *quinoa*) takes place (Figures 3.3 and 3.4). These soils have a coarse-textured surface horizon which lies over a medium- to fine-textured horizon of clay. Luvisols and Lixisols are slightly alkaline with low concentrations of OM and soluble salts (Table 3.2). They are well drained and have a low water-holding capacity. The sandy surface is devoid of structure and prone to wind erosion. Small-scale, wind-blown deposits are found throughout the alluvial terrace, especially down-wind from cultivated fields.

3.3.2.4 Land cover

About 90% of the landscape of SJL was surveyed in terms of land cover. The 11 land-cover types are listed in Table 3.3. Only nine land-cover types are mapped in Figure 3.5, however. This is for a couple of reasons. One is that some cover types occurred as patches that were scaled too small to appear in Figure 3.5. The second reason was that sites designated as "early successional herbfield" or *kallpas* were deemed distinct enough to merit their own land-cover designation, but because this was only an ephemeral stage of food-crop production they were all mapped together as "food crops." The major land-cover types are briefly defined and described below.

Cultivated lands. Cultivated lands are those which produce either annual crops for people and livestock or perennial forages for livestock. The lands yielding the annual crops tend to be rain-fed and have substantial acreage in fallow. Lands yielding perennial forages have a combination of sub-irrigation, surface irrigation and rain-fed components and little or no fallow. Cultivated lands are also referred to by the generic term Cades.

Annual food and forage crops and fallow. The first focus for land-cover is on sites used for production of annual crops. Annual food crops like potato and *quinoa* and annual forages like barley and wheat are vital components of the agroecological system at SJL. Potato and *quinoa* are primarily grown under rain-fed conditions on the alluvial terrace, which is comprised of soils in the Luvisol/Lixisol association (Treadwell and Libermann 1992; Barrera 1994). Barley is by far the most popular annual forage crop, with wheat a distant second choice as annual forage (Barrera 1994). Barley and wheat are primarily grown via flood irrigation and rain-fed means on the artificial alluvial fan, which is comprised of coarse-textured Fluvisols.

Cropping cycles and rotations for each food and forage crop are discussed in detail in Ciro and Cáceres (1994) and Barrera (1994). Crop sequences change depending on the subtending geomorphological unit (Dr. J. de Queiroz, IBTA/SR-CRSP, personal observation). The most common sequence on the alluvial terrace is a year of potatoes followed by a year of *quinoa* and then fallow. The next most-common sequence is potatoes followed by *quinoa*, barley and fallow. On the alluvial fan a common sequence is barley followed by alfalfa; there are several others which also use barley as the first crop. On the deltaic deposits the sequence of barley followed by alfalfa is most common.

For purposes of this chapter, however, general similarities in crop cycles for rain-fed annuals will be emphasised. For example, for potato, *quinoa* and rain-fed barley and wheat it can be broadly asserted that the cycle consists of up to three years of repeated cultivation on a given field, followed by an extended fallow of <15 years. In most cases fallowing appears to result in a re-establishment of native vegetation, which tends to be a mix of short, evergreen shrubs and perennial bunchgrasses on these sites (see below). The cropping cycle is re-initiated when animal draught power or tractor tillage is used to plough up later successional stages of native vegetation and create a barren, sandy substrate. The extended fallow is a traditional practice dictated by constraints of climate, soil infertility and attempts to manage soil-borne pests such as nematodes. Impacts of modernisation are probably altering some aspects of the traditional cropping cycle in both positive and negative ways (see Section 3.3.4: *Integration of ecological findings*).

The rain-fed fallow consists of a couple of distinct stages in land cover, lumped here as an early stage and a later stage. During the first three to four years, fallow fields are dominated by annual herbs or forbs as an early successional stage. This is locally referred to as *kallpas* in *Aymara* vernacular (Cáceres 1994; Ortega et al 1995; Table 3.3; Plate 3.5). *Kallpas* offers important grazing at certain times of the year (Chapter 5: *The grazing livestock of San José Llanga*). *Kallpas* occurs as small patches (i.e., from 0.25 to 1.0 ha in size; Barrera 1994) interspersed within another, more extensive cover type called *tholares*. *Tholares* is the shrub-dominated, cover type indicative of an advanced stage of successional recovery. *Tholares*

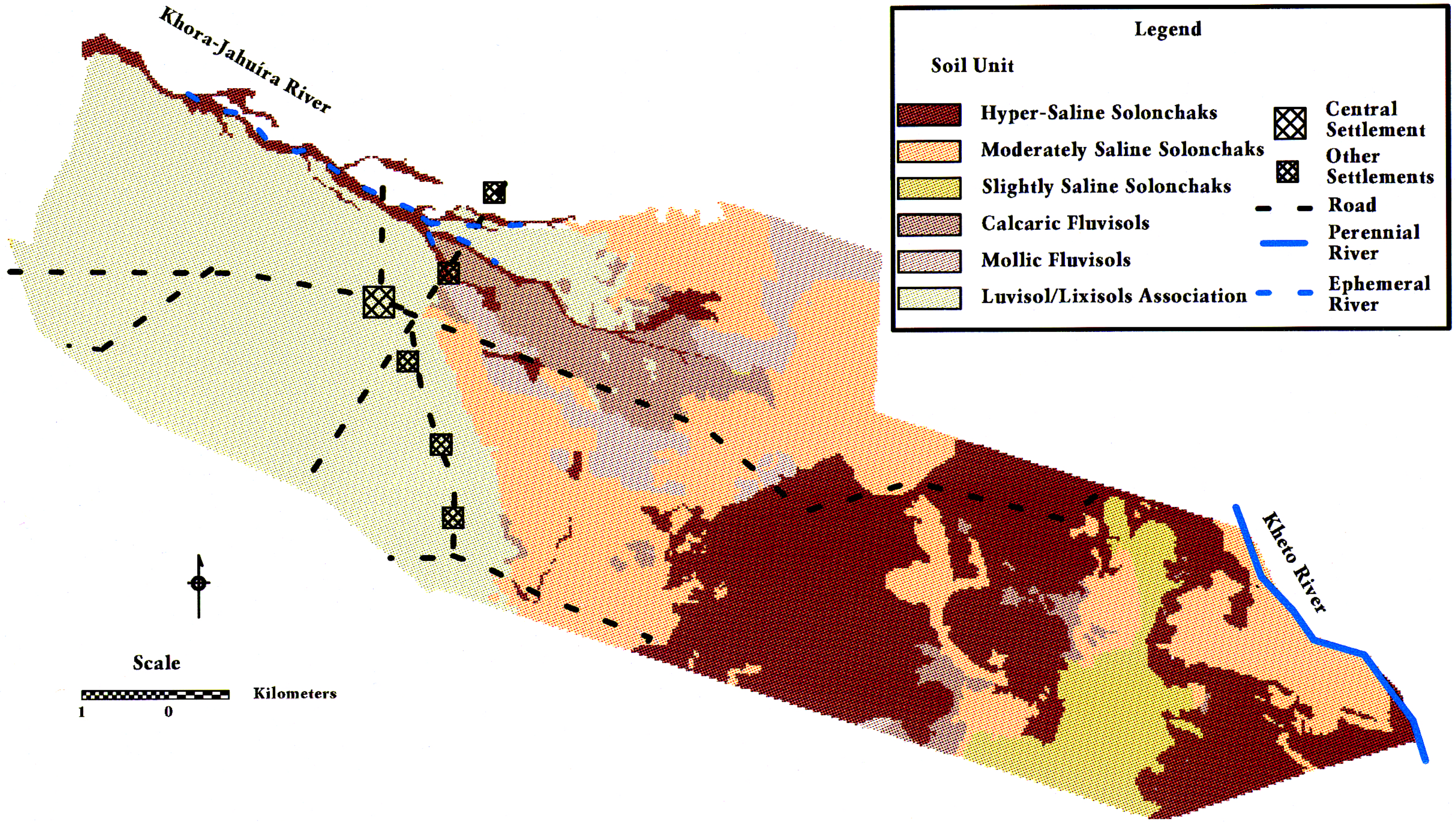


Figure 3.4. Soil units for the agropastoral community of San José Llanga. Settlements and roads are included for orientation. The area covered by this map is 5832 ha (58 km^2). The alluvial plain north of the Khora-Jahuíra River was not surveyed. Soil classification follows FAO/UNESCO/ISRIC (1988) classification. Source: GIS adaption by R.A. Washington-Allen from Treadwell and Libermann (1992).

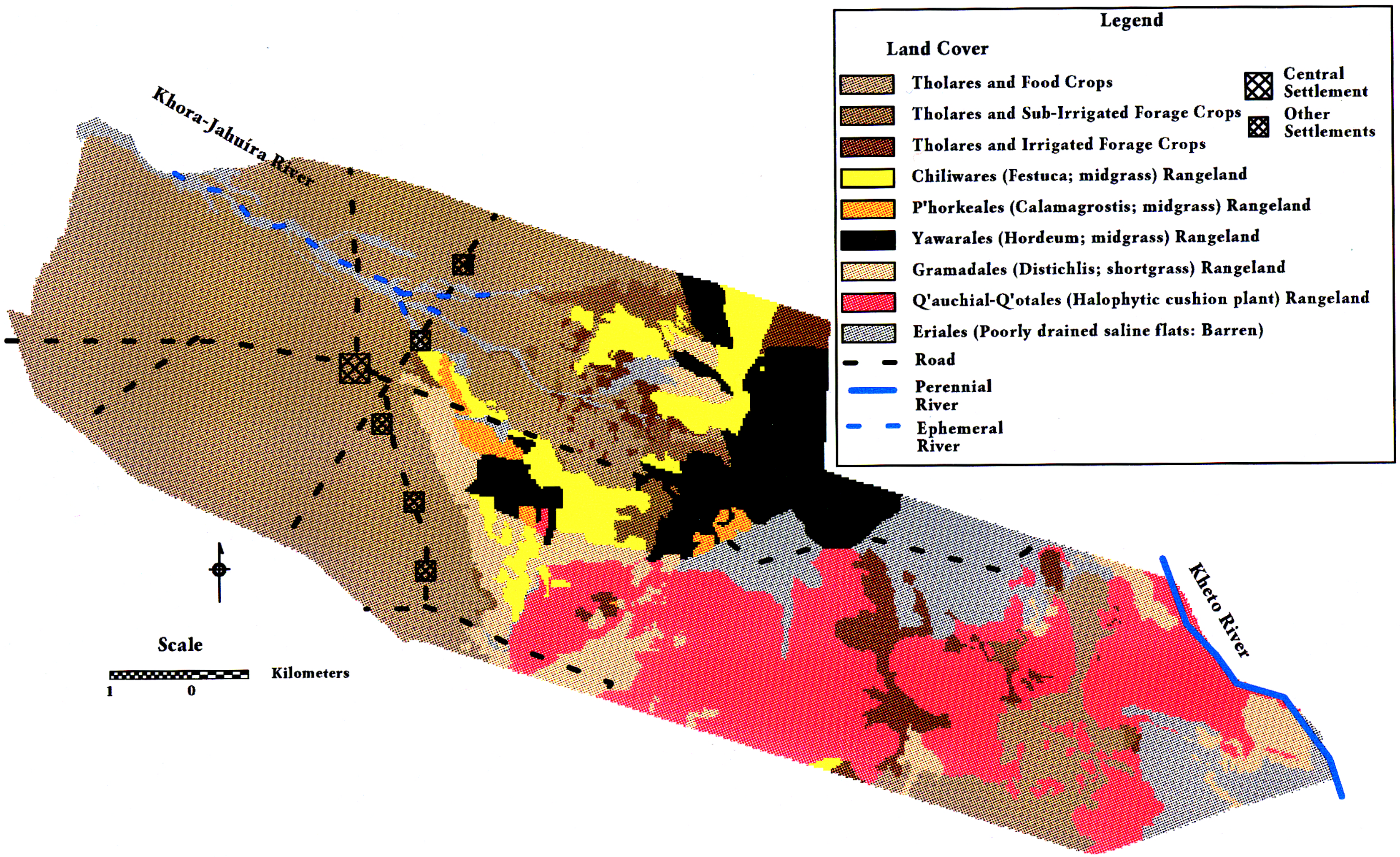


Figure 3.5. Land cover types for the agropastoral community of San José Llanga. Settlements and roads are included for orientation. The area covered by this map is 7200 ha (72 km²). Source: Land cover classification follows Treadwell and Libermann (1992) with GIS adaption by R.A. Washington-Allen.

Table 3.3. *Features of selected land-cover types in San Jose Llanga*. Source: Adapted from Miranda (1995).

Land Cover Type[1]	Characteristic Plant Species	Other Common Plant Species	Soil Unit
Kallpas (early successional herbfields)	*Chenopodium petiolare, Bouteloua simplex,*	*Erodium cicutarium, Tarasa tenella, Heterosperma tenuisecta, Gnaphalium lacteum*	Luvisol/Lixisols, Slightly Saline Solonchaks, Medium-textured Fluvisols
Tholares (late successional shrub-bunchgrass fields)	*Parastrephia lepidophylla, Festuca orthophylla*	*Stipa ichu, Tetraglotchin cristatum, Nasella pubiflora, Astragalus* spp.	Luvisol/Lixisols, Slightly Saline Solonchaks, Medium-textured Fluvisols
Annual forage crops	*Hordeum vulgare, Triticum aestivum*	NA	Luvisol/Lixisols, Slightly Saline Solonchaks, Medium-textured Fluvisols
Food crops	*Chenopodium quinoa Solanum tuberosum*	NA	Luvisols/Lixisols, Slightly Saline Solonchaks
Alfalfares	*Medicago sativa*	NA	Medium-textured Fluvisols, Slightly saline Solonchaks
Q'auchiales-Q'otales	*Salicornia pulvinata, Anthobrium triandrum*	*Atriplex nitrophiloides, D. humilis*	Hyper-saline Solonchaks
Eriales	NA (barren)	NA	Hyper-saline Solonchaks
Yawarales	*Hordeum muticum,*	*Muhlenbergia fastigiata, Eleocharis albibracteata, D. humilis*	Moderately saline Solonchaks
Gramadales	*D. humilis, M. fastigiata*	*E. albibracteata S.pulvinata, A. thriandrum*	Moderately saline Solonchaks
Chilliwares	*Festuca dolichophylla,*	*H. muticum, M. fastigiata, Calamagrostis curvula, D. humilis*	Fine-textured Fluvisols
P'horkeales	*C. curvula*	*H. muticum, F. dolichophylla, D. humilis, M. fastigiata*	Fine-textured Fluvisols

[1]Where *Kallpas* and *tholares* were two stages of crop fallow, while annual forage crops and food crops were currently planted fields. *Alfalfares* were surface and sub-irrigated alfalfa plots. The other six land cover types were on native rangelands.

is characterized by the low-growing shrub *Parastrephia lepidophylla* (or *thola* in *Aymara* vernacular; Plate 3.5). *Tholares* in itself provides important resources for grazing (bunchgrasses) and fuel wood (shrubs). In the SJL region *tholares* succeeds *kallpas* after four to five years of fallow. *Kallpas* and *tholares* are lumped as one mapping unit called "*Tholares* and food crops" in Figure 3.5.

Assuming a cropping sequence of three years on a given field (Barrera 1994), an average field size of 1.0 ha (Barrera 1994), a total of about 2500 fields (C. Jetté, IBTA/SR-CRSP, personal observation) and a cropped:fallow ratio of 1:5 (Norton 1992), we estimated that *kallpas* occupies about 500 ha of the SJL landscape and *tholares* occupies another 1500 ha. It must be noted, however, that these are only rough estimates. A lower estimate would result if figures of Ortega et al (1995) had been used. They estimated SJL had 3000 crop fields averaging 0.36 ha in size, which results in a total coverage of 180 ha for *kallpas*. Barrera's (1994) estimates were used here because he measured about 53 fields selected on a stratified-random basis across three geomorphic units. Using information from Barrera (1994) as well as data from Norton (1992) that 43, 36 and 21% of the cropped fields supported potato, *quinoa* and barley or wheat, respectively, the area planted to various crops can be estimated. From this we surmise that about 395 ha was dedicated to food crops, with 105 ha dedicated to cultivated annual forages, during our study period. More information on cropping and crop yields is reviewed in Chapter 4: *Household economy and community dynamics at San José Llanga*.

Perennial cultivated forage. *Alfalfares* is the vernacular term for irrigated alfalfa fields (Table 3.3; Plate 2.8c). These occur only on the alluvial fan and deltaic deposits. As previously noted, on the alluvial fan alfalfa roots tap slightly saline groundwater (Peña 1994). In the second case alfalfa is flood irrigated with saline water from the Desaguadero River. Based on visual estimates from the map of Treadwell and Liebermann (1992), it appears that the *alfalfares* occupies between 70 to 100 ha of the SJL landscape. As previously mentioned, the *alfalfares* is a vital component of animal production strategies for sheep and dairy cattle. Under local management the alfalfa is treated as a long-lived (20+ years) perennial crop. The preferred alfalfa variety is "Ranger". Other varieties are used depending on seed availability (Dr. H. Alzérreca, rangeland ecologist, personal observation).

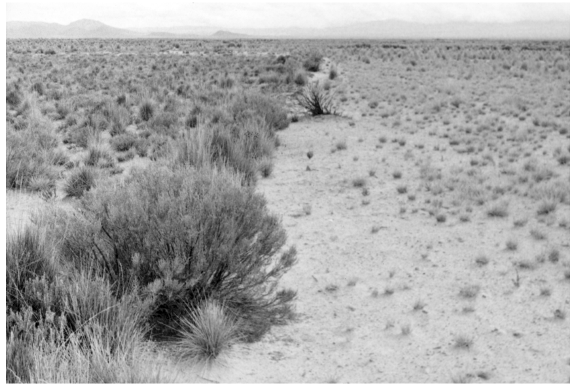


Plate 3.5. *Extremes of the ecological succession on cultivated fields of the alluvial terrace are shown with adjacent fields of climax* tholares *dominated by shrubs and bunch grasses (to the left) and annual herb fields called* kallpas *(to the right). This scene also illustrates the high structural diversity of adjacent sites in the crop plot matrix. Mature* thola *shrubs* (Parastrephia lepidophylla) *are important sources of fuelwood while* kallpas *is important for sheep grazing.* Photograph: Christian Jetté

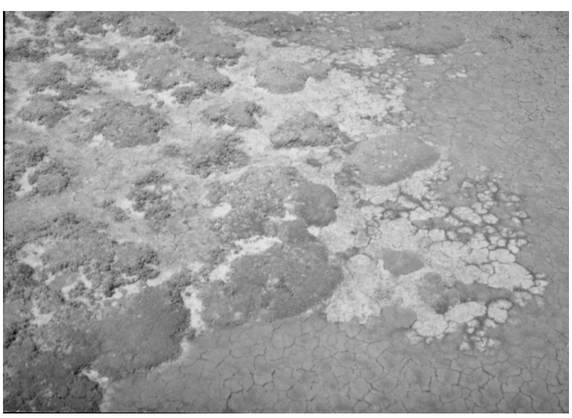
Rangelands. Overall, rangelands add to almost half of the landscape area of SJL. The rangelands consist of native plant communities and supplied grazing for roughly 5000 sheep, 500 cattle and 125 donkeys during the course of our research (Chapter 5: *The grazing livestock of San José Llanga*). The poorer quality rangelands are communally used and managed, while some of the higher quality rangelands may be privately annexed by households if precipitation has been high and grazing resources are abundant. Conversely, all grazing areas become communal during dry years and droughts (see Chapter 5: *The grazing livestock of San José Llanga*). The major land-cover types of rangeland at SJL are briefly defined and described below.

Rangeland having high soil salinity. The association dominated by salt-tolerant cushion plants (*Salicornia pulvinata* and *Anthobrium triandrum*) dispersed on otherwise nearly denuded ground covers about 1700 ha (or 62 % of the grazing lands) at SJL and primarily occurs on hyper-saline Solonchaks at lower points in the fluvio-lacustrine plain (Figures 3.4 and 3.5 and Plate 3.6a,b). In *Aymara* vernacular these associations are referred to as *q'auchiales-q'otales*. Both species of cushion plants are capable of withstanding soils with an ECe >12 S/m. There are a few associated woody and herbaceous species (Table 3.3). Whereas *S. pulvinata* appears to be an obligatory halophyte, *A. triandrum* is not because it also occurs on non-saline soils. For example, Garabito (1995) found that *S. pulvinata* cover tends to peak when ECe varies from 6.0 to 8.0 S/m, while that for *A. triandrum* peaks when ECe <2.5 S/m. Although these vegetation types only provide very limited forage for grazing sheep (<200 Kg DM/ha; Dr. J. de Queiroz, IBTA/SR-CRSP, personal observation), they are valued more for their contributions to supplement the mineral content of livestock diets, with a particular benefit in terms of the flavor imparted to meat. For example, local informants claimed that meat from sheep reared in areas with *q'auchiales* and *q'otales* have superior taste compared to those reared in non-saline environments (Dr. J. de Queiroz, IBTA/SR-CRSP, personal observation). Such sheep meat may have a premium price in local markets (Dr. H. Alzérreca, rangeland ecologist, personal observation).

Rangeland having moderate to low soil salinity. *Eriales* is the name ascribed to barren patches of saline rangelands that occur across 280 ha in the central portion of the fluvio-lacustrine plain (Table 3.3; Figures 3.4 and 3.5). Contrary to our expectations, *eriales* were not necessarily more saline than *q'auchiales, q'otales* or even some areas of well-vegetated *gramadales* (Garabito 1995; Miranda 1995; *gramadales* are described below). This is interpreted to indicate that soil salinity is not the only reason for the occurrence of *eriales*. Garabito (1995) presents evidence to support the hypothesis that populations of *S. pulvinata* are invading the *eriales*. In other cases we observed where stands of the perennial grass *H. muticum* (a species associated with non-saline soils; see below) had colonised patches of previously barren *eriales*. We suspect that *eriales* reflect a past hydrologic regime when the central portion of the fluvio-lacustrine plains was submerged for long periods of time. We believe that the frequency and duration of floods at SJL have diminished over the past decade, and this has allowed a variety of salt-tolerant and other plants to recently invade and grow on what once were totally barren patches.

Yawarales are vegetation stands characterized by *H. muticum*, a perennial, erect grass with a wispy panicle locally known as *yawara* in SJL (Plate 3.7). Associated species were described by Massy (1994) and are listed in Table 3.3. Stands of *H. muticum* are regarded as very valuable for grazing by sheep and cattle (Ramos 1995). *Hordeum muticum* communities also occur on moderately saline Solonchak soils within the fluvio-lacustrine plain, with the largest patch located about six kilometers east of the main barrio of SJL (Dr. J. de Queiroz, IBTA/SR-CRSP, personal observation). Access to distant patches of yawarales is made difficult during periods of heavy rainfall due to poor drainage characteristic of the soils of the fluvio-lacustrine plains. The *yawarales* occupy about 450 ha of SJL overall.

The *gramadales* consist of heavily grazed patches of vegetation dominated by perennial, low-growing (or prostrate) and stoloniferous grasses such as *D. humilis* (or *chiji blanco*) and *M. fastigiata* (or *chiji negro*). This community is depicted in Plate 3.8. The balance between these two species shifts with changes in soil salinity; *D. humilis* becomes



a

b

Plate 3.6 (a,b). *Land cover (*q'auchiales *and* q'otales*) associated with the hyper-saline Solonchaks of the fluvio-lacustrine plain: (a) Close-up of key species such as* Salicornia pulvinata *on a* q'auchiales *site and (b) a wide-angle view of a* q'otales *site with* Anthobrium triandrum. Photographs: (a) Brien E. Norton and (b) João S. de Queiroz more dominant as salinity increases (Garabito 1995). Associated species were initially described by Massy (1994) and are listed in Table 3.3. This vegetation type is restricted to about 520 ha of poorly drained, mostly salt-affected soils within the fluvio-lacustrine plain (Dr. J. de Queiroz, IBTA/SR-CRSP, personal observation). It tends to skirt the boundary between the fluvio-lacustrine plain and the alluvial terrace (Figures 3.4 and 3.5). By virtue of its position on the landscape the *gramadales* is heavily used for grazing throughout the year (Victoria 1994; Ramos 1995), but is not among the highest quality site-types (below). Where soil salinity has an ECe <1.0 S/m, we believe that *gramadales* result from heavy grazing which has eliminated highly palatable species such as *H. muticum* (Dr. J. de Queiroz, IBTA/SR-CRSP, personal observation). The carpet-like canopy created by *D. humilis* and *M. fastigiata* appears to be extremely stable and resistant to incursions by other, possibly less-tenacious species. This interpretation is supported by the fact that *H. muticum* grows well along vehicle tracks where the dense canopy typical of gramadales has been opened. Another factor may be that *H. muticum* benefits from water accumulation in vehicle tracks (Dr. H. Alzérreca, rangeland ecologist, personal communication). Thus, we have speculated that patches of *gramadales* in heavily grazed areas represent a degraded, but stable, vegetation state. These may be especially prevalent in "sacrifice zones" nearer to homesteads and corrals which are subject to continuous grazing. It is important to note, however, that this label of "degradation" is from the standpoint of livestock production. Due to its low-growing habit and relatively low productivity [i.e., 3.87 t DM/ha reported by Prieto and Yazman (1995)], the *gramadales* are regarded as most suitable for grazing by Criollo sheep. Improved sheep may also graze *gramadales* for short periods of time. Cattle are commonly precluded from grazing *gramadales* due to the low-growing habit of the dominant forages (Dr. H. Alzérreca, rangeland ecologist, personal observation).

Chilliwares derive its name from *chilliwa*, the *Aymara* name given to *Festuca dolichophylla*, the characteristic species of this vegetation type (Plate 3.9). This highly productive (7.6 t DM/ha; Prieto and Yazman 1995) vegetation type occupies about 300 ha (or 11%) of the fluvio-lacustrine plain on fine-textured Fluvisols to the west. Soils are high in OM and relatively low in soluble salts (Miranda 1995). Common species within the *chilliwares* are listed in Table 3.3. The *chilliwares* are considered an important grazing resource by the campesinos of SJL.

P'horkeales are vegetation stands characterized by *Calamagrostis curvula* (or *p'horke* in *Aymara* vernacular), a coarse, rhizomatous grass of moderate palatability (Ramos 1995). These sites occur on <5% of the fluvio-lacustrine plain. Associated species are listed in Table 3.3. According to the campesinos, *C. curvula* tends to increase with heavy grazing at the expense of more palatable grasses such as *H. muticum* and *F. dolichophylla*.

Plate 3.7. *Land cover associated with mixed-grass communities called* yawarales *on the fluvio-lacustrine plain (peak growth following the rainy season). Species such as tall* Hordeum muticum *are regarded as valuable forages.* Yawarales *occur on moderately saline soils.* Photograph: João S. de Queiroz

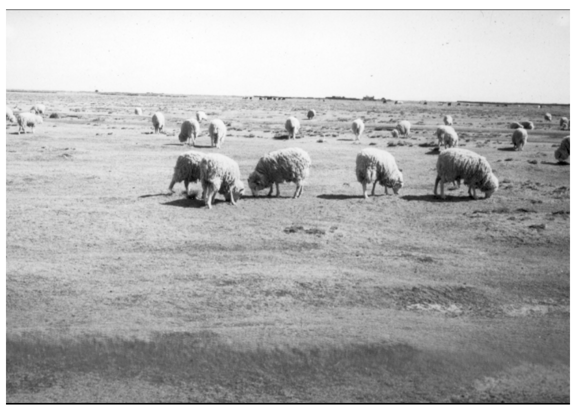


Plate 3.8. *Land cover associated with the short-grass communities called* gramadales *which occurs between the fluvio-lacustrine plain and alluvial terrace. Species such as* Distichlis humilis *are low-growing and tolerant of moderate salinity. The* gramadales *is one of the few range types where plant species composition has likely been degraded by heavy grazing, especially near settlements where livestock activity increases.* Photograph: João S. de Queiroz

Plate 3.9. *Land cover associated with the mixed-grass communities called* chilliwares *which occur on moderate to lightly saline soils on the fluvio-lacustrine plain. Species such as* Festuca dolichophylla *are regarded as valuable forages.* Photograph: Christian Jetté

When *p'horkeales* are heavily grazed *H. muticum* is found primarily within tufts of *C. curvula* where it can escape repeated defoliation (Dr. J. de Queiroz, IBTA/SR-CRSP, personal observation). *P'horkeales* are highly productive [7.9 t DM/ha; Prieto and Yazman (1995)] and tend to be heavily grazed due to their proximity to the main barrio of SJL where livestock are corralled at night.

3.3.3 Natural resource dynamics

3.3.3.1 Photosynthetic activity of herbaceous vegetation

In rangeland environments worldwide it is typical that growth of vegetation is related to periods when temperatures are favourable and there is a positive balance for soil moisture. These conditions most often occur during and shortly after the main wet season(s). In very hot climates where evapotranspiration rates are high and the water holding capacity of soils is low, growing periods can thus be very short. Woody plants often have longer growth periods than herbaceous plants in such settings because the deeper root systems of woody plants provide access to soil moisture unavailable to herbaceous plants which can only exploit upper soil horizons (Coppock 1985). Conversely, length of growing period increases when climates are more moderate and water holding capacity of soils is higher. This picture is made more complicated, however, when herbaceous plants gain access to reliable ground water, and the linkage between plant growth and precipitation events is weakened. The rangelands of SJL exhibit complexity in patterns of photosynthetic activity. This can be traced to variation in geomorphology, associated quality and accessibility of ground water, and other features of climate (e.g., moisture, temperature) and forage interactions.

Considering first the alluvial terrace, photosynthetic activity by herbaceous cultivated and native species is closely coupled with rainfall. The elevated nature of the alluvial terrace means that herbaceous plants do not have access to ground water. Thus, herbaceous plant growth on the alluvial terrace is largely initiated with the onset of the rainy season in November or December and may continue to June. Harvest time for potatoes is typically in April, while harvest time for barley occurs in May or June (Dr. J. de Queiroz, IBTA/SR-CRSP, personal observation). Native plants such as thola shrubs or herbaceous species may grow well into the cold, dry season if soil moisture is available (Peréz 1994).

In contrast to the alluvial terrace, situations in the low-lying alluvial fan and fluvio-lacustrine plain are different. Washington-Allen's (1994) analysis of six satellite images obtained for 1972-87 revealed limited photosynthetic activity (as indicated by TNDVI) during the late dry-season months of August (1986-7) and September (1987) in rangeland areas covered by *gramadales* (or *Distichlis/ Muhlenbergia*), *p'horkeales* (or *Calamagrostis*), *yawarales* (or *Hordeum*) and *chilliwares* (or *Festuca*). Vigorous photosynthetic activity, however, was evident in the same vegetation types at the very end of the dry season (October) in 1986, through the end of the following wet season in May, 1987. The most persistent green patches were in the vicinity of the boundary between the alluvial terrace and fluvio-lacustrine plain, an area dominated by *gramadales*, *p'horkeales* and *chilliwares*. These are locations where water salinity is low and the water table is relatively closer to the soil surface (Peña 1994). A similar pattern was observed for alfalfa on the alluvial fan in 1994, which was also an "average" rainfall year (Dr. J. de Queiroz, IBTA/SR-CRSP, personal observation). These alfalfa fields were dormant in the cold, dry season but resumed growth by early October, 1994, when green forage was badly needed for livestock. This surge of alfalfa production, however, was probably mitigated by the frequent hard frosts which occurred until mid-November when air temperature began to increase.

We interpret the results of Washington-Allen (1994) and other field observations to suggest the following: for low-lying rangeland plant communities of SJL where ground water is accessible to herbaceous plants but happens to be less saline, length of growing season is determined, to some extent, by temperature (i.e., restricted by hard frosts) rather than rainfall. Furthermore, because availability of ground water is only loosely coupled to local rainfall (Peña 1994), the patches of sub-irrigated, higher quality range and the cultivated alluvial fan serve as important buffers which help the system mitigate against climatic variability. These resources resemble one facet of "key resources" for rangeland systems proposed by Scoones (1991).

3.3.3.2 Biomass dynamics for selected rangeland vegetation types

Prieto and Yazman (1995) estimated monthly standing crops for three vegetation types in the low-lying rangelands (Figure 3.6). For *Calamagrostis* (*p'horkeales*) the peak biomass (1.8 t DM/ha) occurred in March; rates of ANPP varied from 3 to 6 kg DM/ha/day in January and February, respectively. For *Festuca* (*chilliwares*) the peak biomass (2.0 t DM/ha) also occurred in March; rates of ANPP were around 21.6 kg DM/ha/day over the preceding two months. In contrast, for *Distichlis/Muhlenbergia* (*gramadales*) the peak biomass was much lower (0.9 t DM/ha) and occurred in April; rates of ANPP averaged about 7 kg DM/ha/day. Standing crops precipitously declined from May to August as the cold, dry season progressed. Losses of biomass were largely due to weathering in these protected sites.

It is difficult to elaborate on results of Prieto and Yazman (1995) because they did not provide climate data for their period of study. It is surmised, however, that rates of production would shift at least slightly from year to year depending on the timing of rainfall and hard frosts. Because each of the three vegetation types is situated over readily accessible ground water, the apparent abrupt decline in ANPP beginning in April is interpreted to suggest that the growing period was curtailed by cold temperatures (frosts) rather than lack of moisture. According to data presented in Table 3.1, the incidence of frosts increases 10-fold in April compared to that for December through March.

3.3.3.3 Seasonal changes in CP content for selected native forages

Concentration of crude protein (CP) for three important forage species studied by Prieto and Yazman (1995) peaked either in January or February (Figure 3.7). Peak values coincide with the period of early growth having higher soil moisture and warmer temperatures. Table 3.4 shows seasonal quality of forages selected by livestock. This illustrates the high nutritive value of forbs in the growing period. It also illustrates that CP content declined for grasses and forbs in the dry season relative to the growing season. Results overall were thus consistent with young plants having higher relative concentrations of cell solubles relative to cell wall and higher proportions of leaf versus stem (Van Soest 1994).

The overall pattern that forage quality declines with time (i.e., with increasing plant maturity) is in agreement with the literature (Van Soest 1994). The small number of samples analysed each month, however, makes it impossible to assess meaningful variation among species across months. The data are interpreted to suggest some interesting trends, and some speculation is provided. The pattern can be interpreted to indicate that some species may decline more rapidly in forage value than others. For example, CP content for *C. curvula* and *M. fastigiata* appeared to linearly decline to values between 5.0 and 6.1% by the second half of the cold, dry season. Considering conventional guidelines that dietary CP content should not decline <7.0% for proper maintenance of ruminal fermentation (Van Soest 1994), one can infer that tissues of *C. curvula* and *M. fastigiata* were below minimum requirements as early as May and July of this year, respectively. In contrast, CP content for *H. muticum* may have remained above 8.0% through August. These results agree with ranking of forage species by campesinos at SJL reported by Ramos (1995) in which *H. muticum* was rated as the highest quality native species for grazing, while *M. fastigiata* and *C. curvula* were ranked as "average" forages. How *H. muticum* could maintain a higher CP value for a greater length of time is unclear. The simplest explanation is related to species and site factors: *H. muticum* may exist in sites where it can better access the ground water, and therefore remain greener longer. No root excavations were performed on this species to confirm this idea, however. In addition, *H. muticum* could have a higher degree of frost tolerance (previously discussed). It is common to observe green *H. muticum* near permanent sources of fresh water at the height of the cold, dry season. This can be interpreted to suggest that *H. muticum* is more sensitive to moisture

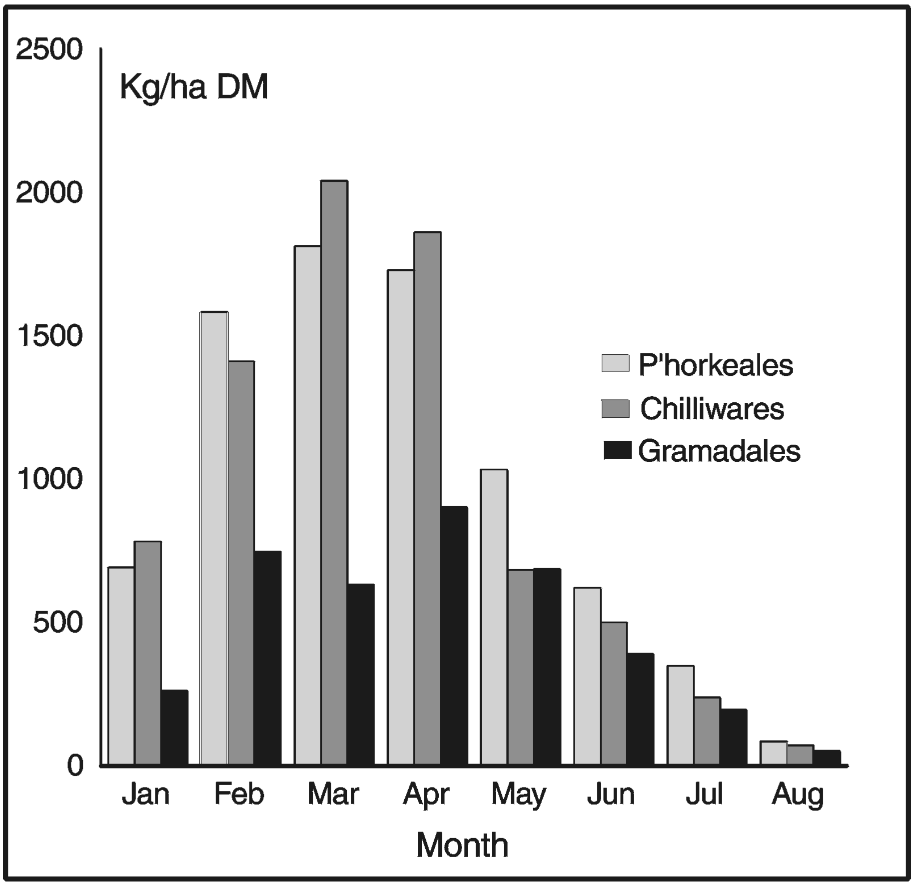


Figure 3.6. *Monthly dynamics of standing biomass (dry matter in kg/ha) for three range community types protected by exclosures at San José Llanga from January through August, 1995. Each bar value represents the mean of three observations.* Source: Prieto and Yazman (1995)

availability than cold (Dr. H. Alzérreca, rangeland ecologist, personal observation).

3.3.3.4 Vegetation change on fallow fields

The character of vegetation in fallow fields changes with length of fallow. As vegetation composition and structure shifts so does its value for grazing (Ramos 1995) and fuel wood (Barrera 1994). Communal rules govern use of fallow land, and the rules change with length of fallow (Chapter 5: *The grazing livestock of San José Llanga*). The sheer size (up to 500 ha) and productive potential of fallow on the alluvial terrace makes fallow a vital resource to the community of SJL. An understanding of vegetation dynamics in fallow fields is crucial, therefore, to understanding agropastoral production strategies.

Analysis of space-for-time relations has been interpreted to suggest that total plant cover on fallow fields remains relatively constant during the first five years (Cáceres 1994). A focus on total cover, however, masks large, gradual changes in cover composition that occur according to plant species. For example, Ramos (1995) found that across six or more years of fallow the relative abundance of coarse perennial grasses (i.e., *F. orthophylla*) and shrubs (i.e., *P. lepidophylla*) increased by nearly 10- and 20-fold, respectively, while cover of palatable annual forbs and grasses declined (Figure 3.8a,b). The decrease in cover of annual *Chenopodium petiolare* [the most desirable forage within fallow fields, according to Ramos (1995)] after the fourth year of fallowing is of particular importance, along with declines in cover of other palatable annuals such as *Boutelona simplex* and *Tarasa tenella*. This temporal change in plant species composition and grazing value justifies differing controls exerted by the community

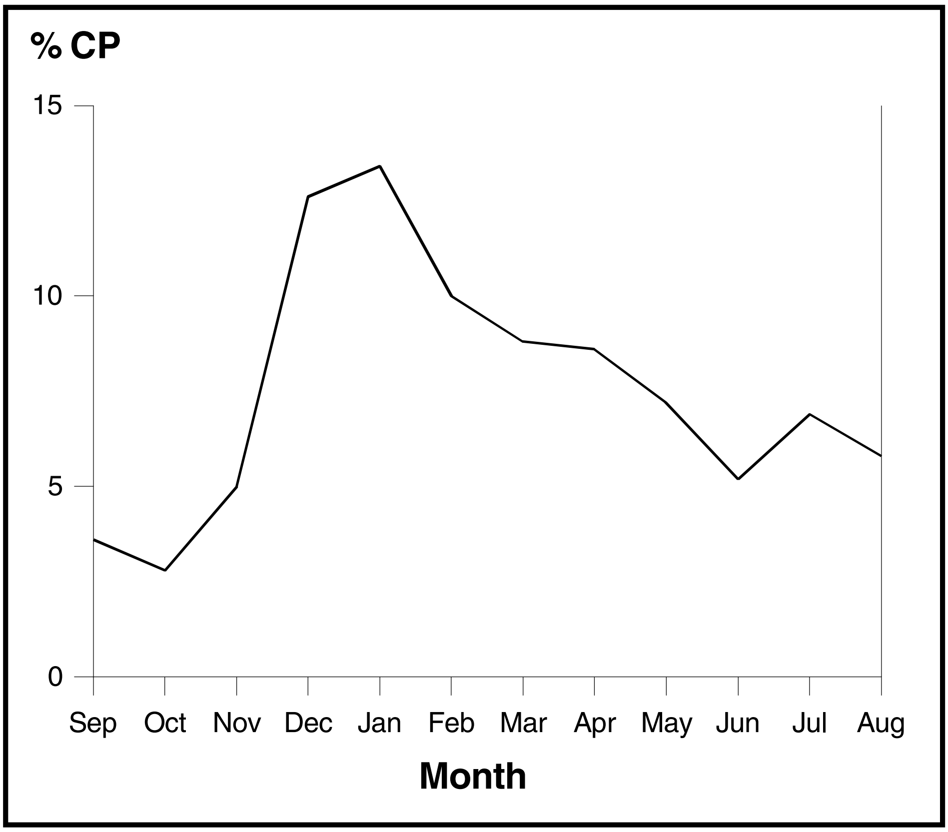


Figure 3.7. *Crude protein content (CP%) on a dry-matter basis of important grass, forb and shrub forages selected by three livestock species (i.e., sheep, cattle and donkeys) by month throughout the year at San José Llanga during 1992-3. The period November through March approximates the main growing season for rain-fed plants while April through October constitutes the dry season. Each data point represents the mean for 14-15 observations. Forages were selected on a mix of sites including crop fallow (mostly forbs) and rangeland.* Source: Lopéz (1994, 125)

over fallow fields. Those in fallow <4 years are treated as a privately owned and managed resource, whereas those in fallow for longer periods are treated as common property (Ramos 1995). The exact mechanisms of successional changes on fallow fields remain unclear (see below).

In another study that focused exclusively on perennial plant species on fallow fields, Queiroz et al (1994) found that the suite of perennial species in fallow fields tended to stabilise after the fifth year of fallowing. On the other hand, density and cover of the shrub *P. lepidophylla* (or *thola*) continued to increase, reaching peak values between eight to 10 years on the Luvisol/Lixisol soil association and 11 to 12 years on the medium-textured Fluvisols of the alluvial fan (Figure 3.9a,b). A decrease in cover and density of shrubs in fields under fallow for longer periods may be due to losses from fuel wood harvesting (Barrera 1994) or age-related shrub mortality. Shrub density and cover on medium-textured Fluvisols was over twice that on Luvisols/Lixisols (Figure 3.9a,b). This difference could be related to the more accessible water table for the Fluvisols associated with the alluvial fan.

As reviewed elsewhere (Chapter 4: *Household economy and community dynamics at San José Llanga*) biomass of mature *thola* is extensively collected by the campesinos. It is used either in the home as fuel for cooking (especially bread) or to generate income. *Thola* is sold to traders who fill large trucks with the material and transport it to urban centres for fuel (Plate 3.10a,b). Given this importance of *thola* as fuel, a study was conducted by Barrera (1994) to determine biomass yields associated with mature plants (>40 cm in height) which are the ones typically harvested for fuel. Plants are harvested with a pick and collected

Table 3.4. *Crude protein content (CP%) on a dry-matter basis of 180 samples of important grass, forb and shrub forages[1] selected by three livestock species (i.e., sheep, cattle, and donkeys) during the wet and dry season, and pooled over both seasons, at San José Llanga during 1992-3. Forages were selected from a mix of sites including crop fallow (mostly forbs) and rangeland.* Source: Lopéz (1994).

	Time Period							
	Growing Season[2]			Dry Season[2]			Overall[3]	
Forage Class	n	$\bar{x}$	SE	n	$\bar{x}$	SE	n	$\bar{x}$
Grasses	32	8.6	0.79	48	6.2	0.40	80	7.1a
Forbs	27	12.9	1.00	29	7.3	0.58	56	10.0b
Shrubs	7	8.2	1.46	7	8.4	1.89	14	8.3ab

[1]Hand-plucked samples simulated materials selected by livestock (Lopéz 1994).

[2]Where the growing season for plants dependent on rainfall was November through March and the dry season was April through October.

[3]Means in this column accompanied by the same letter (a,b) were not significantly different (P>0.05) according to Fisher's LSD test (Lopéz 1994). Means were based on 14-15 samples each.

material includes aboveground and belowground wood. Barrera (1994) estimated that up to 40% of the harvested biomass per plant may be comprised of the crown and upper root mass. Harvestable, standing-crop biomass (air-dried basis) for *thola* peaked between 8 and 10 years of fallowing on Luvisols/Lixisols and 11 to 15 years of fallowing on Fluvisols (Table 3.5). The peak biomass accumulation on fluvisols was 4-fold that on Luvisols/ Lixisols. The proportion of biomass suitable as fuelwood increased as plants aged, ranging from 6% for plants in fields fallowed <3 years to over 50% for plants in fields fallowed for >11 years.

The description of vegetation changes on fallow fields presented above is interpreted to suggest that: (1) the value of forage decreases with duration of fallow; (2) there is little further change in the suite of species present within a given field after the fourth or fifth year of fallow; (3) the production of fallow field vegetation varies tremendously with soil type at SJL; (4) there is a pronounced change over time in vegetation structure and woody biomass accumulation up to around 11 years of fallowing; and (5) secondary succession on fallow fields is somewhat predictable.

Studies on the agroecology of fallowing have been conducted by other investigators at the campesino community of Pumani, located 50 km to the northeast of the Cantón of SJL. While some of the work at Pumani has revealed that fallowing for up to five years increased soil fertility, there were no clear effects of fallowing for more than five years on soil nutrient content (Hervé 1994). Also in Pumani, Cary and Hervé (1994) were able to show only a weak correlation between length of fallow and soil microbial populations. Instead, they found that during the first five years of fallow microbial activity was more strongly influenced by the preceding cropping regime. At a similar altitude to SJL, in the Department of Cusco, Peru, Blanco (1994) found that the number of potato nematodes decreased with length of fallow for a period of up to five years, beyond which no nematodes were found.

Taken together with our studies in SJL, the results of Blanco (1994), Hervé (1994) and Cary and Hervé (1994) may be interpreted to indicate that from the standpoint of grazing value, pest control and soil fertility there is little justification for extending fallow periods on the semi-arid puna be-

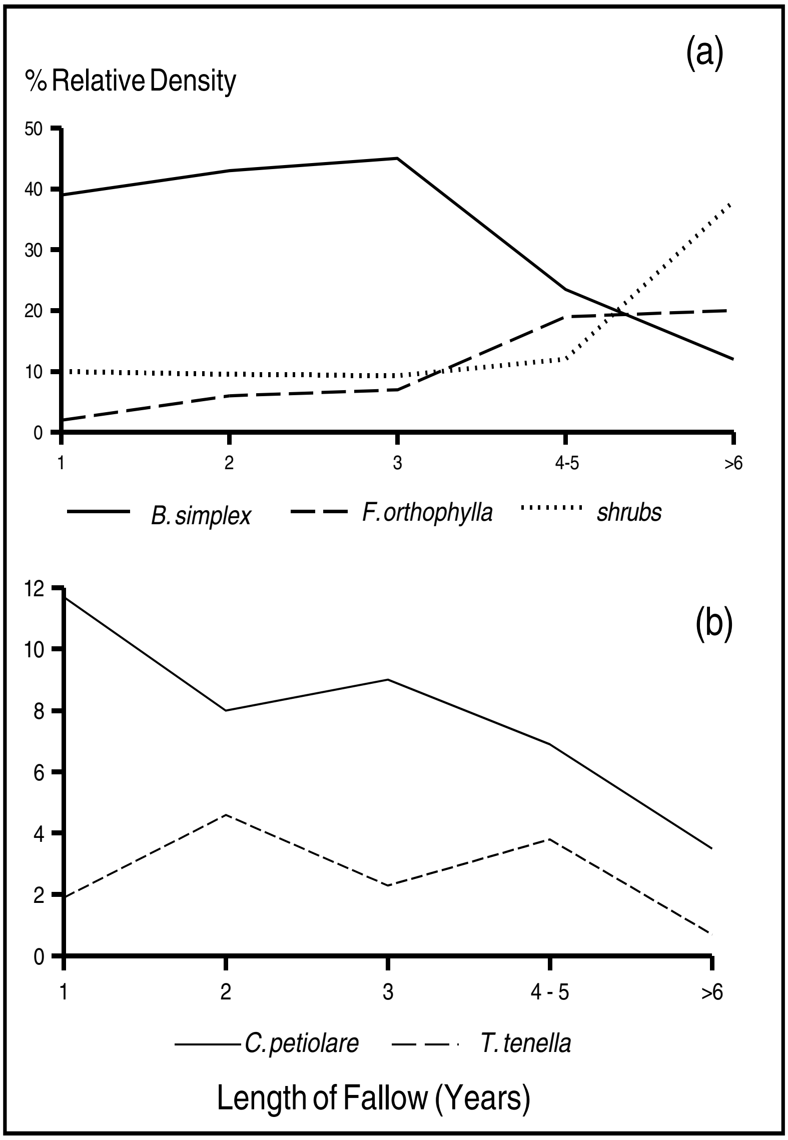


Figure 3.8 (a,b). *Changes in relative crown cover (%) for selected plant species over time on fallow fields on the alluvial terrace at San José Llanga: (a) is where species cover was calculated on the basis of total vegetation cover while (b) is where species cover was calculated on the basis of total cover that includes bareground, plant litter, etc. In both cases cover response over time was regarded as a continuous response variable.* Source: Adapted from data in Ramos (1995)

yond five years. If this is true, the paradox is that shortening the fallow period at SJL by an average of six (or more) years could have a large effect on boosting food production if the area devoted to cropland is limiting. On the other hand, however, continued increases in woody biomass (and thus fuelwood) with increased length of fallow up to about 11 years, and the possibility to sustainably harvest and market fuel wood, could suggest that fallow periods longer than five years are justified from a multiple-use perspective that includes fuel wood production (Dr. J. de Queiroz, IBTA/SR-CRSP, personal observation). Alternatively, results from Pumani may not be transferable to SJL, and the long fallow at SJL may be symptomatic of a gradual deterioration in soil quality and variable suitability of plots for sustained cultivation (C. Jetté and Dr. L. Markowitz, IBTA/SR-CRSP, personal communications). In addition, fewer households may be regularly engaged in cultivation due to the increasing prevalence of economic activity off-farm. Thus a lengthening fallow may be related

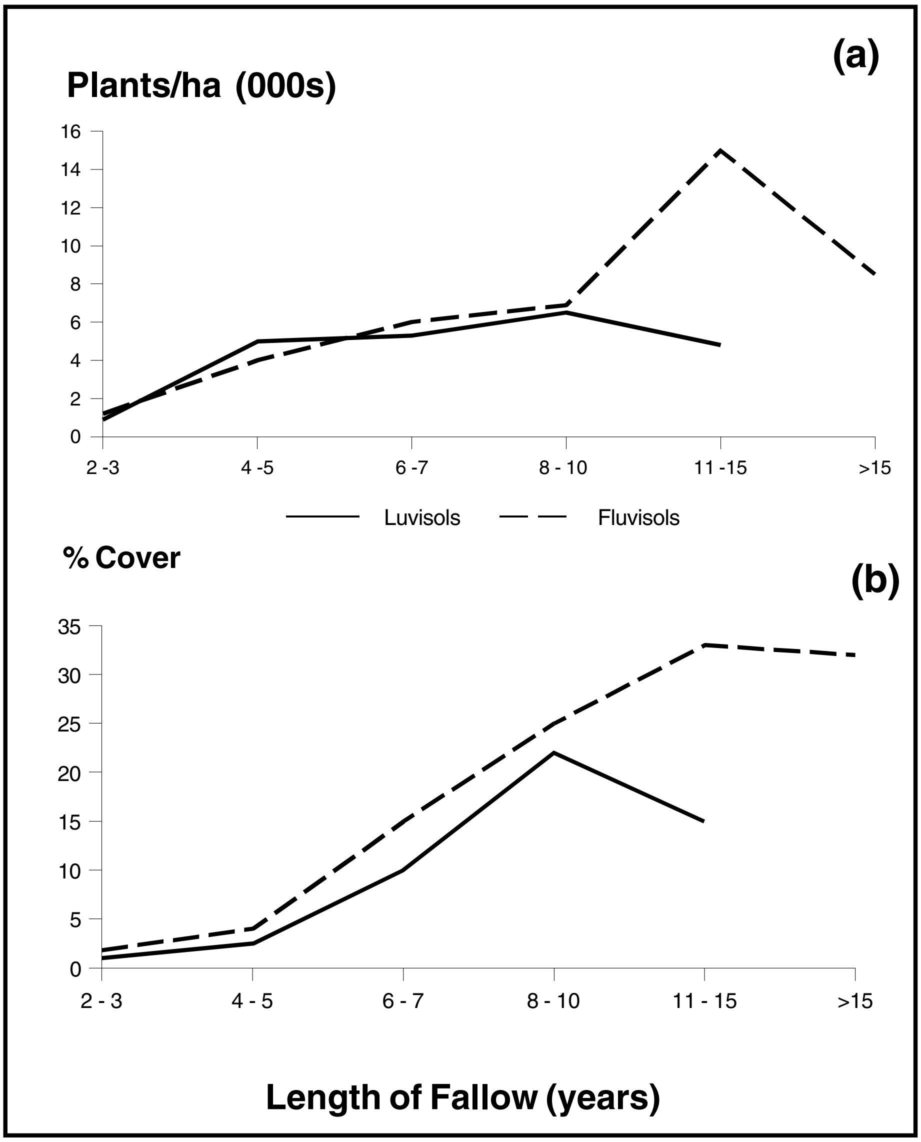
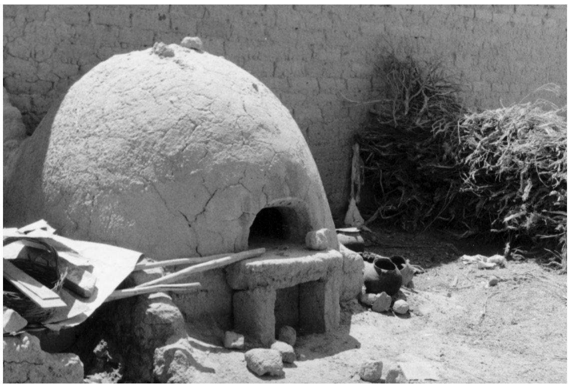


Figure 3.9 (a,b) *Changes in relative crown cover (%) and density (no./ha) for the shrub* Parastrephia lepidophylla (thola) *over time on fallow fields occuring on: (a) Luvisol/Lixisols associations and (b) medium-textured Fluvisols. Cover and density responses over time were regarded as continuous response variables. Source: Adapted from Queiroz et al (1994)*

simply to more absentee farmers and variability in access to labour (Dr. L. Markowitz, IBTA/SR-CRSP, personal communication). In sum, many social and biological factors are likely responsible for determining duration of fallow periods.

3.3.3.5 Soil movement among fallow fields

Although Barrera's (1994) rudimentary study of soil movement in fallow fields of SJL was statistically deficient, the results provide some practical insights into effects of wind erosion on the alluvial terrace. Barrera (1994) concluded that during the cold, dry season there was considerable redistribution of soil among fallow fields, but not necessarily a net loss overall. Between two consecutive monthly readings the level of the soil surface either rose or dropped around each of five, randomly located rods in each of the five fallow fields. The variation in soil-surface level was more pronounced in fields under fallow for <4 years; these differences ranged up to 9 mm per rod. These younger fields were characterised by having lower total plant



a

b

Plate 3.10 (a,b). *Uses of local shrubs* (P. lepidophylla *or* thola) *including: (a) Fuel for baking bread in a traditional kiln at San José Llanga and (b) export of shrubs via truck to generate cash income for local campesinos. Truck drivers then sell the shrubs in urban areas.* Photographs: Christian Jetté

cover than older fields, and thus wind movement of surface soil on younger fields could be more pervasive.

By assuming a soil bulk density of 1.5 g/cm^3 and averaging changes in soil surface level across the five rods in each field the three months of observation, Barrera (1994) estimated the weight of soil material deposited or removed within the five fields. Every field had zones of deflation and deposition; however, those under fallow for <4 years experienced a net soil loss, whereas fields under fallow from five to six years experienced a net soil gain. More specifically, fields under fallow from two to three years lost 69 and 33 metric tons of soil per hectare, respectively. Fields under fallow from five to six years gained 30 and 42 metric tons of soil per hectare.

In spite of its limitations, Barrera's (1994) study can be interpreted to indicate that a large proportion of wind-blown soil remains within the alluvial terrace. This localised redistribution occurs because current agricultural practices produce a checkerboard of small fallow fields supporting physiognomically distinct vegetation types. Thus, soil materials blown from cropped and recently fallowed fields are trapped by adjacent areas supporting a significant cover of shrubs and perennial grasses. Were larger contiguous areas to be subjected to cultivation in a given year, the magnitude of soil erosion in terms of spatial displacement and amount of material lost to the system is bound to dramatically increase (Dr. J. de Queiroz, IBTA/SR-CRSP, personal observation). On the other hand, even under the current pattern of land-use, as the soil material is transported between fields fine-sized clay and silt particles are removed in suspension, which reduces the nutrient- and water-holding capacity of the surface horizon. In some cases, surface soil removal has exposed the hard argic "B" horizon typical of Lixisols and Luvisols. Thus, the adoption of practices to control soil erosion could enhance the performance of the agronomic component of the SJL agropastoral system. A return to using regular application of sheep manure to cultivated fields could do much to increase OM content of soils; this would enhance the structure of soil surfaces, increase fertility, better distribute seeds of annuals and reduce erosion (Dr. J. de Queiroz, IBTA/SR-CRSP, personal observation). In recent times chemical fertilisers have been purchased by the campesinos at SJL to replace animal manures. Manures, in turn, have increasingly become a cash crop sold out of the system. These and related issues are reviewed at length in Chapter 4: *Household economy and community dynamics at San José Llanga*.

3.3.3.6 Ecotone migration in the saline rangelands

Garabito (1995) studied ecotones in the saline areas of the fluvio-lacustrine plains. Ecotones are boundaries between ecological site types. Ecotones may exhibit sudden or gradual changes in ecological features, and this gives clues as to what

Table 3.5. *Accumulation of total above-ground biomass and biomass as fuel wood for specimens of* Parastrephia lepidophylla *on medium-textured Fluvisols and Lixisols/Luvisols at San José Llanga during 1992-3. Fuel wood biomass corresponds to specimens >40 cm in height.* Source: Adapted from Barrera (1994).

Years Site was Fallowed	Luvisols/Lixisols		Medium-textured Fluvisols	
	Biomass (kg ha^{-1})	Fuel wood[1] (kg ha^{-1})	Biomass (kg ha^{-1})	Fuel wood (kg ha^{-1})
2-3	168	10	492	79
4-5	196	16	3766	736
6-7	1096	167	--	--
8-10	1697	351	4251	3781
11-15	733	558	7221	5735
>15	--	--	5929	3053

[1]Shrubs harvested for fuel were removed with a pick and harvested material included a significant portion of roots. Barrera (1994) estimated that up to 40% of plant biomass harvested for fuel wood was below-ground material.

factors influence the shift from one site type to another. Garabito's work has been interpreted to suggest that in addition to the short- and medium-term ecosystem dynamics previously discussed, portions of the study area are subject to longer-term changes. He investigated changes in the size structure of salt-tolerant, cushion-plant populations (i.e., *S. pulvinata* and *A. triandrum*) and soil parameters across three ecotones. Results for two ecotones are presented in some detail below, and comments are provided on the third ecotone.

In his investigation of an ecotone between *Salicornia* (*q'auchial*) and *Anthobrium* (*q'otal*) community types, Garabito (1995) focused on the population of *S. pulvinata* plants, a key dominant of the more saline zone. Garabito (1995) found that the proportion of large *S. pulvinata* plants decreased nearer to the abrupt boundary between the two vegetation types (Figure 3.10a). In contrast, the proportion of small *S. pulvinata* plants increased near the abrupt boundary. To illustrate, 4.5-m deep into the *Salicornia* (*q'auchial*) community type *S. pulvinata* plants with a diameter between 41to 60 cm accounted for 22% of the total, while those with diameter between 21 to 40 cm accounted for another 28% of the total. In contrast, just half a meter from the abrupt boundary, 97% of all *S. pulvinata* plants were very small with diameters <21 cm. Taking diameter as a proxy for plant age, Garabito (1995) concluded that the wedge of small plants at the abrupt boundary indicated that *S. pulvinata* was invading the other community type. This large change in the size structure of the *S. pulvinata* population towards predominance by small plants in the vicinity of the boundary was therefore a tell-tale sign of ecotone migration. In this case, the *Salicornia* (*q'auchial*) community would be advancing at the expense of the *Anthobrium* (*q'otal*) community.

Taking his investigation a step further, Garabito (1995) looked at changes in salinity for surface soil and ground water along a transect that straddled the ecotone. He found that the ECe of the surface horizon on the far side of the *Salicornia* (*q'auchial*) community was >3.6 S/m, whereas at the far side of the *Anthobrium* (*q'otal*) community the ECe was <1.7 S/m. Furthermore, the ECe of the ground water was higher (i.e., 2.7 S/m) for the *Salicornia* side of the transect than for the *Anthobrium* side at 2.0 S/m. Finally, Garabito (1995) noted that sur-

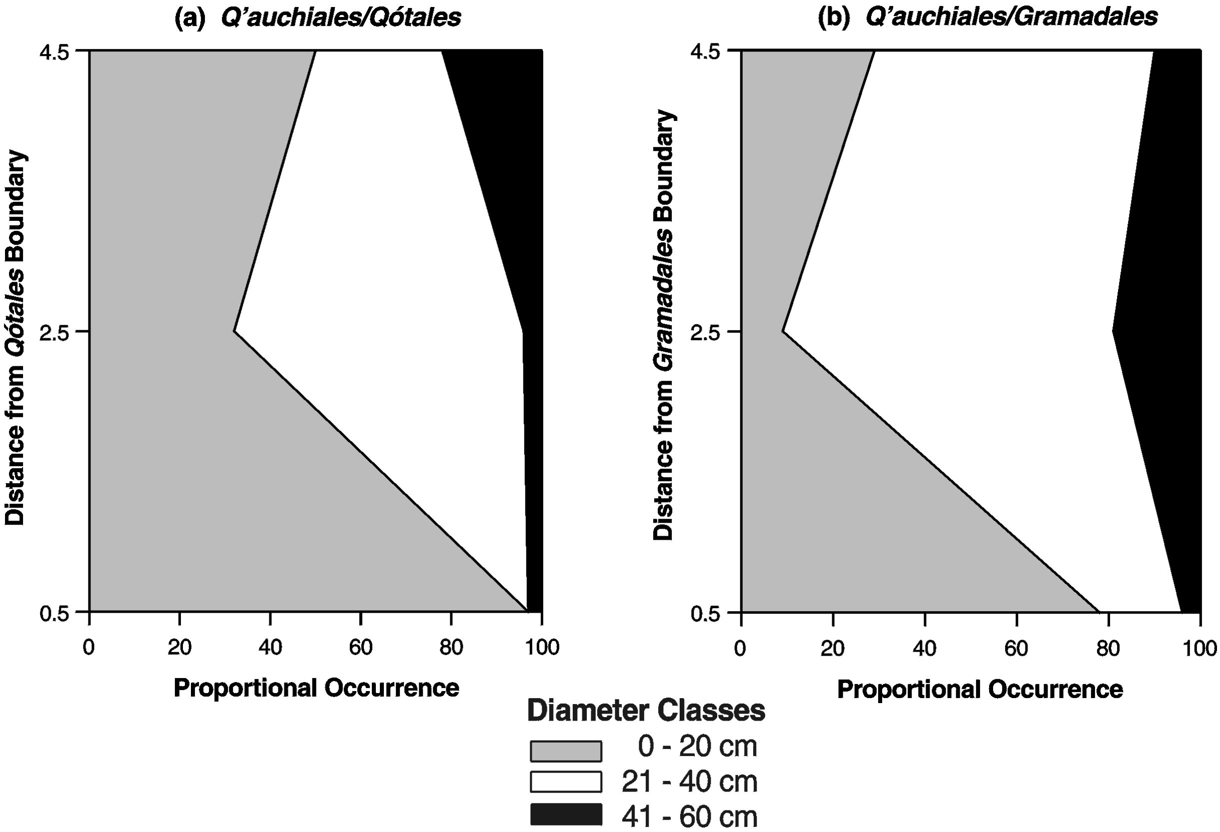


Figure 3.10 (a,b). *Size distribution of populations of the halophyte* Salicornia pulvinata *in two ecotones: (a)* Q'auchial-Q'otal*, an ecotone where a* Salicornia *population met an* Anthobrium *population; and (b)* Q'auchial-Gramadale*, an ecotone where a* Salicornia *population met a short-grass association. In both ecotones the core population of* Salicornia *was associated with more saline substrates than* Anthobrium *or* Distichlis *characteristic of the* gramadale*. "Distance from the boundary" refers to the distance that* Salicornia *individuals were located from the front edge (or mid-point) of the ecotone.* Source: Adapted from data in Garabito (1995)

face soil texture was clay on the *Salicornia* side and sandy-loam on the *Anthobrium* side of the transect.

Based on the premise (and supported by analysis of population-size structure for *Salicornia*) that the ecotone is moving, and the fact that the location of the ecotone is linked to abrupt changes in salinity, Garabito (1995) hypothesised that the spatial distribution of soil salinity is in a state of flux. In this particular case he argued that the area of hyper-saline soils (under a cover of *Salicornia*) is expanding at the expense of the less-saline soil supporting a stand of *Anthobrium*. Because changes in the conductivity of sub-surface water and texture of the soil were associated with changes in salinity of the soil surface, Garabito (1995) speculated that changes in texture and sub-surface water were both driving changes in salinity of the soil surface. His raw data showed that the coarse-textured (sandy-loam) surface horizon on the *Anthobrium* side of the transect had lower salinity than the underlying fine-textured (clay) material in the same location, indicating that the increased salinity of the soil surface where *Salicornia* dominated could have resulted from erosion of the surface layer found with *Anthobrium*.

Garabito (1995) also investigated changes in the size-structure of *S. pulvinata* alongside an abrupt ecotone between a *gramadale* dominated by the grass *D. humilis* and another *q'auchial* having *Salicornia*. Once again he found clear shifts in the size-structure of *S. pulvinata* as the boundary between vegetation types was approached (Figure 3.10b). To illustrate further, 4.5-m deep into the *Salicornia* side the population of *S. pulvinata* consisted predominantly (71%) of plants with diameter >20 cm. On the other hand, only 0.5-m from the gramadale border, 81% of the plants were small and had diameters <21 cm. Garabito (1995) quantified differences in soil salinity on both sides of the boundary as before: on the *Salicornia* side surface ECe was invariably >4.7 S/m, and on the *Distichlis* side it was always <1.7 S/m. In contrast to the first analysis, this time he found no clear differences in other soil parameters between the two vegetation types. Based on the premise that plant size is a proxy for plant age, Garabito (1995) explained the differences in population size structure along the gradient from the ecotone as an indication of ecotone migration, with the *Salicornia* expanding at the expense of the *Distichlis*. Thus the predominance of young (small) *S. pulvinata* plants near the boundary between the two vegetation types.

While Garabito's (1995) studies are exploratory, and alternative hypotheses to ecotone migration may be advanced to explain changes in size structure of *S. pulvinata* described above, the evidence he presented is compelling that ecotones in the salt-affected rangelands of SJL migrate. Evidence he cited also included the overall appearance of ecotones where young, vigorous plants of *S. pulvinata* intermingle with moribund *A. triandrum* and *D. humilis* individuals. We cannot, however, state that the spatial shifts in ecotones stem from human-induced pressures. In fact, a multiple regression analysis undertaken by Garabito (1995) of 126 sample points in which ECe was regressed against several edaphic and hydrologic parameters showed that percentage of silt was the most important predictor of soil surface ECe, followed by the ECw of ground water. Soil salinity at SJL appears to be closely associated with silt-rich parent material often deposited within endoreic lakes, a common geomorphic feature on the Altiplano (see Section 2.3.1: *Regional highlights of physical geography and environment*). In some cases, human pressure may lead to change in the extension of salinised areas by triggering erosion of soil surfaces and exposing saline soil material. At SJL, irrigation with salt-laden water from the Desaguadero River is probably the most important cause of human-induced soil salinity (Dr. J. de Queiroz, IBTA/SR-CRSP, personal observation). In addition, soil salinity may be increasing due to a slight dessication caused by initiation of a dry climate cycle (see Figure 3.2). If the community is in a dry-phase of a cycle, a decrease in flooding and increase in rainfall variability could contribute to an increasing trend for salinisation (Dr. H. Alzérreca, rangeland ecologist, personal observation).

3.3.3.7 Change in vegetation cover 1972-87

The preceding material dealing with system dynamics has focused on a small-scale level of resolution. The analysis of remotely sensed data by Washington-Allen et al (1998) revealed that: (1) all vegetation types at SJL were impacted by the 1982-3 drought, but more mesic range sites exhibited the least response (see Section 3.3.3.1: Photosynthetic activity of herbaceous vegetation); and (2) approximately 90% of vegetation cover had not changed between 1972 and 1987. This latter finding was interpreted to suggest that livestock grazing was not contributing to resource degradation in terms of change in total vegetation cover, irrespective of vegetation type.

3.3.4 Integration of ecological findings

A summary of various findings for the four key geomorphic units (i.e., alluvial terrace, alluvial fan, deltaic deposits and fluvio-lacustrine plains) is presented in Table 3.6. Collectively these four units comprised 88% of the land area of SJL and probably contributed to virtually all of the productive output for the agropastoral system during the period of observation by the joint IBTA/SR-CRSP project. Diversity in most of the tabulated features is apparent across the four geomorphic units. Each, therefore, is somewhat unique with regards to land cover, hydrology and land-use.

Table 3.7 outlines our interpretation of the likely ecological sustainability for maintaining production from each of the four geomorphic units. This includes apparent environmental trends and events as well as presumed causes of such trends or events. Some of the tabulated information is reported in subsequent chapters of this volume. Many of the causal relationships are hypotheses or speculations based on direct observations by team members and/or opinions of local informants expressed in interviews. The short time frame of field activity for the joint IBTA/SR-CRSP in Bolivia precluded rigorous tests of most causal relationships dealing with ecological sustainability. Many of these relationships may involve decades of complex interactions. Further observation is therefore needed to test hypotheses. A discussion follows that outlines what we see as key issues for each geomorphic unit.

Table 3.6. *Summary of general physical, hydrologic, edaphic, land-cover and land-use features for four key geomorphic units at San José Llanga.*

	Features[1]					
Geomorphic Unit	Percent of Cantón	Common Soil Types	Common Land-Cover	Dominant Sources of Moisture	Common Land Use	Other Remarks
Alluvial Terrace	25	Luvisols Lixisols	Tholares, food crops, forage crops, *kallpas*	Precipitation	Cultivation, grazing, fuel wood	Elevated relict site; non-saline
Alluval Fan	15	Fluvisols	Forage crops, food crops, *tholares, kallpas alfalfares*	Over-flow from ephemeral river; high water table; precipitation	Cultivation, grazing, fuel wood	Site created by river diversion; non-saline
Deltaic Deposits	10	Solonchaks	Food crops, forage crops, *tholares, kallpas*	Precipitation, surface irrigation from perennial saline river	Cultivation, grazing	Relatively new site expanded by irrigation; slightly saline
Fluvio-lacustrine						
Fluvio-lacustrine Plain	38	Solonchaks Fluvisols	*Chilliwares, eriales, gramadales, p'orkeales, q'auchiales, q'otales, yawarales*	Precipitation, high water table; periodic flooding in center	Grazing	Old lake bed; varies from hyper-saline to non-saline

[1]See text for detailed descriptions of features.

Table 3.7. *Summary of apparent environmental trends/events, hypothesized causal agents of trends/events, and implications for sustainability of the agropastoral system as outlined for four key, geomorphic units at San José Llanga.*

Geomorphic Unit	Features		
	Apparent Environmental Trends/Events	Hypothesised Causal Agents of Trends[1]	Implications for System Sustainability
Alluvial Terrace	Perceived gradual decline in crop productivity	Declining rainfall[2], increased use of chemical fertilisers relative to manure, increased use of tractor tillage, shortened fallow period	Negative, but effects mitigated by human emigration and increased market integration
Alluvial Fan	Very gradual expansion of site	Depositional processes of ephemeral river	Positive
Deltaic Deposits	Gradual increases in site salinisation	Use of saline irrigation water from perennial river	Negative over the long-term, but over the short-term irrigation allowed expansion of production
Fluvio-Lacustrine Plain	Shifts in species composition of forages to less-desirable species in the *gramadales* and *p'horkeales*	Chronic, heavy grazing on sacrifice sites nearer to settlements	Slightly negative, as a relatively small area is afflicted and "increaser" species are still utilised. Degraded but stable composition
	Migration of saline soil frontiers	Heavy grazing erodes topsoil and exposes more saline subsoils	Negative, but likely unmanageable
	Large barren patches devoid of vegetation	Past inundation of lake bed	Negative, but likely unmanageable
	Homogenisation of ground water	Proliferation of hand-dug wells perforates formerly isolated cells of saline and non-saline water	Negative, but extent is unclear

[1]Proximal causes.

[2]The strongest hypothesis according to Dr. J. de Queiroz (IBTA/SR-CRSP, personal observations).

3.3.4.1 Sustainability of the alluvial terrace

The finding that may bode most unfavorably for the production system overall is the repeated assertion from local informants that crop productivity is declining on the alluvial terrace (Dr. J. de Queiroz, IBTA/SR-CRSP, personal observation). Assuming for the purpose of discussion that this is a real phenomenon, possible proximal causes of declines in crop productivity could include factors related to climate and/or management.

The simplest and best hypothesis to explain a decline in crop productivity is a decline in precipitation (Dr. J. de Queiroz, IBTA/SR-CRSP, personal observation). This is speculative given the limited climate data that were available. Although no long-term trend in mean annual precipitation was apparent during 1952-92, analysis of 7-year running means was interpreted to indicate that the community during the 1990s may have been in the midst of an 11 to 13-year drier-than-average period, which may occur as part of a precipitation cycle (Figure 3.2). Available evidence also suggests that the fluvio-lacustrine plain has endured less flooding in the past 20 years (Section 3.3.2.1: *Geomorphic units*). If a precipitation cycle is occurring, then it is likely that the decline in crop production on the alluvial terrace is also somewhat cyclic and not a long-term trend. Given the link between increased aridity and increased risk of frost (see Section 3.3.1.2: *Air temperature and frost*), crop production could also vary in a cyclic fashion as a result of increased rates of frost damage. A possible cycle involving precipitation/frost and cultivation success has implications for risk management interventions in this agropastoral system (see Chapter 8: *Conclusions and recommendations*).

Management factors may be contributing to a decline in crop productivity, but they probably do not offer as comprehensive an explanation as do periodic swings in precipitation. Possible management factors that could be implicated include changes in soil management. This has several dimensions as discussed below.

Informants commonly reported that many campesinos have shifted from traditional reliance on livestock manure as a crop fertiliser to relatively greater use of bagged chemicals such as urea (Dr. J. de Queiroz and Mr. C. Jetté, IBTA/SR-CRSP, personal observations). This shift has occurred over the past 30 years. Chemical fertilisers became locally available as a result of subsidisation and extension programmes carried out by governmental and non-governmental organisations. Chemical fertilisers are attractive to campensinos because they have been relatively inexpensive, offer short-term boosts for crop production, and are much easier to transport and apply than bulky manure. Disadvantages of chemical fertilisers perceived by campesinos include poor-tasting potatoes, less biomass production of native annuals during subsequent fallow periods, and a long-term hardening of top soil (Dr. J. de Queiroz, IBTA/SR-CRSP, personal observation). Campesinos at SJL have traditionally transported manure significant distances from corrals to crop lands using donkeys or human labour, which is an arduous process. Although manure markets have recently emerged around SJL and campesinos now regularly export manure to generate cash income, we speculate that this has had less of an effect on decisions to use chemical fertilisers than issues of convenience (see Chapter 4: *Household economy and community dynamics at San José Llanga*). Manure has many attributes as a soil ammendment that can positively influence soil structure, water-holding capacity, erodibility and fertility. This is particularly apparent when dealing with the otherwise structureless, sandy topsoil that characterises the alluvial terrace (Dr. J. de Queiroz, IBTA/SR-CRSP, personal observation). For example, the OM in sandy soils is tightly linked to an increase in water-holding capacity. Besides contributing nutrients such as nitrogen (N) and phosphorus (P), the OM from manure is probably the most important contributor to the cation-exchange complex in sandy substrates. Manuring may also have a series of positive effects on the nutrient content of croplands by virtue of additive influences dealing with plant successional dynamics. For example, young fallow fields which had been previously fertilised with manure in the cropping rotation showed a much higher production of annual forb biomass compared to fallow fields which had received chemical fertilisers in the cropping rotation (Dr. J. de Queiroz, IBTA/SR-CRSP, personal observation). Such annual forbs are important for grazing by livestock (Chapter 5: *The grazing livestock of San José Llanga*), and weeds are even harvested for cut-and-carry feeding for tethered cows (Dr. B. Norton, IBTA/SR-CRSP, personal observation). It is unclear whether the surge in forb biomass on previously manured fields is due to the presence of added seed from manure and/or a more favourable growing environment, but regardless it is likely that the higher levels of forb biomass in turn lead to a greater accumulation of detritus and soil OM over time, a factor perhaps more important to long-term site productivity than the original addition of manure (Dr. J. de Queiroz, IBTA/SR-CRSP, personal observation). Manuring also has implications for reducing erodibility of sandy soils (Dr. J. de Queiroz, IBTA/SR-CRSP, personal observations). Because manure increases the OM content of sandy soils, this favors formation of aggregates which result from binding togther single grains of sand. These aggregates are heavier than single grains and hence more difficult to lift and remove via action of wind or water. The observation that plots treated with chemical fertilisers appear to have top soils which become more hardened over time compared to plots treated with manure may be related to an increased erodibility of soils under the chemical-fertiliser regime. The apparent hardness of such plots could be related to increased exposure of the B horizon with gradual depletion of the A horizon from wind or water erosion (Dr. J. de Queiroz, IBTA/SR-CRSP, personal observation). In addition, a breakdown of OM over time causes apparent soil hardening because OM particles become smaller (Mr. D. Huber, Utah State University, personal communication). Hardening of the top soil could contribute to reduced infiltration of rainfall.

Increased use of tractor tillage may also have some role in declining crop productivity on the alluvial terrace by virtue of the negative effects that poorly managed tractor tillage could have on erodibility of sandy soils (Dr. J. de Queiroz, IBTA/SR-CRSP, personal observation). It is speculated, for example, that the more-thorough mixing of surface soil by disc ploughing tends to break down soil structural units to a greater extent than traditional methods using wooden ploughs drawn by oxen. Use of tractors has increased in the past 30 years at SJL. The current situation is that one wealthy individual at SJL owns a tractor, which he then rents out to the community. The owner is also the driver of the tractor. Individual households rent the tractor to till family-owned plots in the cropping matrix. The traditional system of land tenure, which maintains the structurally diverse matrix of tilled and fallow fields, is important in this case because it dictates that tractor tillage not occur on larger spatial scales. If tractor tillage were to occur on larger plots in cases where numerous small plots had been combined, it is conceivable that the alluvial terrace could be more vulnerable to net losses of top soil due to wind erosion. The fact that the driver of the tractor is not the owner of the plots being tilled could raise problems in terms of promoting tillage practices that are expedient rather than careful or conservative in nature (Dr. C. Valdivia, IBTA/SR-CRSP, personal observation). That wind-blown topsoil tends to be redistributed among adjacent plots of fallow and tilled fields, and not lost to the system, is likely important in the long-term sustainability of the alluvial terrace (Barrera 1994).

Management factors include some reports that a shortening of the fallowing period is occurring on the alluvial terrace, especially among households that are "land-poor" (Cala 1994; see Chapter 4: *Household economy and community dynamics at San José Llanga*). This could also be a proximal cause of declining crop yields in some cases. A shortening of the fallow could lower crop production by interfering with nutrient management or pest management.

3.3.4.2 Sustainability of the alluvial fan

Unlike the alluvial terrace, the alluvial fan appears to offer a highly sustainable subsystem. It is expanding due to depositional process (Table 3.7). There were no reports from campesinos of perceived changes in productivity of the alluvial fan. This is fortuitous given the crucial role of cultivated forage production on the alluvial fan in support of emerging small-holder dairying and production of improved sheep (Chapter 4: *Household economy and community dynamics at San José Llanga* and Chapter 5: *The grazing livestock of San José Llang*a). The alluvial fan is a testament to the high and sustained value of irrigation engineering using a source of fresh-water that is wholly controlled within one community. The relative impact of such a development investment for this and similar communities is reviewed in Chapter 8: *Conclusions and recommendations*.

3.3.4.3 Sustainability of the deltaic deposits

Development of the deltaic deposits starting in the mid-1980s with saline irrigation water from the Desaguadero River has granted the campesinos of SJL more than a decade of expanded production in cultivated forages and crops (Table 3.7). The cultivated forage component has allowed more households to become involved in smallholder dairying at SJL (Chapter 4: *Household economy and community dynamics at San José Llanga*). However, the recent appearance of halophytic plants (i.e., *Salicornia* sp.) on some sites suggests that the deltaic deposits are gradually becoming salinised (Dr. J. de Queiroz, IBTA/SR-CRSP, personal observation). The use of the deltaic deposits therefore appears unsustainable unless a source of fresh irrigation water could be found. Therefore, this is perhaps the best example of how people, in the pursuit of short- or medium-term gains, could mis-manage a production site. Another view could be forwarded, however, namely that given available resources, the campesinos have been clever enough to engineer a significant increase in system productivity for a relatively short period at a site that otherwise may have yielded much less over a much longer time frame.

3.3.4.4 Sustainability of the fluvio-lacustrine plain

Despite the high site-to-site variation within the fluvio-lacustrine plain, our overall impression is that abiotic factors are most crucial in affecting contemporary patterns of vegetation abundance and productivity on this geomorphic unit (Table 3.7). Some clarification follows. The large expanses of the central fluvio-lacustrine plains which are denuded are hypothesised not to be in that condition because of overgrazing, but because of either past flooding regimes (as in the case of the *eriales*) or high endogenous salinity (*q' otales* or *q' auchiales*). Heavy grazing may contribute to effects of salinisation through influences on erosion of top soil. It is also notable, however, that in central Asia heavy grazing has been observed to contribute to salinisation of subirrigated grasslands by reducing water loss via transpiration and hence exacerbating water losses via evaporation. Salts thus move up in the soil profile and are deposited on the surface as part of the evaporative process (Dr. J. Dodd, rangeland ecologist, North Dakota State University, personal communication). The key to understanding why such a large portion of SJL is subjected to these phenomena is landscape position. Being in the centre of the Altiplano, the Cantón of SJL serves as a resource sink for the collection of water and eroded salts from around the region (see Section 2.4.1: *Local environment*). These factors essentially overwhelm most effects of grazing or other aspects of resource use by people on the fluvio-lacustrine plain.

The other non-saline or moderately saline sites nearer to the periphery of the fluvio-lacustrine plains tended to be dominated by perennial grasses (i.e., the *chilliwares*, *yawarales*, g*ramadales or p'horkeales*). These sites largely appeared stable in terms of plant species composition, especially in cases where deeper-rooted perennial species have access to fresh or slightly saline ground water. When clear shifts in the species composition of these plant communities occurs, a major factor to consider is change in the salinity level of soil or ground water. Moving saline ecotones or homogenisation of ground water from proliferation of hand-dug wells could be considered as factors inducing change in such instances. It is also notable that there is probably a relationship between saline ecotones and hydrology (Dr. J. de Queiroz, IBTA/SR-CRSP, personal observation). Saline ecotones may shift because of changes in drainage patterns associated with a precipitation cycle, for example.

Based on our investigations, it is not possible to know with certainty whether or not the contemporary composition or productivity of plant communities like *chilliwares*, *yawarales*, *gramadales* or *p'horkeales* has appreciably changed from that of the past due to chronic and heavy grazing pressure. Unfortunately, there were no ungrazed relict communities to serve as comparative baselines in the Cantón of SJL. There were, however, a few instances where chronic grazing pressure in recent times appeared to have slightly altered grass species composition. Again, *gramadales* and *p'horkeales* sites nearer to human settlements appeared to have reductions in the most palatable species such as *H. muticum*.

As will be reviewed in Chapter 5 (*The grazing livestock of San José Llanga*), the current levels of grazing pressure are indeed high and pervasive. Most of the cantón is grazed each year, and much of the readily accessible grass and forb biomass seems to be removed by grazing. Exploitation of grazing lands at SJL is very efficient. How, then, has massive environmental degradation due to grazing been seemingly avoided at SJL? Again, the landscape position of SJL is probably crucial to this end. The fact that SJL occurs in the bottom of a relatively flat plain between two massive mountain chains means that it is a net collector of nutrients, water and eroded soil. Given a relatively high abundance of such resources for growth, plants are probably endowed with a higher ability to withstand heavy grazing compared to most other Andean locales. The physical system is therefore relatively resilient to effects of grazing and trampling by herbivores. The landscape position confers other fortuitous advantages with regards to natural constraints which facilitate grazing management (Chapter 5: *The grazing livestock of San José Llanga*). For example, water often accumulates on much of the fluvio-lacustrine plains during rainy periods. The resulting water and mud can make much of this area impassable for herders and livestock. One outcome of this pattern is a de facto deferred grazing system on much of the fluvio-lacustrine plain. Sites which are temporarily inaccessible during the rains have plants which are allowed to grow in the absence of grazing. Much of the fluvio-lacustrine plains are actually grazed most heavily in the dry season when the dominant grass vegetation appears senescent and hence likely to be relatively immune from grazing damage in physiological terms. Deferred use of the fluvio-lacustrine plains is also encouraged in some cases by grazing on fallow fields in the cropland matrix. See Chapter 5 (*The grazing livestock of San José Llanga*).

One fundamental flaw in our ecological research was that the project did not establish protected grazing exclosures on important range sites at the start of the project in 1991. The fact that the community of SJL uses virtually all of the available grazing each year made the politics of exclosure establishment problematic. Observation of possible changes in plant community composition and productivity over the ensuing five years would have allowed us to make better-founded conclusions regarding short-term effects of grazing and have insights relevant to the stability and resilience of range plant communities. In light of this problem we can at least make reference to other studies, however, in which sites were protected on the semi-arid puna or in similar eco-regions and describe these findings.

In general, the semi-arid puna is typically regarded as over-grazed (Browman 1974; Cardozo 1979; LeBaron et al 1979; Posnansky 1982; McCorkle 1990). Exotic species such as sheep and cattle have been often implicated in over-grazing due to their particular foraging methods and trampling effects which may impact plants to a higher degree compared to attributes of indigenous camelids (Posnansky 1982). The Altiplano, however, has endured pastoralism of one form or another for up to 7000 years (see Section 2.3.2: *Regional historical highlights*). Plant communities which have persisted over this time frame should be regarded as somewhat adapted to heavy grazing even if their current status is suboptimal in terms of species composition or productivity (Milchunas and Lauenroth 1993). Despite the general concensus that over-grazing is considered to be the norm on the Altiplano, a lack of detailed research leaves many questions unanswered. For example, it is not known the degree to which perceived degraded states of plant communities are stable or unstable. It also is unclear if perceived degraded conditions are reversible or irreversible given appropriate management inputs (Genin and Alzérreca 1995). Evolutionary history is important in considering dynamics of grazing systems.

Results of the few exclosure studies conducted in the semi-arid Altiplano and similar environments often offer equivocal interpretations. Braun (1964) studied the impact of five years of rest from grazing on the composition, density and height of range vegetation at Patacamaya Experiment Station. He found that compared to unprotected range sites, protection from grazing resulted in grass plants that were 50% taller but occurred at a lower density. He also found that a native clover slightly increased in the understory. He observed no other changes. In contrast, work reported in Parker (1974) showed estimates that grazing protection could result in four times greater above-ground biomass yield for range vegetation on the semi-arid Altiplano compared to production under a continuous grazing regime. This work was based on two years of grazing protection using 55 exclosures on seven range sites. In some cases plant biomass yield was 10-times greater than that found on paired plots outside exclosures (Parker 1974). He also noted that species composition changed inside the exclosures to a more palatable and nutritious mix compared to that outside the exclosures. Other work conducted on an eroded site at the Patacamaya Experiment Station revealed that four years of protection from grazing resulted in only slight improvements in biomass production, but species mix became more favourable, compared to adjacent unprotected sites (Freeman et al 1980, cited by Dr. H. Alzérreca, rangeland ecologist, personal communication). Buttolph (1998) has noted that compared to continuously grazed sites, one to three years of grazing protection appears to have resulted in largely negligible differences in productivity and species composition of bofedal and gramadal vegetation at a higher elevation site at Cosapa where camelid production dominated.

In other "cold desert" systems there is an ongoing re-assessment of how grazing affects plant community dynamics. It has been found in the Intermountain West of the USA that removal of livestock from desert grasslands and shrublands has often resulted in no subsequent vegetation change (Smith and Schmutz 1975; Smeins et al. 1976; West et al 1984). In his study of plant dynamics over a 60-year period in a salt-desert shrub community in Utah, Alzérreca (1996) found that while grazing pressure typically reduced plant cover compared to ungrazed locations, major changes in plant species composition and cover usually occurred as a result of shifts in amounts and distribution of annual precipitation.

The results of Smith and Schmutz (1975), Smeins et al (1976), West et al (1984) and Alzérreca (1996) all reveal discrepancies with respect to predictions of traditional range trend and grazing management models. Such traditional models emphasise the role of management control versus abiotic influences. They are based on assumptions of tight, interactive linkages between herbivores and plant communities and relevance of a linear (or Clementsian) succession of plant communities from an early seral stage to a stable climax. In effect, such models predict that a lessening of grazing pressure will result in a linear trajectory towards climax. Conversely, increasing grazing pressure should ultimately result in creation of early seral stages. The possible mis-application of Clementsian principles to arid-land ecology was noted by Westoby et al (1989). In contrast to the traditional concepts, they promoted a "state and transition" model whereby a variety of system states was possible for a particular patch of vegetation. What state the patch happened to be in was determined by coincident events which could include abiotic forces (climate, fire, etc.) and biotic forces (grazing, plant competition, etc.). Accordingly, whether or not the vegetation patch moved from one state to another was postulated to be dependent on the occurrence of one or more coincident events.

Ellis and Swift (1988) and Ellis (1992) echoed similar perspectives with respect to hyper-arid and arid pastoral systems in East Africa. In essence they disputed the idea that grazing was the main determinant of vegetation dynamics in these systems. Their contention was that the high variability in rainfall for a dwarf-shrub savannah in Turkana, Kenya, largely dictated the direction of plant community dynamics. Livestock and people were essentially ineffectual contributors to change in many respects. As climate, not consumers, was postulated to be the main controller of arid-system dynamics, such systems were referred to as "non-equilibrial." In his review of African grazing systems, Dodd (1994) noted that making a clear distinction between equilibrial and non-equilibrial systems could be a problem. Coppock (1993) took some of these arguments a bit further and attempted to identify a gradient of "equilibrial" and "non-equilibrial" systems for East African rangelands. In this analysis he noted that arid African systems receiving <300 mm rainfall per year under hot ambient conditions often supported annual grasslands which are relatively immune from acute grazing pressures; these indeed fit the non-equilibrial paradigm. In contrast, however, cooler semi-arid systems receiving >400 mm of rainfall are often dominated by perennial grasses. The low frequency of drought in these semi-arid systems, in conjunction with clever management by pastoralists, often resulted in high numbers of livestock with the capability to periodically alter vegetation composition and productivity. In the case of southern Ethiopia this included encroachment of woody plants as a result of grass cover being reduced by cattle grazing. This case was referred to as an example of an equilibrial system (Coppock 1993).

The broad issues reviewed in the three preceding paragraphs are relevant to interpreting rangeland dynamics on the fluvio-lacustrine plain of SJL. The equivocal nature of results from other work on the Altiplano by Braun (1964), Parker (1974), Le Baron et al (1979), Freeman et al (1980) and Buttolph (1998) is important and collectively tends to undermine the classical notion that all types of range sites would exhibit dramatic improvements as a result of protection from grazing. This variation in response to protection may be due to differences in degrees of site degradation, site resilience and/or coincidences such as certain precipitation regimes that happened to occur for each trial, etc.

Only the *gramadales* and *p'horkeales* sites nearer to settlements showed shifts in plant species composition as a result of heavy grazing pressure. These sites comprised <20% of the grazing of the fluvio-lacustrine plain (Dr. J. de Queiroz, IBTA/SR-CRSP, personal communication).

We have now set the stage to make some educated speculations about the dynamics of these *gramadales* and *p'horkeales* sites: (1) It is likely that such sites would exhibit some changes in plant composition and productivity if they were protected from grazing; but (2) it is unlikely that these sites would change further unless, for example, there was a long-term shift to a drier or wetter climatic regime. Therefore, these particular *gramadales* and *p'horkeales* sites are probably degraded, but relatively stable, in terms of species composition. Given this situation, it is evident that some sites or patches have been altered by chronic livestock grazing and thus represent one outcome of equilibrial interactions between herbivores and vegetation. The total numbers of livestock also appear generally static on an annual basis. The annual increment of animals produced seems to be effectively marketed (see Chapter 4: *Household economy and community dynamics at San José Llanga* and Chapter 5: *The grazing livestock of San José Llanga*).

3.4 Conclusions

The major questions to be answered by ecological research were: (1) Is the environment at SJL "degraded" in terms of potential to support grazing or cultivation?; (2) if the environment is degraded, which components appear most affected and why?; and (3) what are the roles of people and livestock versus those of natural processes in causing degradation? Before outlining our conclusions it is important to acknowledge the relatively short period of time we were able to make observations at SJL. This makes any conclusions risky.

First, SJL exhibits signs of environmental degradation, but attention to geomorphic units and associated land use is critical to understanding relevant processes. Blanket generalisations for the environment overall are therefore not appropriate or informative. It is also important to note that the unique environmental character of SJL is largely defined by its landscape position as an environmental sink for water, soil and salt. Inference is restricted to similar production systems at the centre of the Altiplano, and has little relevance for systems involving hillside agriculture, for example.

The denuded character of the fluvio-lacustrine plains suggests extreme degradation to the casual observer, especially during dry seasons. Large flocks of grazing sheep and other livestock could easily be interpreted to be the major cause of denudation. Indeed, over hundreds of years of continued use at SJL it is highly probable that grazing has contributed to gradual, negative change in some aspects of plant communities and soils. However, we surmise that the only contemporary degradation attributable to grazing per se is found in *gramadales* and *p'horkeales* sacrifice zones located nearer to settlements. This occurs on <20% of the fluvio-lacustrine plains and thus <8% of the cantón overall. This degradation takes the form of changes in the species composition of forages, which appear relatively stable even under heavy use. It thus seems unlikely that significantly more degradation could occur in these sites under current patterns of precipitation and resource use. Consequently, it appears unlikely that altering stocking rates would have much utility with regards to environmental protection, especially in relation to the marginal returns from range improvements and other social and economic costs (see Chapter 8: *Conclusions and recommendations*). The scenario observed for sacrifice zones of *gramadales* and *p'horkeales* conforms more to the equilibrial theory for plant/herbivore interactions, both in terms of biological dynamics and the associated semi-arid climate.

In contrast to sacrifice zones of *gramadales* and *p'horkeales*, however, the vast majority of acreage on the fluvio-lacustrine plains has been denuded by historical flooding and salinisation processes, for which management by campesinos at SJL plays little or no role. This scenario conforms to the non-equilibrial theory of abiotic processes determining composition and trend of range vegetation by overwhelming effects of grazing management.

There are additional situations where climate and landscape have interacted with grazing to promote maintenance of forage cover. The best example is where temporal patterns of flooding, and thus seasonally limited access for livestock, have encouraged deferred grazing systems on the fluvio-lacustrine plain.

Contemporary threats to sustainable resource use may occur more in the farming dimension of this system rather than in the grazing dimension, consistent with findings in other semi-arid agropastoral situations (Dr. H. Alzérreca, rangeland ecologist, personal observation). The best example of degradation promoted by people at SJL is the irrigation of crops on the deltaic deposits with saline water. Other examples—that remain to be verified—involve potential mis-management of topsoils on the alluvial terrace. While these human-induced effects may indeed be negative, it is important to note that the people have played very positive and creative roles in terms of improving the sustainability of their agroecosystem. The best example of this is the use of environmental engineering to channel non-saline water to create the alluvial fan.

In summary, we conclude that people have played positive and negative roles in modifying the environment at SJL. The livestock currently seem to play a role that is either neutral or slightly negative in most cases. Overall, the contemporary roles of people and livestock seem minor, however, compared to a dominant background of salinisation, flooding and drought that profoundly define system dynamics. A mix of abiotic and biotic controls on environmental trends is the result, which is probably logical for any agroecosystem. In terms of vegetation change in a rangeland context, different patches within the same geomorphic unit exhibited both equilibrial and non-equilibrial features. This undermines the utility of either paradigm for making broad generalisations about the behaviour of this and similar systems.

Intervention concepts to mitigate management-related problems in the environment, as well as recommendation for further research, are found in Chapter 8: *Conclusions and recommendations*.

3.5 Literature Cited

Alzérreca H. 1996. *Spatial and Temporal Dynamics of Plant Populations in Salt-Desert Shrub Vegetation Grazed by Sheep*. PhD dissertation, Utah State University, Logan, Utah, USA. 292 pp.

AOAC (Association of Official Analytical Chemists). 1980. *Official Methods of Analysis*. 13th edition. AOAC, Washington DC, USA. 1016 pp.

Barrera C. 1994. *Uso de la Tierra y Características de Poblaciones de* Thola [Parastrephia lephidophylla (*Wedd C.*)] *en el Cantón San José Llanga*. BS tesis, Universidad Mayor Real y Pontificia de San Francisco Xavier, Sucre, Bolivia. 88 pp.

Behnke, R.H. and Scoones, I. 1993. Rethinking range ecology: Implications for rangeland management in Africa. In: Behnke R.H., Scoones I. and Kerven C. (eds), *Rangeland Ecology at Disequilibrium: New Models of Natural Variability and Pastoral Adaptation in African Savannahs*. The Commonwealth Secretariat and the Overseas Development Institute, London, UK. pp. 1-30.

Blanco O. 1994. Efecto del descanso del suelo sobre el número y la viabilidad de quistes de Globodera spp. de la papa. En: Hervé D., Genin D. and Riviere G. (eds), *Dinámica del Descanso de la Tierra en los Andes*. ORSTOM/IBTA (Institut Francais de Reserche Scientifique Pour le Développement en Coopération/Instituto Boliviano de Tecnología Agropecuria), La Paz, Bolivia. pp. 171-174.

Braun O. 1964. *Forrages del Altiplano*. Ministerio de Agricultura, Servicio Agrícola Interamericano, Boletín Experimental no. 30, La Paz, Bolivia.

Browman D.L. 1974. Pastoral nomadism in the Andes. *Current Anthropology* 15:188-196.

Buttolph L.P. 1998. *Rangeland Dynamics and Pastoral Development in the High Andes: The Camelid Herders of Cosapa, Bolivia*. PhD dissertation, Utah State University, Logan, Utah, USA. 286 pp.

Cáceres M. 1994. *Comportamiento y Sobreposición Alimenticia en Tres Especies Domésticas en el Altiplano Central de Bolivia*. BS tesis, Universidad Mayor Autónoma Tomas Frias, Potosí, Bolivia. 111 pp.

Cala E. 1994. *El Sistema de Tenecia de Tierras en la Comunidad San José Llanga*. BA tesis, Universidad Mayor de San Andrés, La Paz, Bolivia. 147 pp.

Cary S. y Hervé D. 1994. El estado microbiólogico del suelo, indicador de una restauración de la fertilidad. En: Hervé D., Genin D. and Riviere G. (eds), *Dinámica del Descanso de la Tierra en Los Andes*. ORSTOM/IBTA (Institut Français de Recherche Scientifique Pour le Développement en Coopération/Instituto Boliviano de Tecnologia Agropecuria), La Paz, Bolivia. pp. 185-197.

Caughley G., Shepherd N. and Short J. 1987. *Kangaroos-- Their Ecology and Management on the Sheep Rangelands of Australia*. Cambridge University Press, Cambridge, UK. 253 pp.

Cook C.W. and Stubbendieck J. 1986. *Range Research: Basic Problems and Techniques*. SRM (Society for Range Management), Denver, Colorado, USA. 317 pp.

Coppock D.L. 1985. *Feeding Ecology, Nutrition and Energetics of Livestock in a Nomadic Pastoral Ecosystem*. PhD dissertation, Colorado State University, Fort Collins, Colorado, USA. 274 pp.

Coppock D.L. 1993. Vegetation and pastoral dynamics in the southern Ethiopian rangelands: Implications for theory and management. In: Behnke R.H., Scoones I. and Kerven C. (eds), *Rangeland Ecology at Disequilibrium: New Models of Natural Variaiblity and Pastoral Adaptation in African Savannas*. Overseas Development Institute, London, UK. pp. 42-61.

Coppock D.L. 1994. *The Borana Plateau of Southern Ethiopia: Synthesis of Pastoral Research, Development and Change 1980-91*. Systems Study 5. ILCA (International Livestock Centre for Africa), Addis Ababa, Ethiopia. 374 pp.

Cossins N. and Upton M. 1988. The impact of climatic variation on the Borana pastoral system. *Agricultural Systems* 27:117-135.

Dodd, J. 1994. Desertification and degradation in sub-Saharan Africa – The role of livestock. *BioScience* 44:28-34.

Dollfus O. 1982. Development of land-use patterns in the central Andes. *Mountain Research and Development* 2:39-48.

Ellis J.E. 1992. Recent advances in arid land ecology: Relevance to agropastoral research in the small ruminant CRSP. In: Valdivia C. (ed), *Sustainable Crop-Livestock Systems for the Bolivian Highlands. Proceedings of an SR-CRSP (Small Ruminant Collaborative Research Support Program) Workshop, held at Lubbock, Texas, USA, 14-17 May 1991*. University of Missouri, Columbia, Missouri, USA. pp. 1-14.

Ellis J.E. and Swift D.M. 1988. Stability of African pastoral ecosystems: Alternate paradigms and implications for development. *Journal of Range Management* 41:450-459.

FAO/UNESCO/ISRIC (Food and Agricultural Organisation/United Nations Educational, Scientific and Cultural Organisation). 1988. *FAO-UNESCO Soil Map of the World - Revised Legend*. FAO, Rome, Italy.

Freeman P., Cross B., Flannery R., Harcharik D., Hartshorn G., Simmonds G. and Williams J. 1980. *Bolivia: State of the Environment and Natural Resources - a Field Study*. USAID (United States Agency for International Development) contract no. PDC-C-Q247. JRB Associates, Inc., McLean, Virginia, USA. ca. 300. pp.

Garabito M.A. 1995. *Estudio Sinecologico de las Poblaciones de Salicornia pulvinata y Anthobrium triandrum en los Campos Nativos de Pastoreo del Cantón San José Llanga, Provincia Aroma, Departamento de La Paz.* BS tesis, Universidad Mayor Autónoma Tomás Frias, Potosí, Bolivía. 160 pp.

Genin D. y Alzérreca H. 1995. Reseña de la vegetación de la zona de Turco. En: Genin D., Picht H., Lizarazu R. and Rodriquez T. (eds), *Waira Pampa: Un Sistema Pastoril Camélidos-Ovinos del Altiplano Árido Boliviano*. ORSTOM/IBTA (Institut Français de Recherche Scientifique Pour le Développement en Coopération/Instituto Boliviano de Tecnología Agropecuria), La Paz, Bolivia. pp. 35-56.

Hervé D. 1994. Respuestas de los componentes de la fertilidad del suelo a la duración del descanso. En: Hervé D., Genin D. and Riviere G. (eds), *Dinámica del Descanso de la Tierra en Los Andes*. ORSTOM/IBTA (Institut Français de Recherche Scientifique Pour le Développement en Coopération/Instituto Boliviano de Tecnología Agropecuria), La Paz, Bolivia. pp. 155-170.

IBTA (Instituto Boliviano de Tecnología Agropecuria). 1992. *Analisis Ex-Ante de Alternativas Tecnológicas*. Proyecto Sistemas du Produccion en el Altiplano Boliviano. IBTA Boletín técnico no 128, La Paz, Bolivia. 74 pp.

INTECSA (Internacional de Igeniería y Estudios Técnicos Sociedad Anónima). 1993. *Plan Director Global Binacional de Protección-Prevención de Inundaciones y Aprovechamiento de los Recursos del Lago Titicaca, Rio Desaguadero, Lago Poopó, y Lago Salar de Coipasa (Sistema Titicaca Desaguadero Poopó Salares)*. INTECSA and EEC (European Economic Community), La Paz, Bolivia. 581 pp.

Kolata A. 1993. The *Tiwanaku: Portrait of an Andean Civilisation*. Blackwell Publishing Co., Cambridge, Massachusettes, USA. 317 pp.

Le Baron A., Bond L., Aitken P. and Michaelsen L. 1979. An explanation of the Bolivian highlands grazing-erosion syndrome. *Journal of Range Management* 32:201-208.

Le Tacon P.H., Vacher J.J., Eldin M. y Imaña E. 1992. *Los Riesgos de Heladas en el Altiplano Boliviano*. En: Actas del VII Congreso Internacional Sobre Cultivos Andinos, La Paz, Bolivia, Febrero 1992. IBTA/ORSTOM/CIID (Instituto Boliviano de Tecnología Agropecuaria/Institut Francais de Recherche Scientifique pour le Developpement en Cooperation/Centro Internacional de Investigación y Desarrollo). La Paz, Bolivia.

Lopéz E.C. 1994. *Contenido Nutricional del la dieta al Pastoreo en Tres Especies: Ovinos, Bovinos y*

Equinos del Altiplano Central. BS tesis, Universidad Técnica de Oruro, Oruro, Bolivia. 136 pp.

Massy N. 1994. *Mapeo y Caracterización de Campos Nativos de Pastoreo del Cantón San José Llanga, Provincia Aroma, Departamento de La Paz.* BS tesis, Universidad Técnica de Oruro, Oruro, Bolivia. 77 pp.

McCorkle C. (ed). 1990. *Improving Andean Sheep and Alpaca Production: Recommendations from a Decade of Research in Peru*. SR-CRSP (Small Ruminant Collaborative Research Support Program). University of Missouri, Columbia, Missouri, USA. 220 pp.

Milchunas D. and Lauenroth W. 1993. Quantitative effects of grazing on vegetation and soils over a global range of environments. *Ecological Monographs* 63:327-366.

Miranda R. 1995. *Caracterización Física-Química de los Suelos de la Comunidad San José Llanga y su Relación con las Asociaciones Vegetales.* BS tesis, Universidad Mayor de San Andrés, La Paz, Bolivia. 135 pp

Norton B.E. 1992. Range ecology. In: Barber J. and Keane M. (eds), *SR-CRSP Annual Report 1992*. Management Entity, SR-CRSP (Small-Ruminant Collaborative Research Support Program), University of California, Davis, California, USA. pp. 3-20.

Odum E.P. 1971. *Fundamentals of Ecology.* Third edition. W.B. Saunders Co., Philadelphia, Pennsylvania, USA. 574 pp.

Ortega I.M., Cáceres M., Massy N., Garay C., Victoria Z. and Lopéz C. 1995. *Caracteristicas de al Vegetacion en Cades, San José Llanga, Provincia Aroma*. Unpublished report. IBTA/SR-CRSP (Instituto Boliviano de Tecnología Agropecuria/ Small Ruminant Collaborative Research Support Program), La Paz, Bolivia.

Painter M. 1992. Changes in highland land use patterns and implications for pastoral development. In: Valdivia C. (ed) *Sustainable Crop-Livestock Systems for the Bolivian Highlands. Proceedings of an SR-CRSP (Small Ruminant Collaborative Research Support Program) Workshop, held at Lubbock, Texas, USA, 14-17 May 1991.* University of Missouri, Columbia, Missouri, USA. pp. 93-122.

Parker, K.G. 1974. *A Cursory Appraisal of Plant Resources of Bolivia and Simplifications of Production Potential*. Utah State University Series 11/74. Utah State University, Logan, Utah, USA.

Peña O. 1994. *Evaluación de los Recursos Hídricos del Cantón San José Llanga, Provincia Aroma, Departamento de La Paz*. BS tesis, Universidad Mayor de San Andrés, La Paz, Bolivia. 147 pp.

Peréz R.M. 1994. *Comportamiento Hídrica - Fisiológico y Fases Fenólogicas de la* Thola (Parastrephia lepidophylla *Wedd C. y* Bacharis incarum *Wedd C.*). BS tesis. Universidad Técnica de Oruro, Oruro, Bolivia. 130 pp.

Posnansky M. 1982. Los efectos sobre la ecología del Altiplano de la introducción de animales y cultivos por los españoles. En: Geyger E. y Arze C. (eds), *Ecología y Recursos Naturales en Bolivia.* Instituto de Ecología, Universidad Mayor de San Andrés, La Paz, Bolivia.

Prieto G.J. and Yazman J. 1995. *Disponibilidad y Calidad Forrajera en Pastizales Naturales del Altiplano Central de Bolivia.* IBTA/SR-CRSP (Instituto Boliviano de Tecnología Agropecuria/ Small Ruminant Collaborative Research Support Program). IBTA 175/Boletín técnico 43/SR-CRSP 41, La Paz, Bolivia. 41 pp.

de Queiroz J.S., Barrera C. y Valdivia J. 1994. La estructura y composición botanica de la vegetación de los campos agrícolas de la comunidad de San José Llanga, Altiplano central, en función de los suelos y períodos de descanso. En: Hervé D., Genin D. and Riviere G. (eds), *Dinámica del Descanso de la Tierra en los Andes.* ORSTOM/IBTA (Institut Français de Recherche Scientifique Pour le Développement en Coopération/Instituto Boliviano de Tecnología Agropecuria), La Paz, Bolivia. pp. 215-223.

Ramos A. 1995. *Relaciones de Presión de Pastoreo, Productividad Animal y Disponibilidad de Forrage en Areas de Pastoreo del Cantón San José Llanga, Provincia Aroma, Departamento de La Paz.* BS tesis, Universidad Mayor Autónoma Tomás Frias, Potosí, Bolivia. 67 pp.

Ropelewski C.F. 1992. Predicting El Niño events. *Nature* 356(6369):476-477.

Scoones I. 1991. Wetlands in drylands: key resources for agricultural and pastoral production in Africa. *Ambio* 20(8):366-371.

Servant M. et Fontes J.C. 1978. Les lacs quaternaires des hauts plateaux des Andes Boliviennes. ORSTOM/IBTA (Institut Français de Recherche Scientifique Pour le Développement en Coopération/Instituto Boliviano de Tecnología Agropecuria. *Série Geologie* 10:9-23.

Smeins, F.E., Taylor T.W. and Merrill L.B. 1976. Vegetation of a 25-year exclosure on the Edwards Plateau, Texas. *Journal of Range Management* 29:24-29.

Smith D. and Schmutz E. 1975. Vegetative changes on protected versus grazed desert grassland ranges in Arizona. *Journal of Range Management* 28:453-458.

SENAMHI (Servicio Nacional de Metereologia y Hidrologia). 1994. D*atos Meteorológicos de la Estación Experimental de Patacamaya*. La Paz, Bolivia. 44 pp.

Solomon Bekure, de Leeuw P.N., Grandin B.E. and Neate P.J.H. (eds). 1991. *Maasai herding: an analysis of the livestock production system of Maasai pastoralists in eastern Kajiado District, Kenya*. Systems Study 4. ILCA (International Livestock Centre for Africa), Addis Ababa, Ethiopia. 154 pp.

Stoddart L.A., Smith A.D. and Box T.W. 1975. *Range Management*. 3rd edition. McGraw-Hill Book Co., New York, New York, USA. 532 pp.

Treadwell D. and Libermann M. 1992. *Mapa de Uso de la Tierra y Vegetación en San José Llanga, Provincia Aroma, Departamento de La Paz*. IBTA/SR-CRSP (Instituto Boliviano de Tecnología Agropecuria/Small-Ruminant Collaborative Research Support Program), La Paz, Bolivia.

USDA (United States Department of Agriculture). 1951. *Soil Survey Manual*. Handbook no. 18. USDA, Washington DC, USA. 503 pp.

Van Soest P J. 1994. *Nutritional Ecology of the Ruminant*. Second edition. Cornell University Press, Ithaca, New York, USA. 476 pp.

Victoria Z. 1994. *Distribución y Comportamiento en Pastoreo del Ganado Doméstico (Ovinos, Vacunos, y Equinos) en el Altiplano Central de Bolivia*. BS tesis, Universidad Mayor Autónoma Tomás Frias, Potosí, Bolivia. 126 pp.

Walkley A. and Black I.A. 1934. An examination of Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science* 37:29-37.

Washington-Allen R. 1994. *Historical Analysis of Land Use/Land Cover Change on the Bolivian Altiplano: a Remote Sensing Perspective*. MS thesis, Utah State University, Logan, Utah, USA. 85 pp.

Washington-Allen R., Ramsey R.D., Norton B.E. and West N.E. 1998. Change detection of the effect of severe drought on subsistence agropastoral communities on the Bolivian Altiplano. *International Journal of Remote Sensing* 19(7):1319-1333.

West N.E., Provenza F.D., Johnson P.S., and Owens M.K. 1984. Vegetation change after 13 years of livestock grazing exclusion on sagebrush semidesert in west central Utah. *Journal of Range Management* 37:262-264.

Westoby M., Walker B. and Noy-Meir I. 1989. Opportunistic management for rangelands not at equilibrium. *Journal of Range Management* 42:266-274.

Chapter 4

Household economy and community dynamics at San José Llanga

Economía familiar y dinámica comunal en San José Llanga

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Summary

The main objective of work in this chapter is to describe the current situation at San José Llanga (SJL) in terms of general features of the human population and agropastoral production system. We wanted to know about standards of living, diets and food security, income and expenditure patterns, gender roles and aspirations of the people. We wanted to know about population dynamics, community leadership, resource tenure and off-farm activities. We wanted information on the types of crops and livestock produced and the contributions that different commodities made to household economies and market integration. This empirical information would be used to answer questions of practical and theoretical merit. First, what was the trajectory of the community in broad social and economic terms (i.e., positive, negative or neutral)? In other words, was there reason for concern in terms of living standards, food security and prospects for economic growth? Second, what was the mixture of market versus non-market factors in the production system, and how did these contribute to human welfare? How have new technologies contributed to improving human welfare? Have new technologies replaced old technologies, or have they been combined in novel ways?

Methods mostly relied on social surveys involving individuals and groups. In other cases historical archives were studied and physical measures were taken of young children in support of human nutrition assessments.

In 1994, the Cantón of SJL had six settlements supporting over 400 people. The population contained about 100 households. Households were highly variable in composition, but in general were comprised of a married couple with dependent children. About two-thirds of households were in a young or mid-life stage of productivity and resource accumulation. The remainder was comprised of more passive retirees who were in the process of passing resources on to the next generation.

Households managed an average of 20 widely scattered parcels of crop land. Use of crop land was dominated by production of potato, *quinoa*, other cereal grains, beans and *cañawa.* Cultivated forages such as alfalfa and barley were also important for households involved in production of improved breeds of livestock. Households typically managed about 50 head of sheep and five head of cattle on average. Sheep were almost evenly split between Criollo and crosses of Criollo with improved breeds such as Corriedale, Targhee and Merino. Cattle included Criollo stock for draft and Holstein or Brown Swiss crosses for smallholder dairying. Breeding programmes to improve sheep were introduced in the 1960s. Improved cattle have resulted from subsidised local dairy initiatives (i.e., Programa de Industrialización Lechera or PIL) started in 1989. About 25% of SJL households were involved with PIL by the early 1990s.

Community leadership at SJL was strong and organised in formal and informal ways. Formal institutions included elected posts held by senior males and the practice of holding monthly assemblies. Assemblies provided a forum to set community policies, settle disputes and manage logistics for community-based projects. Informal leadership was provided by wealthier male entrepreneurs.

Formal education was valued by the community. About 75 and >90% of children between the ages of 12 to 15 and 6 to 11, respectively, attended school. Literacy rates among adults were relatively high. Access to public health services, however, was mixed. Incidence of childhood

morbidity and peri-natal mortality was reportedly high. Problems in sanitation persist. Women had an average of 5.3 to 5.7 pregnancies each, typical of the rural Altiplano.

Cropping plots were not deeded to households and thus were not an asset that could be sold. Households maintained controlled access to cropping plots, however, by virtue of privatisation initiatives that began with the Agrarian Reform Act of 1952. A surge in local population growth in the 1950s and 1960s, resulting in resource pressure, probably also contributed to promotion of controlled access to crop land. Since the 1950s cropping plots and parcels of higher value grazing have been typically passed via inheritance among males. In contrast, lower-value grazing lands have always been under rules of communal access. In the 1990s households varied in terms of crop land under controlled access—land-wealthy households had up to 120 ha of crop land while land-poor households had <10 ha. A variety of traditional relationships, however, allowed land-poor households to increase their access to crop land via temporary leasing arrangements with other households. One-quarter of crop land in production in 1994 was used under some form of temporary tenancy arrangement.

The time for planting, production and harvest of crops, respectively, was October to December, January to April, and March to June. Males and females shared cultivation tasks. Food crops were grown in a four-year rotational cycle starting with potato, which has the most complicated management requirements including tractor tillage, hand-fertilisation and fumigation. In the fifth year crop plots are commonly fallowed for another five to 10 years.

In contrast to crop land, livestock were owned by households. Livestock thus played a vital role as liquid assets, given that other forms of formal and informal finance appeared scarce. About one-third of sheep and nearly 20% of cattle, however, were managed by someone other than the owner during our study period. Like crop land, temporary arrangements were often made that redistributed livestock resources throughout the community. Herders and owners benefitted from reciprocal relationships involving labour and animal products. Gifting and inheritance were important means for individuals to acquire livestock, starting in childhood. Households varied in the composition, numbers and value of livestock owned. Livestock-wealthy households could have 20 to 30-times more livestock wealth than livestock-poor households. Livestock-wealthy households were typically more involved in dairying with high-value cattle breeds.

Overall, livestock play important roles in terms of food, fibre and manure production and in their service as financial assets. Livestock management is described. Animal feeding systems were founded on grazing, with some cut-and-carry forage feeding occurring for high-value dairy cattle in dry periods. Livestock management was typically low-input in character. Animals grazed by day and were corralled by night. Sheep management and marketing was typically in the domain of females, while females and males tended to share cattle management duties. Females tended to milk cows while males took care of cattle herding, marketing and breeding. Sheep manure has been traditionally used as a fertiliser for potato crops. Cattle manure was more commonly used as a household fuel.

Human diets were carbohydrate-based and relatively uniform. Variety in diet was due more to variety in food preparation than ingredients. The diet was no longer traditional. Traditional diets based on potato, *quinoa* and *cañawa* were often altered by an increasing reliance on store-bought pasta, rice and maize. Store-bought fruit was also occasionally added to the diet. The main source of dietary protein was lamb. Criollo lambs were slaughtered at a rate of about one per month by three-fourths of households. Dietary assessments were made using household-level social surveys and anthropometric measurements of children <5 years of age. Results were interpreted to suggest that intake of protein and energy is probably adequate for most individuals, but that intake of micronutrients and compounds such as animal fat may be substandard. Chronic malnutrition may occur for some groups of young children.

The total annual average household income in 1992-3 was 1365 Bolivianos (or USD 321), considered for 45 households. This was a near-average year in terms of precipitation. Total income was highly variable, however, as the top 20% of households had total incomes 25-times greater than those of the bottom 20% . Overall, total income was nearly evenly divided between cash income and in-kind income as products consumed in the home. In-kind income was dominated by food crops used for subsistence, while cash income was derived more from cattle production (i.e., sales of milk and live animals), followed by wages from off-farm labour and sales of live, improved sheep.

Improved breeds of cattle and sheep fetched substantially higher prices compared to Criollo breeds. Income from sheep sales was controlled by female heads of households and was used for welfare items such as food, clothing and expenses associated with formal education of children. The bi-weekly cash income from milk sales was reportedly the main reason why smallholder dairying has become so popular. Males and females may control income from milk sales, and this income was used for welfare expenditures and purchase of farming inputs. Income from sales of live cattle was controlled by male heads of households and was used for asset accumulation and diversification in the form of building cattle herds and larger investments in education and property in nearby urban locales. Evidence suggested that in economic terms, sheep and cattle production in most cases were at least complementary, and possibly even synergistic.

The local sheep market appeared diverse in terms of the variety of buyers and sellers and number of marketing channels. In contrast, the local cattle market appeared less diverse. Patterns of sheep supply to market peaked in some instances with higher seasonal demand associated with festive periods. Because sheep sales were routine to procure welfare goods, we speculated that supply may be often inelastic in relation to demand throughout the year. At the household level income from sales of sheep manure was poorly quantified, but related studies of manure production and use at a community level were interpreted to suggest that manure sales were probably pervasive. Manure was likely taken by traders to vegetable producers closer to major metropolitan areas. Over 90% of sheep manure at SJL may have been sold, with only 8% used as fertiliser on potato fields. Manure was sold for only 10% of its true value in terms of a urea equivalence.

We speculated about the recent history of SJL in relation to population dynamics and features of the agropastoral system. One hundred years ago we surmise that SJL had about 60 households. Crop and grazing lands were communally used. Llamas were present in the system. Sheep numbers per person were several times greater compared to today. Temporary migration was common, but it usually involved travel between other rural destinations. Traditional cottage industries such as manufacture of woolen garments were common. By the 1970s, however, the higher-value crop lands had been under controlled access for a generation. Llamas were gone. The number of households had grown to 125 as a result of improved food production and the periodic attractiveness of the rural economy relative to the urban economy. Market integration was also underway, having started in the 1950s. By 1994 the 100 households at SJL represented a decline of 18% compared to the 1970s. Large-scale irrigation projects had been implemented to expand options for sustainable cultivation. Cottage industries had declined. Migration, both short- and long-term, remained common, but now involved travel to urban destinations. It was anticipated that the number of households at SJL would decline to around 80 in the near future as retirees pass away and attractions of the urban economy prevail.

Migration at SJL has always been a dynamic process. Emigrants, often younger males between the ages of 15 and 30 years, have had mixed success—some have become small-scale entrepreneurs while others have failed or have been forced to return to SJL for family-related reasons. Young females were often discouraged from emigrating due in part to demands for their labour in sheep production. Emigrants maintained links to SJL by retaining control over crop lands and their ownership of livestock. Non-emigrants gained access to crop and livestock resources through various care-taking relationships. The motivation to emigrate was commonly to improve standards of living by increasing cash incomes through wage employment. Emigrants accordingly desired more access to formal and informal education to improve their marketability. There was also a common desire to gain access to modern amenities such as electricity and improved transportation. The severe drought of 1982-3 was also cited as important in promoting emigration. Emigrants came from the top and bottom of the economic ladder at SJL. Wealthier emigrants sought to diversify their economic base, while poorer emigrants desired to improve economic security and lifestyle options. Our observations also suggested that more emigrants at SJL came from settlements having a poorer endowment of natural resources, which reduced options for cultivated forage production and hence involvement in lucrative activities such as smallholder dairying. Households involved with smallholder dairying were less likely to have a household head involved in wage employment outside of SJL. This suggested that options such as smallholder dairying could contribute to helping maintain households at SJL.

We concluded that the community at SJL is evolving. In general terms, the trajectory of the community in social and economic aspects appeared rather positive. The people have a strong base of social capital and food security. They have embraced formal education and several types of new technology that have diversified the local economy and contributed to economic growth. Problems may persist, however, in some aspects of human nutrition and public health. Equity in terms of improved access of young women to more formal education was also an issue. The increasing dependence on smallholder dairying, considering its subsidised nature, may be worrisome. The community is almost polarized in terms of the stratification of household wealth, but the significance of this for system dynamics and equity remained unclear. High rates of migration are not new to SJL. The fact that emigration has been promoted by recent circumstances may be beneficial in the long run in terms of community development and resource allocation.

Households have selectively incorporated new technologies and activities that complement traditional options. This has created a mix of market-driven relations in parallel with non-market traditions. Non-market traditions, underlain by a fabric of social capital, help to secure access of households to land, labour and capital in situations that the market cannot otherwise guarantee. Social relations that redistribute production resources probably reduce risk exposure for emigrants and care-takers alike.

In terms of social capital, SJL was a strong community. The value of this social capital was also revealed by recent efforts undertaken by the leadership to improve living standards in terms of local access to education, potable water, electricity and modern sanitation practices. The desire for an improved standard of living is paramount among emigrants. While such efforts may not stem the current high rates of emigration, they make SJL a more desirable place to live and probably encourage the maintenance of linkages among rural and urban components of the system.

Various commodities in the agropastoral system played varied socioeconomic roles. With the rare exception of marketable surpluses for land-wealthy households, food-crop production served a subsistence function. Dairy cattle served to increase cash incomes and diversify assets and enhance market integration. Sheep served both subsistence requirements and a need for income generation. Improved sheep were important for food security because they could be sold to buy food. Criollo sheep were also important for food security, but more in the sense of their role as a regular source of inexpensive protein in human diets. These patterns indicated that economic diversification and market linkages can permit economic growth in a risky and fragile environment.

Traditional gender roles were evident in the agropastoral system, but flexibility occurs that permits opportunism in incorporating new endeavors. One of the critical roles of small ruminants in the system is how they are sold to provide funds for welfare expenditures, a function articulated by female household heads.

Resumen

El objetivo principal de este capítulo es describir la situación actual de San José Llanga (SJL), presentando las características generales de la población humana y del sistema agropastoril. Se buscó conocer los estándares de vida, la dieta y seguridad alimentaria, los patrones de ingreso y gasto, los roles según género y las aspiraciones de la gente. También se buscó información sobre la dinámica de la población, el liderazgo comunal, la tenencia de recursos y las actividades no agrícolas, así como datos sobre los tipos de cultivo y ganado y las contribuciones de las diferentes actividades a la economía del grupo doméstico, y su integración al mercado. Esta información empírica sería utilizada para contestar a las preguntas prácticas y teóricas. Primero, ¿cuál fue la trayectoria de la comunidad en términos amplios, tanto sociales como económicos (i.e. positiva, negativa o neutral)? En otras palabras, ¿había razón para estar preocupados por los estándares de vida, la seguridad alimentaria y las posibilidades de crecimiento económico? Segundo, ¿cuál fue la mezcla de factores de mercado y no mercantiles en el sistema de producción, y como contribuyeron al bienestar humano? ¿Cómo han contribuido las nuevas tecnologías a mejorar el bienestar humano? ¿Han remplazado las nuevas tecnologías a las viejas, o han sido incorporadas en formas novedosas?

La metodología se basó mayormente en encuestas de tipo social a individuos y a grupos. En otros casos se estudiaron los archivos históricos, y se tomaron medida antropométricas de niños para apoyar las evaluaciones de nutrición humana.

En 1994, el Cantón de SJL tenía seis asentamientos abarcando a más de 400 personas, en aproximadamente 100 grupos

domésticos. Los grupos domésticos variaban mucho en su composición, pero por lo general estaban conformados por una pareja de esposos y sus hijos dependientes. Alrededor de dos tercios de los grupos domésticos se encontraban en el grupo de los jóvenes o en el de los de mediana edad en términos de su productividad y acumulación de recursos. El resto lo constituían los pasivos, retirados, gente mayor en proceso de heredar sus recursos a la siguiente generación.

Los grupos domésticos trabajaban en promedio unas 20 parcelas dispersas de tierras de cultivo, cuyo uso estaba dominado por la producción de papa, *quinua*, otros cereales para grano, habas y *cañawa*. Los forrajes cultivados como la alfalfa y la cebada eran importantes para los hogares que se dedicaban a la producción de ganado mejorado. Los hogares estudiados manejaban unas 50 cabezas de ovino y cinco cabezas de ganado vacuno. Los ovinos se dividían casi en igual proporción entre criollos y cruzas con criollo como con Corriedale, Targhee y Merino. El stock ganadero incluía al ganado criollo para yunta, y cruzas de Holstein y Pardo Suizo para la producción de leche a pequeña escala. Los programas de mejoramiento genético para el ganado ovino fueron iniciados en los años sesenta. El ganado mejorado vacuno es resultado de iniciativas locales de subsidio a la lechería (i.e. Programa de Industrialización Lechera o PIL), que se iniciaron en 1989. Alrededor del 25 % de los hogares de SJL estaban ligados a la PIL a comienzos de los noventa.

El liderazgo en la comunidad de SJL es muy fuerte, tanto en el ámbito informal como formal. Las instituciones formales incluyen los puestos de gobierno de la comunidad, a la que se eligen a los hombres mayores, y la costumbre de tener asambleas mensuales. Las asambleas constituyen un espacio para que se determinen las políticas comunales, resolver disputas y el manejo de los proyectos comunales. El liderazgo a nivel no formal lo tienen los empresarios más ricos de la comunidad.

La educación formal es valorada por la comunidad. Alrededor de 75 a más de 90 por ciento de los niños entre los 12 y 15 años de edad, y seis a once respectivamente, van a la escuela. El nivel de alfabetismo entre adultos es relativamente alto. El acceso a servicios de salud, en cambio, no era tan claro. La incidencia de enfermedades infantiles y la mortalidad perinatal son altas. Los problemas de saneamiento persisten. El promedio de embarazos de las mujeres fluctúa entre 5.3 y 5.7 por persona, lo cual es típico de la población rural del altiplano.

Las parcelas de cultivo no están a nombre de propietarios individuales, y por lo tanto no son un bien de capital que puede ser vendido. Sin embargo, gracias a las iniciativas de privatización que se iniciaron con el Acta de la Reforma Agraria de 1952, los grupos familiares mantenían acceso controlado a las parcelas de cultivo. El crecimiento de la población local en los años cincuenta y sesenta, que resultó en presión sobre los recursos naturales, probablemente también contribuyó a la promoción del acceso controlado a las tierras de cultivo. Desde los cincuenta el patrón de herencia de las tierras de cultivo y las parcelas de mayor valor para pastoreo han sido patrilineal. En contraste, el acceso a las áreas de pastoreo de menor valor ha sido a través del sistema comunal. En los noventa había variación en el acceso a la cantidad de tierra de cultivo-aquellos con muchas tierras poseían hasta 120 hectáreas de tierras de cultivo, mientras que los que poseían pocas tierras, tenían menos de 10 hectáreas. Sin embargo, a través de relaciones tradicionales, aquellos con pocas tierras podían incrementar su acceso a través de diversos tipos de acuerdo con otras familias para su arrendamiento temporal.

La siembra, producción y cosecha de cultivos se realizan de octubre a diciembre, enero a abril y marzo a junio respectivamente. Tanto hombres como mujeres comparten las labores agrícolas. Los cultivos se sembraron usando un ciclo de rotación de cultivos de cuatro años, empezando con la papa, la cual es la más compleja en su manejo pues requiere de tractor para la roturación y siembra, el aporque y fertilización con yunta y a mano, y la fumigación. Al quinto año se dejaba descansar por unos cinco a diez años.

En contraste a las tierras agrícolas, el ganado era propiedad privada, y jugaba así un papel vital como bienes con liquidez, debido a que en ese entonces otras formas de financiamiento parecían escasas. Sin embargo, alrededor de un tercio de las ovejas y casi 20 % del ganado vacuno, eran manejados por otras personas y no los dueños durante el periodo de estudio. Como con las tierras para cultivos, se hacían acuerdos temporales que permitían la redistribución de recursos ganaderos a través de la comunidad. Los pastores y los propietarios se beneficiaron ambos de las relaciones de reciprocidad respecto al trabajo y a los animales. El regalo y la herencia eran mecanismos importantes para obtener ganado desde la niñez. El ganado de los grupos domésticos varió en composición, número y valor. Los grupos domésticos ricos en ganado podían tener de 20 a 30 veces más riqueza en animales que los grupos pobres. Por lo general, los grupos domésticos ricos en ganado se dedicaban a la lechería con vacunos de raza.

En general, el ganado juega roles importantes en la alimentación, producción de fibra y estiércol y en su rol como bienes de capital con alta liquidez. Se describe el manejo del ganado. El sistema de alimentación animal se basaba en el pastoreo, con corte de forrajes para la alimentación del ganado lechero de alto valor durante la época seca. El manejo de ganado se caracterizaba por ser de pocos insumos. Los animales eran pastoreados durante el día y se mantenían en corrales durante la noche. El manejo y comercialización del ganado ovino era usualmente realizado por las mujeres, mientras que los hombres y mujeres compartían las tareas de manejo del ganado vacuno. El estiércol de los ovinos era utilizado para fertilizar los cultivos de papa. La bosta del ganado vacuno se utilizaba más como fuente de energía en el hogar.

La dieta humana se basaba en carbohidratos y era relativamente uniforme. La variedad en la comida se daba principalmente en la preparación, más que en los ingredientes. La dieta ya no era la tradicional. Alimentos tradicionales como papa, *quinua* y *cañawa* se alteraban a menudo por un incremento en la dependencia de fideos, arroz y maíz comprados en la tienda. Ocasionalmente también se incorporaba a la dieta fruta comprada. La oveja era la fuente principal de proteínas. Los ovinos criollos se sacaban a una tasa de uno por mes, por tres cuartos de los hogares. Las evaluaciones de la dieta se hicieron a través de encuestas de tipo social y de la medición antropométrica de niños menores de cinco años. Los resultados interpretados sugirieron que la ingesta de proteína y energía era probablemente adecuada para la mayor parte de los individuos, pero la de micro nutrientes y compuestos como grasa animal estaba por debajo de los estándares. La malnutrición crónica puede ocurrir en algunos grupos de niños pequeños.

El ingreso promedio anual en 1992-3 fue de 1365 Bolivianos (321 dólares), considerando a las 45 familias de la muestra. Este fue un año de precipitación cercana al promedio. Sin embrago, el ingreso promedio total era muy variable, ya que el veinte por ciento de la población de más altos ingresos tenía veinticinco veces más que el veinte por ciento de menos ingresos. En general el ingreso se distribuía de igual manera entre el ingreso en dinero y en especie, que consistía de los productos consumidos por el hogar. El ingreso en especie era principalmente conformado por los cultivos para el consumo familiar, mientras que el ingreso en dinero se obtenía mayormente de la producción de ganado vacuno (i.e. las ventas de leche y animales en pie), seguida de los salarios del empleo fuera de la unidad de producción, y la venta de ovinos mejorados.

El ganado mejorado, tanto ovino como vacuno, recibía precios más altos que los del ganado criollo. El ingreso de la venta de ovinos era controlado por los jefes femeninos de la unidad económica familiar, o grupo doméstico, y era utilizado para el bienestar familiar, como la compra de alimentos, vestido, y gastos asociados con la educación de los niños. El ingreso quincenal por la venta de leche era la razón por la cual se popularizó esta actividad. Tanto los hombres como las mujeres pueden controlar el ingreso por la venta de leche, y este ingreso era utilizado para gastos del bienestar familiar, así como insumos para la actividad agrícola. El ingreso generado por la venta de ganado vacuno era controlado por el jefe masculino del grupo doméstico, y era utilizado para la acumulación de bienes de capital y diversificación hacia el incremento del capital ganadero e inversiones en educación y terrenos en zonas urbanas cercanas. En términos económicos, la ganadería vacuna y ovina eran complementarias y posiblemente sinérgicas.

El mercado local de ovejas era diverso tanto con respecto a la variedad de compradores y vendedores como al número de canales de comercialización. En cambio el mercado del ganado vacuno era menos diverso. La oferta de ovinos al mercado alcanzaba sus puntos más altos en algunas circunstancias a una demanda estacional abundante asociada con festividades. Debido a que la venta de ovinos se realiza de manera rutinaria para satisfacer las necesidades del hogar, especulamos que la oferta es inelástica con relación a la demanda del mercado. Si bien no se cuantificó adecuadamente los ingresos familiares por la venta de estiércol de ovino, pero otros estudios de producción y su uso a nivel comunal dieron la impresión de que es muy común la venta de estiércol. Es probable que el estiércol se negociara a través de intermediarios que lo venden a los productores de verduras en lugares cercanos a la ciudad. Más del 90% del estiércol de SJL se puede vender, y sólo el 8% es utilizado como fertilizante en los cultivos de papa. El valor de la venta de estiércol es aproximadamente sólo el 10 % de su valor en términos del contenido de úrea.

Se especuló acerca de la historia reciente de SJL con relación a la dinámica poblacional y las características del sistema de producción agropastoral. Estimamos que hace unos cien años SJL contaba con sesenta familias. Las tierras de cultivo y de pastoreo eran manejadas a nivel comunal. El sistema incluía llamas. El número de ovejas era mucho mayor que el que existe hoy. La migración temporal era una actividad común, pero por lo general consistía de migración a otras áreas rurales. La producción de ropa de lana se realizaba a través de la industria artesanal tradicional. Sin embargo, en los setenta las tierras de cultivo de alto valor ya habían estado en manos privadas y bajo acceso controlado, por lo menos por una generación. Las llamas habían desaparecido. El número de hogares creció a 125 familias como resultado del mejoramiento en la producción de alimentos y del atractivo periódico que ejercía la economía rural con relación a la urbana. También progresaba la integración al mercado, que había comenzado en los cincuenta. A la llegada de 1994 las familias se habían reducido, en 18%, a 100 grupos domésticos. Se expandió el área de producción con proyectos de irrigación para ampliar las alternativas de producción sustentable. Las industrias artesanales declinaron. La migración, tanto de corto como de largo plazo, continuaba siendo común, pero ahora consistía de viajes a zonas urbanas. Se anticipaba que el número de hogares en SJL declinaría a 80 en un futuro cercano, con el fallecimiento de los pasivos por un lado, y las atracciones de la economía urbana.

La migración en SJL ha sido siempre un proceso dinámico. Los emigrantes, por lo general hombres jóvenes de 15 a 30 años, han logrado a veces su objetivo convirtiéndose en pequeños empresarios, mientras otros han fracasado, o han tenido que regresar a SJL por razones familiares. A las mujeres jóvenes, en cambio, no se las incentivó a migrar, en parte debido a las necesidades de su trabajo en la actividad ovina. Los emigrantes mantienen relaciones con SJL, reteniendo el control de la tierra de cultivo y la propiedad de ganado. Los no emigrantes obtienen acceso a los cultivos y recursos ganaderos a través de varios tipos de acuerdos. El motivo de la migración se realiza comúnmente para mejorar los niveles de vida, a través del incremento de ingresos con el trabajo asalariado. Los emigrantes deseaban también un mayor acceso a la educación formal e informal para mejorar sus posibilidades de empleo. También había un deseo común por tener acceso a comodidades como la electricidad y mejoras en el transporte. La severa sequía de 1982-83 se citó como una causa importante de la migración. Los emigrantes pertenecían tanto a los niveles altos como de bajos ingresos en la comunidad de SJL. Los emigrantes más ricos buscaban diversificar su base económica, mientras que los emigrantes más pobres deseaban mejorar su seguridad económica y tener más opciones de vida. Nuestras observaciones también sugieren que los emigrantes de SJL provenían de asentamientos con recursos naturales más pobres. Tenían pocas opciones para el cultivo de forrajes y por lo tanto en actividades lucrativas como la lechería a pequeña escala. Se encontró que los hogares que desarrollaban la actividad lechera tenían menos probabilidades de contar con el jefe masculino trabajando fuera de SJL. Esto sugirió que opciones como la lechería podría contribuir a mantener a los grupos domésticos en SJL.

Llegamos a la conclusión de que la comunidad de SJL está evolucionando. En general, la trayectoria de la comunidad en términos sociales y económicos es positiva. La población tiene una base fuerte de capital social y de seguridad alimentaria. La educación formal y muchos tipos de tecnologías nuevas han sido adoptados contribuyendo a la diversificación y al crecimiento económico. Sin embargo, hay problemas que pueden persistir en el área de la nutrición y salud humana. El acceso equitativo a la educación por parte de las mujeres continúa siendo un problema. También es una preocupación el incremento en la dependencia de la lechería, considerando que ésta está subsidiada. La comunidad está casi polarizada con respecto a la estratificación por riqueza familiar, pero su significado respecto a la dinámica a la dinámica del sistema y a la equidad no está claro. Tasas de migración alta no son extrañas en SJL. El hecho de que la emigración haya existido en los últimos años puede ser favorable en el largo plazo en términos del desarrollo de la comunidad y de la asignación de recursos.

Los grupos domésticos han incorporado en forma selectiva nuevas tecnologías y actividades que son un complemento a las actividades tradicionales. Esto ha creado una mezcla de relaciones dominadas por el mercado con tradiciones no mercantiles. Éstas, apoyadas en una base de relaciones sustentadas en capital social, ayudan a asegurar el acceso de estos hogares a tierra, trabajo y capital en situaciones donde el mercado no lo puede garantizar. Las relaciones sociales que facilitan la redistribución de los recursos probablemente reducen el riesgo al que se exponen tanto los emigrantes como los que cuidan de los recursos.

En términos de capital social SJL es una comunidad fuerte. El valor de este capital social también se revela en los esfuerzos recientes que han desarrollado los líderes de la comunidad para mejorar los niveles de vida en términos de acceso local a educación, agua potable, electricidad y servicios sanitarios modernos. El deseo de mejorar los estándares de vida es muy importante para los emigrantes. Mientras que estos esfuerzos no necesariamente reduzcan las altas tasas de emigración, si hacen de SJL un lugar más deseable para vivir y probablemente incentiva el mantenimiento de relaciones entre los componentes rurales y urbanos del sistema.

Muchos de los productos del sistema agropastoral juegan diversos papeles socioeconómicos. Con la rara excepción del excedente comercializado por los productores ricos en recursos, la producción de cultivos es mayormente para el consumo familiar. La lechería tiene el propósito de incrementar el ingreso monetario, diversificar los bienes de capital y mejorar la integración al mercado. Las ovejas sirven para cubrir sus necesidades de subsistencia tradicional y también para generar dinero. Los ovinos mejorados eran importantes pues podían venderse para obtener ingresos que se destinaban a la compra de alimentos. El ganado criollo era importante para la seguridad alimentaria, pero en especial debido al papel de ser fuente constante de proteínas baratas para la dieta humana. Estos patrones muestran que la diversificación económica y los enlaces al mercado pueden permitir el crecimiento económico en un ambiente riesgoso y frágil.

Desde el punto de vista de género, los papeles tradicionales eran evidentes en el sistema agropastoral, pero se da cierta flexibilidad permitiendo la inclusión oportunística de nuevas empresas. Uno de los papeles críticos de los pequeños rumiantes en el sistema es cómo se venden para generar fondos que se utilizan en los gastos para el bienestar familiar realizados por las jefas femeninas del hogar.

4.1 Introduction

This chapter has several main purposes. One is to provide a contemporary image of the peasant production system at San José Llanga (SJL) from 1992 to 1995, the years of our field research. Another purpose is to provide a framework of the historical processes that have influenced local society in this century. We wanted to know about standards of living, diets and food security, income and expenditure patterns, gender roles and aspirations of the people. We wanted to know about population dynamics, community leadership, resource tenure and off-farm activities. We wanted information on the types of crops and livestock produced and the contributions that different commodities made to household economies and market integration. This empirical information would be used to answer questions of practical and theoretical merit. First, what was the trajectory of the community in broad social and economic terms (i.e., positive, negative or neutral)? In other words, is there reason for concern in terms of living standards, food security and prospects for economic growth? Second, what was the mixture of market versus non-market factors in the production system, and how do these contribute to human welfare? How have new technologies contributed to improving human welfare? Are new technologies replacing old technologies, or have they been combined in novel ways?

Answers to these questions would contribute to debate concerning the effects of technology adoption—will new technology encourage households to specialise or diversify (von Braun et al 1989; Cotlear 1989)? Some scholars contend that economic diversification is vital for survival in risky environments, and that diversification is an important means to create stronger socioeconomic insurance mechanisms to promote persistence (Reardon et al 1992; Ellis 1993; Rosenzweig and Binswanger 1993).

Also of interest is the extent to which traditional forms of resource allocation, maintained through networks, i.e., social capital, allow communities to persist when undergoing market integration. For example, in economically developed nations various federal insurance programmes help farmers or ranchers make a living despite the prevalence of ecological or economic shocks. In places like the rural Altiplano, with partially developed markets, no such insurance mechanisms exist in a formal sense. Hence, we devoted some of our effort to understanding how traditional social relations promoted household persistence as the spectrum of ecological shocks is increasingly mixed with economic perturbations. This is further analyzed to understand differences in coping strategies in Chapter 6, where life-cycle patterns are identified, to understand the impacts of climatic shocks on rural livelihoods.

4.2 Methods

Several methods were used for research described in this chapter. Methods included structured household surveys—conducted either once or on a repeated basis—in-depth case studies, informal discussions with individuals or groups, participatory rural assessments (PRAs) and direct observation. The fact that most of the student researchers lived among the campesinos for extended periods was vital to build trust and increased confidence in the accuracy of our data.

One of the first tasks of the social science team was to conduct a community census. The team subsequently monitored the community to record population dynamics. Data from the IBTA/SR-CRSP was augmented with information from official census records.

Study of population and production system attributes over the past 100 years was accomplished using a combination of archival research in La Paz, Patacamaya and SJL along with interviews of elderly community members. Open-ended interviews with emigrants were conducted, including those who had made a successful transition as well as those who were less successful and had to return to SJL. Aspirations of youths were identified using informal interviews of 15 boys and girls between the ages of 15 and 18 years.

The household production system, economy, resource tenure and issues concerning adoption of new technology were analysed using data largely collected from systematic surveys implemented among random samples of households (Cala 1994; Espejo 1994; Céspedes et al 1995a,b; Eyzaguirre et al 1995; Huanca et al 1995; Illanes et al 1995; Ramos et al 1995; Sherbourne et al 1995; Valdivia et al 1996; Fender 1997). From 31 to 45 households were surveyed in these studies, either on a one-time basis or repeatedly, depending on objectives. These samples were deemed representative and made up from 30 to 45% of all households at SJL.

Survey of 32 female heads of households to assess health and nutrition issues was conducted by Murillo and Markowitz (1995). Households were randomly selected from among those having small children. A short structured questionnaire included a 48-h recall on family consumption of food, with quantities of each food item indicated. Intake for household members was based on total food divided by family members present for each meal. Diet adequacy was evaluated by contrasting intake of nutrients with recommended dietary standards for Bolivia (SVEN 1987). Forty-two children under the age of 5 were assessed using standard anthropometric measures (i.e., weight-for-age, height-for-age and height-for-weight) to assess likelihood of acute or chronic nutritional constraints (Murillo and Markowitz 1995).

Finally, another study examined the use of sheep manure by the community. The study involved interviews of 32 households concerning manure use as well as monitoring fecal ouput of sheep over an extended period (Norton 1994). Fecal output was measured twice per month over eight months using three male sheep from each of four flocks between October, 1993, through May, 1994. Fecal collection bags were emptied in mornings and evenings to differentiate between output that would end up in corrals versus grazing areas. Twelve pooled subsamples of fresh and dried feces were analysed for nitrogen (N) and phosphorus (P) content, using standard analytical procedures (AOAC 1980).

4.3 Results and discussion

4.3.1 Human population and resource base

4.3.1.1 Settlements

The Cantón of SJL was divided into six settlements or neighbourhoods named *Callunimaya, Barrio, Savilani, T'olatia, Inkamaya* and *Espíritu Willq'i*. Originally, each settlement was a homestead (estancia) of an extended family. Settlements were physically apparent from clusters of dwellings. During 1992-5 each settlement was home to nine to 23 households. Many of the households in each settlement shared the same family name, reflecting patrilocal residence (Markowitz and Jetté 1994). This pattern resulted from a tendency for families to bequeath land to sons rather than daughters (Cala and Jetté 1994). *Barrio, Callunimaya* and *Savilani* settlements occurred within a kilometer of each other and each was only a few minutes walking distance from the central plaza (see Plate 2.9a). *T'olatia, Inkamaya* and *Espíritu Willq'i*, in contrast, occurred south of the central plaza and were connected to the plaza and each other by a dirt road. *Espíritu Willq'i* was furthest away from the central plaza, about 3.0 km or up to a half-hour walk. Figure 3.3 depicts the location of settlements in relation to geomorphic features of the cantón. Figure 5.10 (a-f) illustrates how grazing and cultivation resources varied among settlements in the context of sheep production and management. In general, *Barrio, Savilani* and *Callunimaya* tended to have higher proportions of cultivated forage and other crop lands, while *T'olatia*, *Inkamaya* and *Espíritu Willq'i* tended to have higher proportions of native rangeland and other lower-value sites in their resource endowments. Households with more cultivated forages and higher-value sites also had more improved sheep and dairy cattle compared to households having access to relatively more native rangeland (see Section 5.3.3: *Management and productivity of sheep*).

The central plaza of SJL was flanked by a church, two school buildings, several small shops and, since 1989, the community milk collection centre of PIL (Programa de Industrialización Lechera). According to community elders this concentration of buildings has gradually occurred over the past few decades as a result of road construction and market development (Jetté 1993; Markowitz and Jetté 1994).

4.3.1.2 Living standards, household structure and human population dynamics

Living standards and vital statistics. Living standards for the campesinos at SJL are reflected in survey data for 32 households collected on formal education, general public health, family health, reproductive practices and quality and quantity of human diets by Murillo and Markowitz (1995) and Dr. C. Valdivia (IBTA/SR-CRSP, unpublished data). Some of their main findings are briefly highlighted here. This sample comprised nearly one-third of the households residing in the Cantón of SJL during 1994. As will be described later in this section and in Section 6.3.1: *Socio-economic groups*, households at SJL were highly variable. They were, however, typically comprised of a husband, wife and up to eight dependents who were children and other blood relatives. Households commonly managed a complex matrix of croplands and forage plots, as well as a small herd of cattle and donkeys and a flock of sheep. Activities and diets of household members reflected these system components.

The population of SJL has a broad-based access to formal education in most cases. Literacy rates for male and female heads of households (MHH and FHH) were 97 and 91%, respectively. About one-third of MHH had completed elementary and junior high school, while 12% had completed high school. Seven of 10 FHH had completed elementary school, while 22% had completed junior high school. All of the MHH, as well as 78% of the FHH, spoke both *Aymara* and Spanish. Fifteen percent also spoke *Quechua* (Dr. C. Valdivia et al, IBTA/SR-CRSP, unpublished data). The majority of non-Spanish speakers were women over 45 years old.

For people >15 years, the average duration of time spent in school was four years (Dr. C. Valdivia et al, IBTA/SR-CRSP, unpublished data). About 75% of the children between the ages of 12 and 15 attended school, while >90% of children between the ages of 6 and 11 attended school (Dr. C. Valdivia, IBTA/SR-CRSP, unpublished data). Until recently, the local school at SJL only offered instruction in grades 1 through 8, and older youths who wished to attend secondary school had to travel outside of SJL to places such as nearby Patacamaya town. Girls have been much less likely than boys to pursue secondary education (C. Jetté, IBTA/SR-CRSP, personal observation). The recent construction of a new school building at SJL will allow secondary school to be offered locally for the first time—this has important ramifications for helping to stem emigration and thus help promote sustainability of agriculture and persistence of the community (Plate 4.1; see Chapter 8: *Conclusions and recommendations*).

Until 1994, about 9 of 10 households at SJL drew water for human use from small wells in their yards or patios. These were essentially open holes, flush with the ground surface, which were susceptible to pollution from various forms of waste. Only two hand-operated water pumps were available throughout the cantón, and these were inconveniently located for many residents. In 1994, the Child and Community Health Programme (CCHP) of USAID installed a solar-powered water distribution system which piped water directly to 60 households. Community mem-

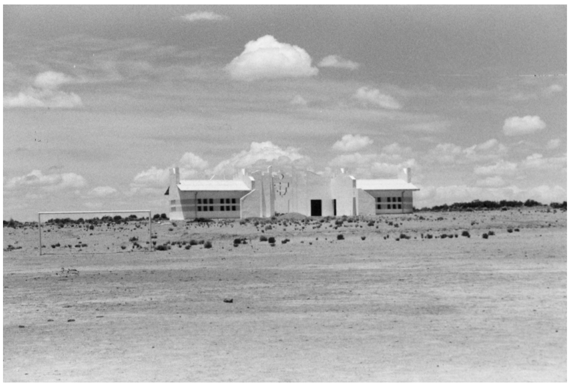

Plate 4.1 *New secondary school at San José Llanga. Access to secondary education may stem emigration of youths from the community.* Photograph: Jim Yazman

bers contributed labour and one-time payments of about 107 Bolivianos (i.e., USD 26.42) to access this service.

Seventy-five percent of households at SJL used a latrine or covered pit for disposal of human waste at the time of the Murillo and Markowitz survey. Marginal units, however, were in the process of being replaced with new latrines under the auspices of the CCHP programme. One quarter of households routinely deposited human waste under open-air conditions. About 30% of households at SJL used some form of trash pit for garbage, 6% burned garbage and 80% deposited garbage under open-air conditions.

Open-air disposal of human waste and garbage contributes to health risks. Murillo and Markowitz (1995, 8-14) found that use and access to public health services was mixed and incidence of debilitating childhood diseases and child mortality was relatively high. For example, although 28% of households had been able to consult with a physician in Patacamaya town when a serious illness occurred, another 50% of households showed no such inclination. Access to transportation may explain this variation (Murillo and Markowitz 1995, 9). Over 80% of children at SJL were vaccinated against measles and other common childhood diseases—this occurred in local vaccination clinics. Diarrhea and colds and flu routinely affected nearly 40% of children at SJL, and these were major causes of child morbidity (Murillo and Markowitz 1995, 10). Seventy percent of mothers at SJL have reportedly had at least one child die. About 16% of households had lost infants or children to diarrhea and dehydration while 16% lost fetuses (stillbirth). Deaths from diarrhea and dehydration should be preventable (Murillo and Markowitz 1995, 11). Nearly 40% of households reported childhood deaths for which causes of death were unknown.

In terms of human reproduction, FHH at SJL averaged 5.3 pregnancies each. The sample for this study only included young mothers and therefore it does not reflect the fertility rate of SJL. There was no access to family planning information, although there was interest among FHH in family planning.

Breastfeeding for infants and young children was common at SJL (Murillo and Markowitz 1995, 12-14). Colostrum (the "first milk" laden with antibodies, vitamins, minerals, protein and energy) was received by newborns in 72% of households. Over 90% of households relied on breast milk for child rearing, while 3% relied on formula milk. Half of FHH breast-fed children for 18 to 24 months, while another 25 and 19%, respectively, breast fed for 12 to 18 months or >24 months (Murillo and Markowitz 1995, 13).

The people of SJL relied on a heavily carbohydrate-based and strikingly uniform diet (Murillo and Markowitz 1995, 14-15). Variety in the diet resulted more from variation in preparation rather than ingredients. A large majority of households relied on fresh and freeze-dried potatoes (e.g., *chuño*), rice, pasta, barley, beans, *quinoa*, peas and wheat. Bread rolls were consumed daily. Rice, pasta and bread were purchased while the other foodstuffs were produced by the family. The most common source of animal protein was lamb. Over three-fourths of households slaughtered a lamb at least once per month for food. Chicken and dried meat were consumed less frequently. Beef consumption was the most rare. Consumption of cheese and milk was widespread, although infrequent and variable. Dairy production tended to fluctuate seasonally, which was a major explanation for variation in intake of dairy products. Chicken eggs occurred weekly in the diets of more than half of the households. Small quantities of purchased onions, tomatoes and carrots occurred as condiments—celery and lettuce were rare. Fruit (i.e., bananas, oranges, apples) was purchased and consumed on a weekly basis. Up to one liter of vegetable oil was used for cooking each week. Purchased sugar sweetened porridges, herbal teas and coffee. Coca leaves were often chewed by adults when socialising or to allevate fatigue. The campesinos typically ate four meals per day. The timing and composition of meals is described in Murillo and Markowitz (1995, 14-15).

Human malnutrition is common in rural areas on the Altiplano (Van Haeften 1996). This reflects pervasive poverty as well as periodic crop failures due to frost or drought. Some forms of malnutrition have been exacerbated by shifts from traditional diets consisting of higher protein cereals such as *quinoa* and *cañawa*—prepared with sheep milk and cheese—to a diet dominated by pasta, rice and maize purchased from local markets (Orlove 1987; Dr. C. Valdivia, IBTA/SR-CRSP, unpublished data). The advantage of the purchased carbohydrates is that they often require less effort to prepare than *quinoa* or *cañawa*, but purchased foods can be less nutritious (Murillo and Markowitz 1995).

Based on verbal recall data for diet quantity and use of nutrient content values for common foods, it was suggested by Murillo and Markowitz (1995, 16-18) that intake of macronutrients (i.e., energy and protein) by members of households appeared to be sufficient, but that deficiencies were likely in intake of micronutrients (i.e., vitamins and minerals) and certain compounds such as animal fats. For example, eight out of 10 households at SJL reportedly had an adequate intake of energy, while seven of 10 had an adequate intake of protein. Intake of Iron, Calcium, Vitamin A, Vitamins B_1 and B_2, Vitamin C and Niacin, however, were below minimum standards for 22 to 88% of households. About 75% of households reportedly had an inadequate intake of animal fat—the minimum standard being 60 g per household per day.

These results were interpreted to suggest that the population may suffer from micronutrient deficiencies, although the occurrence of symptoms of such deficiencies was not assessed (Murillo and Markowitz 1995). Micronutrient deficiencies can lead to a variety of symptoms (Dr. K. Galvin, Colorado State University, personal communication). Iron deficiencies can lead to anemia among women of reproductive age. Calcium deficiencies can impair skeletal development, blood coagulation and absorption of other micronutrients. Vitamin A deficiencies can impair development and maintenance of healthy immune systems, vision and skin. The Vitamin B complex is important for enzyme systems, while Vitamin C is important for maintaining bone, teeth and connective tissue. Lack of Vitamin C can cause scurvy. Animal fats can provide concentrated energy to help meet high demands for energy incurred from hard physical labour in a cold environment. Fats also provide an important source of fat-soluble vitamins. People fail to grow normally on diets deficient in fats. Dietary animal fat primarily came from slaughtering local Criollo sheep, rather than the improved sheep which tended to be sold (Dr. C. Valdivia, IBTA/SR-CRSP, personal observation).

Murillo and Markowitz (1995) conducted physical measurements (i.e., weight-for-height, height-for-age and weight-for-age) on 42 children <5 y old. Weight-for-height is indicative of short-term (i.e., acute) nutritional stress, while the others are more indicative of longer-term (i.e., chronic) nutritional stress. Conclusions from such anthropometric studies are strongly influenced by the accuracy and local applicability of comparative baseline standards (Dr. K. Galvin, Colorado State University, personal communication).

Considering weight-for-height, work was performed four to five months after harvest in 1992-3, a year considered to be "adequate" for crop production. Results, therefore, may be biased high and not representative of times when acute crises occur for child nutrition. For example, short-term nutritional crises for children might be most readily detected during the months immediately preceding harvest (i.e., February or March) or in a drought year. Regardless, weight-for-height results of Murillo and Markowitz (1995) indicated that about 12% of children at SJL exhibited "mild to moderate" forms of acute malnutrition. Others were in the "normal" range.

Considering height-for-age and weight-for-age, results were interpreted to suggest that chronic child malnutrition was more common than acute malnutrition. Chronic malnutrition represents the cumulative effects of food shortages or poor childhood feeding practices throughout a child's lifetime. Height-for-age is a feature which reflects skeletal development and therefore long-term intake of minerals (i.e., calcium, phosphorus), protein and energy (Dr. K. Galvin, Colorado State University, personal communication). Only 48% of children at SJL were "normal" in terms of height-for-age, with 46% in the "mild to moderate" malnutrition range and 6% in the "severe" malnutrition category. Weight-for-age, in contrast, reflects body mass development and therefore long-term intake of energy and protein (Dr. K. Galvin, Colorado State University, personal communication). For weight-for-age, only 52% of children were "normal" and 5% were "above normal." Forty-one percent of children were in the "mild to moderate" malnutrition range and 2% were in the "severe" malnutrition category.

To summarise results from their work, Murillo and Markowitz (1995, 23-24) concluded that: (1) The contemporary composition of the human diet at SJL reflects decades of economic and agrarian change, and is no longer "traditional"; (2) strategic use of foods procured from production and the marketplace furnishes families with diets that are typically sufficient in energy, but may be lacking in important micronutrients; (3) deficiencies in micronutrients may play a prominent role in child morbidity and mortality at SJL; and (4) despite the relatively "wealthier status" of SJL compared to more remote communities on the Altiplano (see Chapter 1: *Project framework and research approach*), deficiencies in child nutrition still appeared to be pervasive. Including more fruits and vegetables in children's diets could help offset several of the micronutrient deficiencies. Intervention concepts and other implications are reviewed in Chapter 8: *Conclusions and recommendations*.

Household structure and population dynamics. Like most rural communities on the Altiplano, the human population of the Cantón of SJL is dynamic. The Bolivian National Census of 1992 registered 431 inhabitants of SJL (INE 1993). In 1994 we estimated that 100 households resided in SJL, with a total population of about 400 people (C. Jetté et al, IBTA/SR-CRSP, unpublished data). Numbers of households and individuals at SJL largely change because of migration, especially the tendency of younger males to move seasonally between SJL and urban locales. It is common, for example, to have people who work or go to school outside SJL to periodically return to assist with agricultural tasks such as planting or harvesting crops (Sherbourne et al 1995).

Most residents of SJL lived in households comprised of nuclear families in which parents and their unmarried children shared a dwelling, cooked and ate together. They also jointly owned and managed livestock and parcels of cropland (Jetté 1993). The nuclear family may be expanded to include parents of the male head of household, children of adult sons or daughters who have emigrated, and sons- and daughters-in-law (Markowitz and Jetté 1994). Such households that were busily raising families and contributing to the productive output of the community were referred to as "activos" (actives) and made up 65% of SJL households during 1992-5. In contrast, the remainder was comprised of elderly couples or widowers. These were called "pasivos" (passives) by the community. Passive households were essentially people in retirement—they were exempted from most community obligations and had handed over much of their crop land and livestock to their children (Markowitz and Jetté 1994; see Section 6.3.1: *Socioeconomic groups*).

The fertility rate, measured as the number of children per married woman, was officially estimated as 5.7 for SJL during 1992 (INE, unpublished data). This figure is similar to regional data for the Department of La Paz where fertility rate has been estimated at 6.0 (INE, 1993). Child recruitment has increased in recent decades on the central Altiplano, primarily a result of a decline in child mortality rather than an increase in natality. The mortality rate for children <5 years of age has been estimated at 166 per 1000 (or 16.6%) for the rural Altiplano during the period 1984-94 (INE/DHS, 1994). See previous material in this section for a discussion of infant mortality at SJL.

In 1992 females represented 53% of the population at SJL overall (C. Jetté et al, IBTA/SR-CRSP, unpublished data). When the cohort between ages 15 and 30 years is considered, however, females outnumbered males 2:1, which reflected the high rate of emigration among males in this age group. A disproportionate number of people at SJL were either <15 years of age (44%) or over 60 (12%), which also reflected age groups least likely to emigrate (C. Jetté et al, IBTA/SR-CRSP, unpublished data).

It is difficult to precisely document population dynamics at the level of the cantón. The main reason for this is because official census records only reported aggregate figures at the level of departments until 1992. In 1992 the smaller cantón unit was finally recognised as a valid administrative unit, and SJL did not become a cantón until 1993 (Medinacelli et al 1993; Markowitz and Jetté 1994). For us to determine human population dynamics, our main recourse was therefore the study of local oral history and unofficial population records. Interpretation must be tempered by the knowledge, however, that such information can be incomplete or inaccurate.

Based on oral history interviews of older campesinos (C. Jetté, IBTA/SR-CRSP, unpublished data) and review of local archives (Medinacelli et al 1993) we have estimated that there were about 55 to 60 households living in SJL at the end of the 19th century. By the 1960s and 1970s the number of households appeared to double to about 120 to 125 (Markowitz and Jetté 1994). We speculate that reductions in child mortality due to gradual improvements in food production were most responsible for this trend. By the late 1970s, however, a downward trend in human population began at SJL—a trend that was sharply accelerated during and after the 1982-3 drought. The 1982-3 drought was considered by many campesinos to be the worst drought in the past 50 years (C. Jetté, IBTA/SR-CRSP, unpublished data; Medinacelli et al 1993; see Section 3.1: *Climate*). There were 100 resident households at SJL by 1994 (C. Jetté et al, IBTA/SR-CRSP, unpublished data). What has caused the population decline from the late 1970s to the present? As we subsequently outline in more detail later, we speculate that a combination of increased access to rural education and concomitant changes in lifestyle expectations, as well as a tilt in economic incentives from rural towards urban situations, have been most responsible for a net outflow from SJL due to emigration. Mix in the brief, but calamitous, effects of the drought in 1982-3 and the cause and effect scenario appears relatively complete. Although environmental degradation, and effects of environmental degradation on lowering agricultural productivity, have been commonly blamed as the cause of the rural exodus in Bolivia over the past 40 years (i.e, more emphasis on “push factors”), this may not be true in the case of SJL where “pull factors” appear most prominent (see Chapter 1: *Project objectives and research approach*, Chapter 3: *Ecology and natural resources of San José Llanga*, and Chapter 8: *Conclusions and recommendations*). Some of these perspectives are revisited and justified below.

We surmise that once the households of retirees (i.e., pasivos) gradually disappear the number of households will stabilise around 80 in the foreseeable future. It is unlikely in the current situation favouring emigration that households of pasivos will be replaced (C. Jetté, IBTA/SR-CRSP, personal observation).

We have personally witnessed departures of several families during 1992-5 at SJL (C. Jetté, IBTA/SR-CRSP, personal observation). We have also observed that some emigrants ultimately returned to SJL either because their emigration experience was not satisfactory or they had to take care of elderly parents (C. Jetté, IBTA/SR-CRSP, unpublished data). We observed fewer departures in 1992-3 than in 1994-5—the higher number of departures in 1994-5 may have been related to greater stress created by a dry rainfall year (See Chapter 6, Section 6.3.2: *Coping with a drought year*; see Section 3.1: *Climate*).

As the heads of households aged they typically expected that at least one of their children would be increasingly responsible for helping to manage family land and livestock resources (Markowitz and Jetté 1994). A few households with a larger-than-average land base were able to bequeath sufficient land so that future, agriculturally based livelihoods of their children are not jeopardised. This is more the exception than the rule, however (Markowitz and Jetté 1994). Variation in permanent access to crop land for households is depicted in Figure 4.1. Households with an average or smaller-than-average land base often must bequeath insufficient land to their children. In this case, the prospects of a marginal existence can motivate young adults to emigrate. The types of land bequeathed was also an important factor in this process—land suitable for growing irrigated crops using fresh water would be most valuable (Markowitz and Jetté 1994). For example, some families in SJL have emigrated because they did not have enough access to land appropriate to growing alfalfa under irrigated cultivation, and the ability to access alfalfa appeared to be strongly associated with the ability to raise improved sheep or participate in smallholder dairying. Both of these enterprises increased the likelihood of higher incomes for households (see Chapter 6: *Household socioeconomic diversity and coping response to a drought year at San José Llanga*). Accordingly, the neighbourhood with the largest proportional population decrease was *Espíritu Willq'i*, which was furthest from key resources such as the alluvial fan where alfalfa was grown under fresh-water irrigation (Markowitz and Jetté 1994; see Figure 3.3 and Section 3.3.2.1: *Geomorphic units*).

Importantly, the motivation to emigrate was not solely possessed by the poorest households, or by the young male pursuing educational opportunities, which the argument above appears to support. Indeed, emigration occurred with households from both the top and bottom of the economic ladder (C. Jette, IBTA/SR-CRSP, personal observation). When poorer households emigrated, the circumstances were typically related to survival. When wealthier households emigrated, the circumstances were typically related to economic expansion or diversification. Regardless of differences among economic strata in the reasons for emigration, there were some common factors that appeared to encourage adults to emigrate (C. Jetté, IBTA/SR-CRSP, personal observation). These included: (1) High risks to personal livelihoods from drought; (2) need to secure a decent education for their children; (3) desire to improve living standards by raising incomes through off-farm employment; and (4) gaining access to amenities such as electricity and better transportation. In many cases this migration took place for a few years, be it to assist in the accumulation goals of the family or to provide for better educational opportunities.

For youths, the desire to emigrate was pervasive among males and females and was largely related to taking a few years outside of SJL to acquire marketable skills, thereby gaining the ability to earn a cash income (Nolan 1994, 35). For youths, the scarcity of cash and difficulty of finding wage employment were the main negative aspects of life at SJL. Young males aspired to enter various skilled trades while young females hoped to be seamstresses. Young males, however, appeared to have a strong sense of community responsibility. Many hoped to keep SJL as a base for agricultural enterprises, especially those involving dairy production (Nolan 1994, 35). For cultural and economic reasons it was easier for young males to emigrate compared to females. The need for female labour to herd livestock was a major factor for households to discourage young women from emigrating (Nolan 1994, 35).

While it has been noted above that some emigrants have been disappointed with their migration experience and returned to SJL, other emigrants appeared quite successful. For example, by 1995 three emigrant households succeeded in establishing a couple of small clothing-factories that manufactured wool sweaters and leather jackets (C. Jetté, IBTA/SR-CRSP, unpublished data). Emigration was carefully planned and could involve several years of trial and error (C. Jetté, IBTA/SR-CRSP, unpublished data).

Emigrants typically maintained their property rights at SJL. It was rare that natural resources

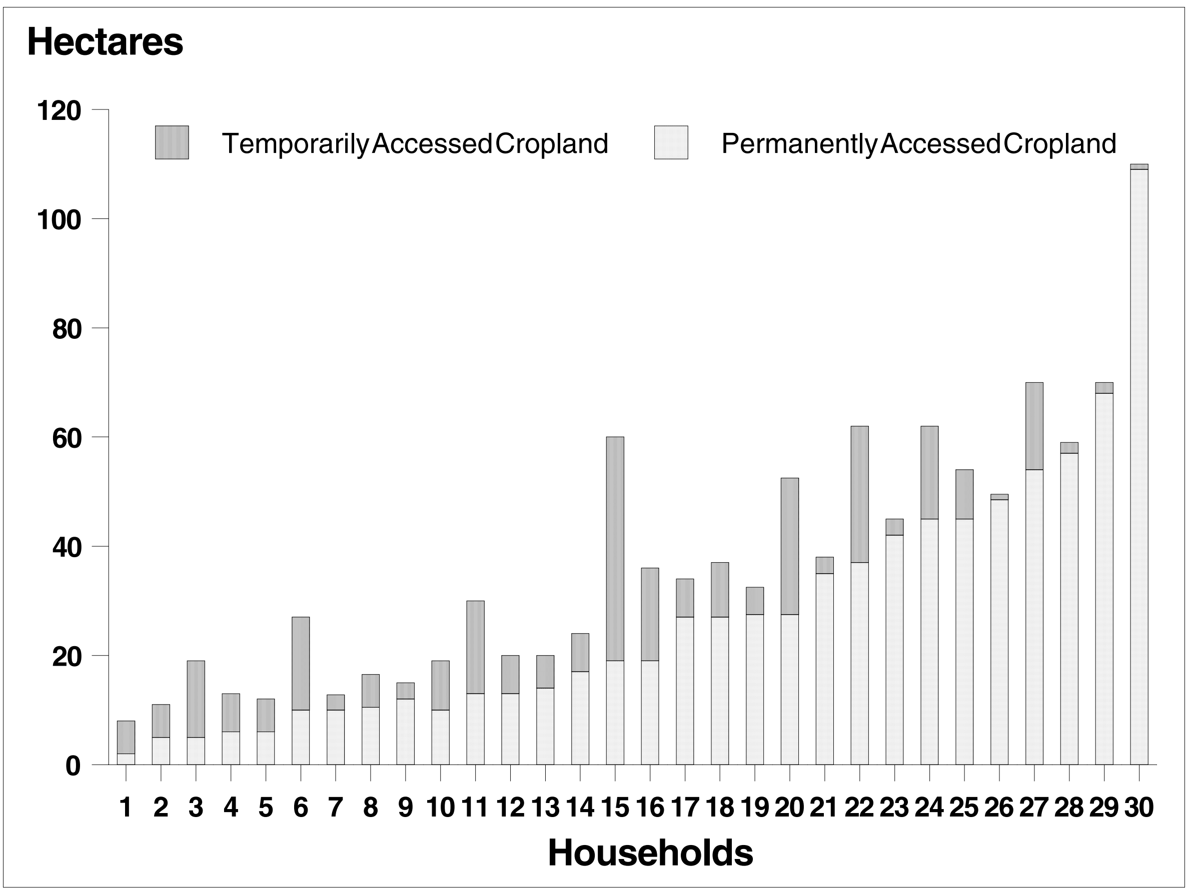

Figure 4.1. *Distribution of local land holdings (ha) according to degree of access for 30 campesino households at San José Llanga.* Source: Cala (1994)

were sold or otherwise transferred—the norm was for land and livestock of emigrants to be put in the hands of care-takers who were usually members of the immediate or extended family. These care-takers benefitted in terms of productive access to resources while the emigrant owner benefitted by maintaining community ties and hence reducing risks and uncertainties of emigration (Markowitz and Jetté 1994). This is consistent with patterns documented throughout the Altiplano by Albó (1988). Contemporary patterns of creating new economic linkages among rural and urban locales appeared to resemble age-old tactics of risk management via integration and diversification of distinct ecological resources—this characterised the traditional *allyus* of the *Aymara* prior to the Spanish conquest (see Section 2.3.2: *Regional historical highlights*). Extended families, therefore, were the main mechanism for emigrants to maintain ties to the land while allowing non-emigrants access to a wider variety of resources compared to if emigration linkages had not occurred (Markowitz and Jetté 1994; Valdivia et al 1996).

The livestock population at SJL has also changed over time, especially during the period 1900 to 1950. Llamas occurred at SJL at the turn of the century, but they were already greatly outnumbered by sheep (C. Jetté, IBTA/SR-CRSP, unpublished data). The higher marketability of sheep, changes in land tenure (below) and decline in the utility of llama for animal production and portage were contributing factors to the gradual disappearance of llama at SJL (see Section 2.3.2: *Regional historical highlights*). In addition, while there was little precise information regarding the Cantón of SJL, there was other evidence that numbers of sheep held per household had declined in the region over the past 50 to 100 years. For example, the majority of our informants agreed that family sheep flocks were larger in the past and that the wealthiest households 50 years ago could easily possess 200 to 300 head (C. Jetté, IBTA/SR-CRSP, unpublished data). Today, in contrast, three of the wealthiest households at SJL possessed 60 to 70 head (Dr. C. Valdivia et al, IBTA/SR-CRSP, unpublished data). Records of neighbouring haciendas indicated that in 1910, campesino families held one or two oxen and 50 to 130 sheep on average (C. Jetté, IBTA/SR-CRSP, unpublished data). In 1993, from a sample of 45 households at SJL, the average (± SE) household flock size was 50 ± 5.4 head, while cattle holdings averaged 5 ± 0.3 head (Valdivia et al 1996).

There have been important changes in land tenure and local economy at SJL during the past 100 years (Jetté 1993). In the 1890s SJL was characterised by: (1) A relatively small human population because of high rates of child mortality; (2) a generally high degree of communal resource use; (3) a generally high degree of human migration in and out of the community, particularly in terms of rural-to-rural linkages which were formed in response to opportunities for inter-regional trade between the central Altiplano and High Valleys; and (4) persistence of traditional diets and cottage industries, the latter prominently including weaving by women with home-spun fibre. Compared to the 1890s, the 1990s at SJL were characterised by: (1) A human population that was declining in size, but still over 50% larger than at the turn of the century; (2) a mix of private access and communal use of resources; (3) a generally high degree of human migration, but more in the form of urban-to-rural linkages; and (4) marked shifts in diets and declines in the prevalence of traditional cottage industries.

Traditional patterns began to be disrupted by the 1950s (Markowitz and Jetté 1994). The first broadside arrived as the Agrarian Reform Act of 1952, which brought community-level titling of land to the central Altiplano. This form of privatisation first affected use of higher-value croplands at SJL (C. Jetté, IBTA/SR-CRSP, unpublished data). Priority access to higher-value croplands was determined on the basis of recent land-use patterns—those families which had been regular users of specific plots became the priority users. In contrast, those who had been irregular users of cropping plots commonly lost out. Subsequent access to crop lands has been primarily determined by inheritance whereby fathers pass controlled-access lands to sons. The new policy of restricted access to land should not, however, be confused with strict privatisation based on deeded ownership of plots. Deeded ownership of land *per se* has not existed at SJL, as there were no laws in Bolivia which allowed the sale of communal lands (Markowitz and Jetté 1994). This restricted use of crop lands also led to limitations in the degree to which fallow could be communally accessed for grazing. Llama, traditionally an animal allowed to roam unhindered, probably was a species that inordinately suffered when grazing access to fallow was curbed. Gradual development of infrastructure linked market centres, and subsequent market growth began to affect the campesino economy at SJL by the mid- to late-

1950s (Drs. C. Valdivia and L. Markowitz, IBTA/ SR-CRSP, unpublished data). Campesinos slowly began to sell surplus produce and obtain cash. Diets began to change through inclusion of non-traditional foods. Demand for cash increased in the 1950s as more small "luxury" items and other goods became readily available in the marketplace. By the 1960s the growth of market linkages, development of textile industries, and an increasing urban-based food demand set the stage for more change, all in conjunction with a long period of above-average precipitation. This is covered in detail in Chapter 7: *Patterns of technology adoption at San José Llanga*. An increased demand for wool and commercial-grade potatoes stimulated campesinos at communities such as SJL to intensify aspects of sheep and crop production. A tractor cooperative was one result that altered potato production in the 1960s (Murillo and Markowitz 1995). This encouraged adoption of improved sheep, improved forages (i.e., alfalfa) to maintain the sheep, more marketable varieties of potatoes, and an increased use of tractor tillage. Adoption of technical innovations was therefore probably not a function of labour scarcity—there was plenty of labour—but rather more a function of campesinos responding to new economic opportunities. International development agencies such as USAID responded by capitalising on such trends in the late-1950s and 1960s by helping spur technology importation, technology development, and helping create a national research capability through entities such as IBTA (e.g., Instituto Boliviano de Tecnología Agropecuria). Subsidies for fertilisers, pesticides and other production inputs also occurred in the 1960s (Markowitz and Jetté 1994; see Chapter 7: *Patterns of technology adoption at San José Llanga*). All of these factors, coupled with rapid growth in the human population due to a decline in child mortality, encouraged subsequent surges in privatisation of higher-value croplands and grazing lands at SJL during the 1960s and 1970s. The outcome remains evident today, with a decided mix of private access and communal tenure (Cala 1994). By the late 1970s textile industries in Bolivia were shrinking and demand for commercial-grade food crops produced on the Altiplano was waning. By the late 1980s urban demand for dairy products began to increase, which led to establishment of PIL and the advent of smallholder dairying at SJL, as will be discussed. This all is interpreted to illustrate the dynamic windows of economic opportunity which appear to shift on a decade-by-decade basis. These shifts result in a re-casting of resource use and agricultural priorities in the community (see Chapter 7: *Patterns of technology adoption at San José Llanga*).

4.3.2 Community organisation, local government and indigenous institutions

The Cantón of SJL utilised formal and informal organisations and leadership structures to make collective decisions. These leadership structures were very strong at SJL. The leadership of the cantón recently played major roles in private initiatives that led to development of community services. Projects included provision of systems for potable water distribution, electric lighting for households and completion of the secondary school (Plate 4.1; Dr. C. Valdivia, IBTA/SR-CRSP, personal observations). These projects were undertaken in order to counter-act the pervasive "pull forces" which have been depleting SJL of its youth via emigration. The leadership at SJL was thus a form of social capital vital to the prosperity and sustainability of the community. It may be relatively rare in many parts of the central Altiplano to have such a concentration of social capital in one cantón. The leadership has also been vital in the promotion of smallholder dairying and creation of irrigation systems (see Section 4.3.3.1: *Household activities and economy* and Section 3.3.2.1: *Geomorphic units*). The following observations on leadership structures and posts have been mostly compiled from Cala (1994) and Markowitz and Jetté (1994).

Most of the important community decisions were collectively made by community members during formal monthly meetings called "asambleas generales" (Plate 4.2). The asambleas generales were convened and conducted by the two most important figureheads in the community, namely the secretary general and the secretary of justice (*jilikata*). As with all senior political posts in SJL, the secretary general and *jilikata* were posts filled by mature males. The secretary general was the coordinating leader for the asambleas generales. The *jilikata* was responsible for details such as settling disputes, organising collective works, overseeing land tenure transactions and attending social celebrations. Topics discussed at the asambleas generales included electing new people to leadership posts, debating relation-

Plate 4.2. *The asambleas generales at the* Barrio *of San José Langa.* Photograph: Christian Jetté

ships that SJL had with other communities and external organisations, logistics of community projects, regulation of grazing areas, financial contributions to community activities, sanctions and penalties for serious malfeasance, and major political issues. Meetings may be called more frequently than monthly as community events require (Markowitz and Jetté 1994).

A representative of each household, usually the male household head (who may be replaced by his wife or an adolescent child), was required to attend the asambleas generales. Other important obligations of community members are to participate in community *faenas* (work projects) and assume community offices. Indeed, one principle of electing authorities was to ensure that all adult males eventually serve each community office, beginning with less-demanding appointments, so people gradually obtain experience. Besides the secretary general and the *jilikata* there were several other senior positions including secretaries of sports, education, recording and finances. There were also two "agentes de campo" (field agents) who had the responsibility of enforcing community regulations concerning grazing and penalise rule-breakers according to degree of infraction (Cala 1994).

All elected posts except for the *jilikata* were filled with new people on an annual basis; the *jilikata* was replaced every six months. The secretary general and *jilikata* positions involved a significant expense of time and money on behalf of the people occupying the posts. The rewards of these posts were largely non-monetary and included social prestige and self-satisfaction based on the scope of community accomplishments while in office.

This extremely democratic form of authority had some drawbacks. For example, the people elected to key posts were often not the most capable. There has been a case where a man was elected secretary general simply to force him to participate in community activities. The annual turnover in leadership can also undermine continuity for management of community projects. To promote continuity of special projects the community formed special ad hoc associations comprised of members who had vested interests in the special projects. Thus, in SJL in the early 1990s there were three associations to oversee irrigation, milk collection and development of potable water. Most households belonged to at least one of these associations, while some were active in all three. The leadership of associations typically operated in a more flexible fashion compared to that of the asambleas generales. The leadership of associations changed on a rotating schedule.

Despite a few flaws, the system revolving around the asambleas generales has functioned well in providing a forum for households to merge their individual interests with community needs in order to achieve a concensus for management of communal resources and provide a mechanism to mobilise the population for community projects. Both are vital for sustainability of the community as a whole.

In addition to the formal asambleas generales there existed a strong informal leadership at SJL that included the few members of the community who were more prosperous and better educated. These individuals often dominated discussion in the asambleas generales. They often took the initiative to conceive and promote new community projects and make initial contacts with outside organisations that could possibly provide funding or expertise to get projects implemented. These leaders usually petitioned the asambleas generales that they be relieved from communal work obligations as compensation for their services. The leaders can be criticised by the rank-and-file for trying to obtain larger personal benefits from projects they conceive and for cultivating privileged relationships with external organisations.

The Bolivian state appeared notably absent in local governance at SJL—the physical presence of the national government was only marked by the existence of the primary school. Extension of public health services was limited to occasional visits by staff from the Patacamaya Health Centre during vaccination campaigns. Traditionally, the official status of the cantón has been low. The cantón, therefore, has not merited much attention from the central government. A civil register has recently been installed at SJL and government involvement could eventually make it easier to offer secondary education now that the new building is finished. Overall, this somewhat marginal situation could soon change, however, with the recent creation of rural municipalities via passage of the Popular Participation Act (see Section 2.2.2.3: *National highlights of social history: 1951 to 1996*).

4.3.3 Household production system

In this section we focus on the diversity of household production activities, use of agricultural innovations and how households varied in terms of land access, income and livestock assets. We end this section with material on how animal production enterprises were controlled by males and females and the consequences for household welfare. In this review we variously call on empirical work of Céspedes et al (1995), Illanes et al (1995), Sherbourne et al (1995), Murillo and Markowitz (1995), Valdivia et al (1996), Valdivia and Jetté (1996), Eyzaguirre et al (1995) and Huanca et al (1995). Aspects of innovation adoption, stratification of households into technology adopters and non-adopters, and the role of livestock in promoting food security are amplified further in Chapter 6: *Household socioeconomic diversity and coping response to a drought year at San José Llanga*.

4.3.3.1 Household activities and economy

Households at SJL were typically involved in a wide variety of agricultural and non-agricultural activities. Agricultural activities included cultivation of food and forage crops, sheep husbandry and cattle production incorporating smallholder dairying. Inheritance, resource sharing and patterns of caretaking played significant roles in the distribution and accumulation of land and livestock at SJL (see Section 4.3.4: *Non-market factors in resource access*). Production of genetically improved sheep and smallholder dairying based on improved cattle are both relatively recent enterprises which owe their existence, in large measure, to expansion of introduced forages such as alfalfa cultivated under irrigation (see Section 3.3.2.1: *Geomorphic units* and Chapter 7: *Patterns of technology adoption at San José Llanga*). Genetically improved sheep were first introduced in the 1960s while smallholder dairying was introduced as recently as 1989. Most other agricultural enterprises, however, including the basic production of food-crop staples (i.e., potato, *quinoa*, *cañawa*, etc.) and husbandry of Criollo sheep and Criollo cattle have endured at SJL for hundreds of years (see Section 2.3.2: *Regional historical highlights*). Non-agricultural activities mostly involved wage employment and opportunistic, local endeavours to augment household income. Wage employment at SJL occurred locally or as a result of long-distance emigration. Many of these non-agricultural employment opportunities were relatively recent due to local infrastructural improvements and a general increase in the economic development of the nation.

The discussion below begins with brief descriptions of the major agricultural and non-agricultural enterprises at SJL, including estimates of the cost of production for key commodities. This is followed by a breakdown of total income (i.e., cash plus in-kind value) attributable to major enterprises averaged for 45 households during 1993 (Drs. E. Dunn and C. Valdivia, IBTA/SR-CRSP, unpublished data). The year 1993 was slightly below-average in terms of annual precipitation and crop production (see Section 3.1: *Climate*).

Crop production. A variety of food and cultivated forage crops are grown at SJL, typically in small plots a few hectares or less in size. Plots for food-crop production were privately accessed by individual households and occurred on the alluvial terrace, alluvial fan and deltaic deposits (see Section 3.3.2.1: *Geomorphic units*). Plots for cultivated forage production were accessed by individual households or groups of households and were relatively more common on the alluvial fan and deltaic deposits. In contrast, most of the lower-value native rangeland tended to be under communal use. More productive rangeland closer to human dwellings tended to be under private access (Dr. J. de Queiroz, IBTA/SR-CRSP, personal observation).

Areas controlled by households for food and forage crop production were highly variable in size, a conclusion based on a study of land holdings at SJL by Cala (1994). Figure 4.1 depicts access to crop land for 30 households at SJL. These data illustrate that the area of crop land accessed by these households varied by 11-fold, with a range of 10 to 120 ha. Households with access to smaller acreages tended to have higher proportions under only temporary rights of use. Conversely, as access to land increased a higher percentage of the land was under permanent access by households.

The poorest household in Cala's (1994) study permanently controlled about 1.0 ha of cropland while the wealthiest permanently controlled 115 ha. In general most households used at least 20 individual parcels of crop and fallow land, widely distributed to reduce risk of crop damage to frosts, pathogens, insects and parasites. Although the scattering of crop plots probably served as an effective risk-mitigating tactic, it also created challenges in the form of increased time and labour requirements for crop management (C. Jetté, IBTA/SR-CRSP, personal observation).

The distribution of crop plots for three representative households is shown in Figure 4.2. The maximum distances among crop plots held by these three households ranged from 7 to 15 km. Plot distribution reflected geomorphology. Most plots occurred on older sites of the alluvial terrace with some on newer sites developed on the deltaic deposits (see Section 3.3.2.1: *Geomorphic units*).

As previously noted, males were typically the land owners at SJL and sons tended to inherit crop land from their fathers. A very small portion of crop land (around 2%), however, was reportedly owned by people who were not residents of SJL. Such land purchases were very rare and must be approved by the leadership at SJL (Cala and Jetté 1994).

The main food crops that are grown in SJL include potato, *quinoa*, barley, wheat, oats, faba beans, peas and *cañawa*. Potato was the most important food staple in this region, comprising the bulk of human diets throughout the year (Sherbourne et al 1995). Some local crops and food products are shown in Plate 4.3 (a,b). Only

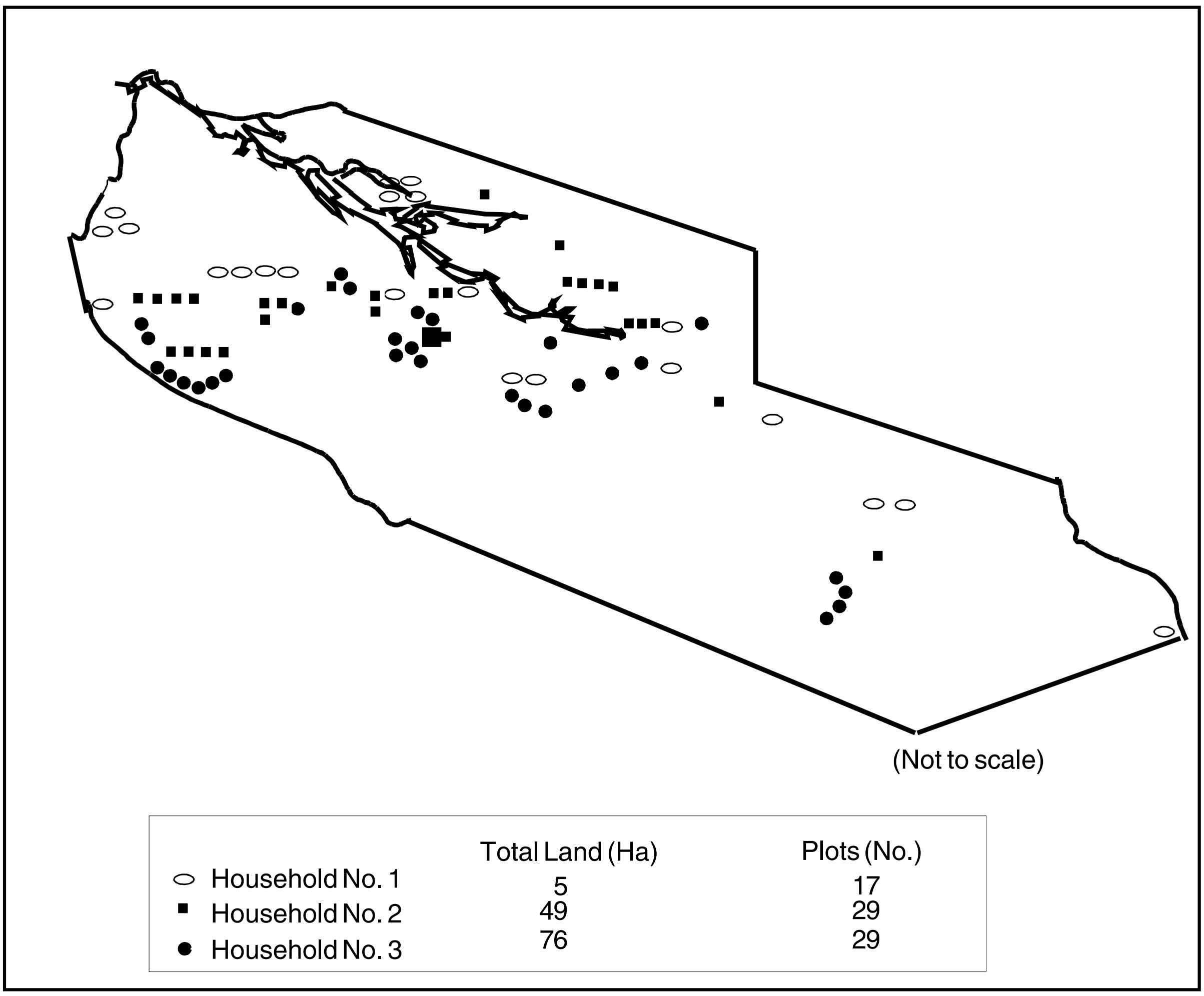

Figure 4.2. *Spatial distribution of crop land plots or parcels accessed by three campesino households at San José Llanga during 1993.* Source: Cala (1994)

those households which owned land near the freshwater *Khora Jahuíra* River could grow beans, peas and *cañawa* (Sherbourne et al 1995). Cultivated forages include alfalfa, forage barley, forage wheat and forage oats. Alfalfa was introduced in the 1960s as part of development programmes (see Chapter 7: *Patterns of technology adoption at San José Llanga*). Crop residues and crops lost to frost are routinely fed to livestock. Some native grasses collectively referred to as *k'ora* were also cut and stored as hay by some households for livestock feeding (Sherbourne et al 1995).

Roughly 80% of the cultivated area at SJL was in fallow at any given time (Section 3.3.3.4: *Vegetation change in fallow fields*). In general, most households rotated their cultivated fields on a four-year planting schedule that first started with potato in newly tilled fields and was then followed by a crop such as barley, *quinoa*, beans, *cañawa*, oats or wheat until the plot was fallowed by the fifth year. Fields may be fallowed for up to 15 years, but more typically 5 to 10, years before potatoes are planted once again and the rotation re-initiated. The crops planted after potato in the rotation often do not require tillage or land clearing prior to cultivation (Sherbourne et al 1995). Other details on cultivation and soil management at SJL are provided in Section 3.3.3: *Natural resource dynamics* and Section 3.3.4: *Integration of ecological findings*.

Crop production at SJL was an activity in which both males and females participated (Valdivia et al 1996) and this has been observed elsewhere on the Altiplano (Caro 1992; Norman 1992). Men and women worked side-by-side to manage and harvest their crops and child labour was used as needed (Plate 4.4). A good example of men and women working together was well-illustrated by soil tillage and sowing seed—when planting the male handled the ox-drawn plough while a female commonly sowed seeds and spread fertiliser. Decision-making on crop production and use (i.e., what and how much to plant, when to harvest, what proportion to allocate for home consumption, sale or seed) appeared to be a joint process between men and women (Valdivia et al 1996).

Table 4.1 illustrates various statistics for crop production among 45 households at SJL during 1993. In terms of cultivated area potato was the most extensively planted food crop, closely followed by *quinoa*. The most extensively planted forage crops were alfalfa and forage barley. Yields (in metric tonnes per hectare) for 1993 indicated that wheat and potato were the most productive food crops, while alfalfa was the most productive forage crop (Table 4.1). Estimates of average crop yields for several other sites from the central Altiplano during 1986-8 were calculated by Dr. C. Valdivia (IBTA/SR-CRSP, unpublished data) based on information in Montes de Oca (1992). The years 1986-8 generally experienced near-average rainfall and thus were generally similar to 1993 in terms of precipitation (Section 3.1: *Climate*). These regional averages included: (1) Potato yields of 4.2 to 5.3 metric tonnes (MT) per hectare; (2) overall grain yields (i.e., barley, wheat and oats) of 0.64 MT per hectare; and (3) overall yields of cultivated forage (i.e., alfalfa, barley) of

a

b

Plate 4.3 (a,b). *Examples of indigenous cultivation and food crops at San José Llanga: (a)* quinoa *grain and (b) woman harvesting potatoes.* Photographs: Christian Jetté

Plate 4.4. *Men and women working side-by-side in the potato fields at San José Llanga.* Photograph: Christian Jetté

2.61 MT per hectare. Although contrasts are crude at best, when we compared crop yields from SJL with the respective regional means, potato yields at SJL (i.e., 1.1 MT/ha) were considerably (i.e., 77%) lower, forage yields (i.e., 1.9 MT/ha on average) were moderately (i.e., 27%) lower, while grain yields (i.e., 0.82 MT/ha on average) appeared moderately (i.e., 28%) higher.

Although the majority of households at SJL did not have an annual surplus which allowed them to regularly sell food crops in the marketplace, a few households well-endowed with crop land did sell some food crops and seed stock every year (Sherbourne et al 1995). Forage crops were very rarely sold, however, which was possibly an indicator that livestock demand for feed was chronically high throughout the Cantón of SJL (Sherbourne et al 1995). Households which were able to store some surplus food crops could make good profits during dry years or droughts—this was observed in 1995 (Dr. C. Valdivia, IBTA/SR-CRSP, unpublished data). In the rare cases when crops were sold the income tended to be used for miscellaneous household expenses (Sherbourne et al 1995).

Potato production was the most labor-intensive and one of the riskiest food crops at SJL. Potato required more inputs and management expertise than any of the other major crops at SJL (Sherbourne et al 1995). Potato plants on the central Altiplano have a 50% probability of loss due to frost damage (Le Tacon et al 1992).

Potato production was relatively complex at SJL compared to other food crops. Huanca et al (1995) noted that potatoes were planted in three types of fields: (1) Those that have been in fallow for 3 to 5 years (*q'allpa*); (2) those in fallow for 6 to 10 years (*puruma*); or (3) those fields planted in the previous year for which crop failure occurred due to frost or drought (*kuti*). In 1992-3 48% of potato acreage was *kuti*, 34% was *q'allpa* and 18% was *puruma*. Producers indicated that the amount of *puruma* land was declining and some land previously dedicated to potato was being used for forage production for dairying (Dr. C. Valdivia, IBTA/SR-CRSP, personal observation).

Eight stages were typically required for potato production at SJL (Sherbourne et al 1995): (1) Tilling the soil; (2) clearing debris from the soil surface; (3) planting; (4) covering the bases of young potato plants with soil; (5) fertilising the young plants with manure or purchased urea; (6) weeding; (7) fumigation against insects and fungal diseases; and (8) harvest. All steps except tillage were performed by hand. Tillage was performed by tractor, or more rarely today, using a plough pulled by oxen. Tractor tillage occurred on a rental basis where the owner of the tractor was paid about 120 Bolivianos (or USD 28.23) per hectare—it took about two hours to till one hectare with a tractor (Sherbourne et al 1995). After harvest the household selected potatoes for three purposes: (1) The smallest were used for *chuño* (freeze-dried potato); (2) the medium-sized ones were used for next year's seed; and (3) the largest were kept for human consumption. *Chuño* was prepared in June when the nights were coldest. Potatoes were first saturated by soaking them in water, afterwhich they were freeze-dried. The process involves placing soaked potatoes in an exposed site and allowing them to freeze by night and dry by day. The drying process was facilitated by stomping the potatoes to periodically squeeze out excess moisture (Sherbourne et al 1995). *Chuño* can be stored for many years, which is markedly longer than the one-year shelf life of fresh potato (Dr. C. Valdivia, IBTA/SR-CRSP, personal observation).

The production of *quinoa*, barley, wheat, oats, *cañawa*, faba beans, peas, alfalfa, forage barley, forage wheat and forage oats required fewer tasks than that for potato production—tillage, for example, was usually not needed for crops other than potatoes (Sherbourne et al 1995). The unimodal pattern of rainfall with the onset of rains and warmer temperatures in November (Section 3.1: *Climate*) dictated the general pattern for crop production throughout the year (Sherbourne et al 1995). For example, tillage and land clearing for potatoes occurred in October, while planting oc-

Table 4.1. *Various statistics for food and forage crops in San José Llanga during 1993.* Source: Drs. E. Dunn and C. Valdivia (IBTA/SR-CRSP, unpublished data).

	Feature[1]				
		Planted Area		Yields	
Crops	Households (no.)	(ha)	(Plot no.)	MT/ha	Quintals
Food Crops					
Barley (grain)	38	30.0	65	0.56	338
Cañawa	9	3.2	10	0.16	10
Faba Bean	17	4.5	17	0.44	40
K'ara	35	13.0	44	0.24	63
Oats (grain)	15	8.1	21	0.52	84
Potatoes	43	35.1	69	1.09	767
Quinoa	34	28.5	50	0.08	46
Wheat	13	5.0	15	1.40	15
Forage Crops					
Alfalfa	36	66.2	NA[2]	2.96	3924
Barley (forage)	34	38.0	66	1.30	988
Oats (forage)	20	17.1	30	1.29	440

[1]Based on survey data of 45 households. Number of households refers to the number out of 45 that grew a given crop. The hectares was the total planted to a given crop, while plot number was the total number of parcels. Yields are averages on a fresh-weight basis based on responses to questionnaires; MT = metric tonnes per unit area while quintals represents estimated total yields.

[2] Not applicable; alfalfa plots were not demarcated by household.

curred for all annual crops in late October through December. Forages were commonly planted in January. Most weeding occurred in January, making this the busiest month for crop production. Harvest usually occurred from March to June, with forages harvested earlier on average than food crops. The agricultural calendar (Table 4.2) shows the timing of cropping as well as the livestock production activities, summarizing five case studies in 1993.

Overall, labour for cultivation was not considered to be a production constraint. Social mechanisms to provide and share labour helped ensure that all tasks were completed in a timely manner (Dr. C. Valdivia, IBTA/SR-CRSP, personal observation).

Climate risks for crop production are illustrated in Figure 4.3 (a-d), which covers annual dynamics for precipitation and air temperature at nearby Patacamaya Experiment Station during the four years between 1990-3. A couple of points should be noted from these data: (1) The low, intra-annual variability in temperature versus the high, intra-annual variability in precipitation; and most importantly (2) the high, inter-annual variability in precipitation during October, November and December, which were the key months for preparation of cultivated fields. Considering total precipitation for these three months, totals varied from 110 mm in 1990 and 1991 to 135 mm (1992) and 145 mm (1993). Considering monthly totals, these varied from 10 to 60 mm (October), 20 to 55 mm (November) and 30 to 60 mm (December). This illustrates the highly

Table 4.2. *General agricultural work calendar[1] observed at San José Llanga in 1993.* Source: Adapted from Sherbourne et al (1995).

	Month											
Crop	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Potato	H/ MC		C	C/T/P	C/T/ P	P	FE	FU/ FE	FU HC	HC	H	H
Quinoa	H			P	C/T							H
Barley	H					P				H	H	H
Wheat					P	P				H	H	
Cañawa							P				H	
Faba Bean				C/T/P			FU				H	H
Forage oats				C/T				P/T/ C				H
Forage barley				T/C			P	P		H		H
Forage wheat							P	P			H	
Alfalfa[2]						H	H			H	H	H
Sheep	L	L								SS/D ML	SS/D ML	

[1]Table Key:

C	Clearing land	H	Harvesting
T	Tilling Soil	L	Lambing
P	Planting	SS/D	Sheep shearing and dipping
FE	Fertilising	ML	Marketing annual lamb crop
FU	Fumigating	HC	Harvesting for consumption
MC	Making *Chuño*		

[2]Perennial crop

variable environment that largely dictates the success or failure of crop production.

Average costs of crop production were calculated by Eyzaguirre et al (1995) and Illanes et al (1995). Labour was the main factor in food and forage crop production overall, ranging from 38 to 70% of the total cost of production for alfalfa and wheat, respectively (Table 4.3). Potato production had the highest cost for purchased inputs (44%), while alfalfa required the highest initial investment in mechanisation (i.e., tractor tillage). The crop with highest overall cost of production was potato while the lowest was *quinoa* (Table 4.3).

Sheep management and production. Thirty-eight families (or 84%) in our sample reported owning sheep. The average flock size was 50 head, but not all animals managed in a given flock were owned by the managing household (Valdivia et al 1995). Most households had a mix of sheep breeds in their flocks. Pure Criollo sheep comprised about half of flocks on average, and these are known for their hardiness (Section 5.3.3: *Management and productivity of sheep*). Crosses of Criollo with introduced breeds such as Corriedale, Targhee and Merino also occured and comprised the remainder of flocks. These crosses are known for their improved meat, wool and milk production and live animals fetched markedly higher prices at market compared to the pure Criollo stock (Section 5.3.3: *Management and productivity of sheep*; see below). Improved rams for breeding could be obtained from within the SJL community. The Patacamaya Experiment Station also has a tradition of supply-

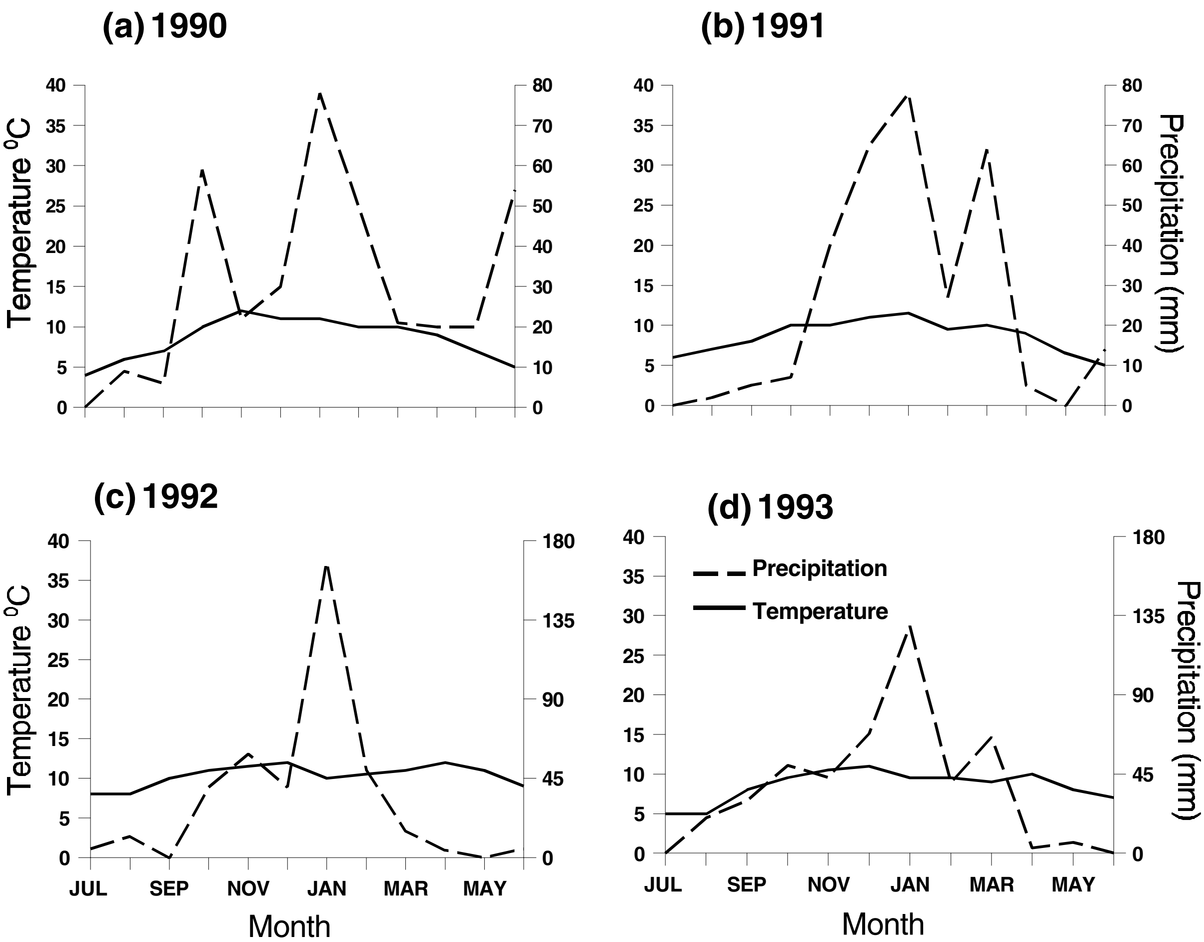

Figure 4.3 (a-d) *Monthly dynamics for air temperature and precipitation at Patacamaya Experiment Station on an annual basis during 1990-3. Note that the plateau for temperature tends to coincide with periods of higher precipitation. Note also the high variation in precipitation across growing seasons in each of the four years.* Source: Dr. J. Céspedes (IBTA/SR-CRSP, unpublished data).

ing improved breeding rams to the campesinos at no cost (Espejo and Jetté 1995).

Sheep husbandry at SJL was mostly in the domain of women, regardless of the practice in question and irrespective of household wealth (Sherbourne et al 1995; Valdivia et al 1996). Women also appeared to dominate sheep marketing. Children were used as labourers for sheep production as needed. These general patterns have been noted elsewhere on the Altiplano (Caro 1992; Norman 1992).

Only very general aspects of sheep husbandry, with a focus on labour and costs of production, will be reported here. Readers should consult Section 5.3.3: *Management and productivity of sheep* for other details.

There were many fundamental tasks associated with rearing sheep at SJL including herding, milking, shearing, dipping, tail docking, marketing and use of sheep products in the home. Ancillary activities include collection of sheep manure for use as a fertiliser and cash crop. Campesinos were also involved with maintaining various watering points for sheep (Sherbourne et al 1995).

Herding involved supervising a flock on day-long grazing orbits throughout the year and usually required the labour of one person per day. If sheep were grazed near crop fields during the growing season, however, two people were required to prevent sheep from eating young crops. The seasonal pattern of site use for grazing is shown in Figure 5.2a. This documents the general sequence where sheep tended to use fallow fields in the cropping matrix during rainy periods and then switched more to rangelands and alfalfa fields in the dry season. In addition to human labour, dogs were used to help herd sheep. A rope or sling was also used as a herding instrument—this was thrown by a herder to help direct a flock and keep animals together. Shepherds ranged from four years old to teenagers. Overall, females outnumbered males as shepherds by 6:1 (Dr. L. Markowitz, IBTA/SR-CRSP, personal observation). Female teenagers were the most common shepherds at SJL. This cohort was available to serve as shepherds because social obstacles typically kept young women from emigrating or enrolling in secondary school (Sherbourne et al 1995). The teenagers were typically far better shepherds than younger children. Households with skilled teenage shepherds could achieve superior levels of sheep performance and range utilisation by virtue of more efficient herding management. This capability could even override other household constraints in terms of lack of access to higher quantity or quality of grazing land (see Section 5.3.1: *Grazing management*; Norton 1994, 7-9). Shepherds received daily herding instructions from the senior female of the household (FHH) each morning (Sherbourne et al 1995). Use of children and youths as shepherds was vital because it freed adults for other activities (Sherbourne et al 1995).

Shearing occurred between the months of April and June. Shearing was accomplished by

Table 4.3. *Costs of production[1] per hectare for various food and forage crops at San José Llanga in 1992-3.* Sources: Eyzaguirre et al (1995) and Illanes et al (1995).

	Crop							
	Food					Forage		
Production Factor	Potato (n=35)	*Quinoa* (n=20)	Barley (n=14)	Wheat (n=19)	Faba (n=11)	Alfalfa (n=46)	Barley (n=23)	Oats (n=18)
Labour (%)	44	56	47	70	60	38	50	47
Equipment (%)	11	29	14	5	8	55	23	31
Other inputs (%)	44	15	39	25	32	7	27	22
Total Bolivianos	1060	153	110	297	232	207	350	238

[1]Exchange rate was 4.05 Bolivianos per USD. Interview data were used to estimate inputs for labour, equipment, etc. Costs were based on hourly rates for labour and equipment rentals.

tying the feet of the sheep together and using a piece of tin to cut the wool off the sheep's body in one continuous piece (Plate 4.5). The average amount of wool obtained per family flock was 65 lbs (or 30 kg), and 28 lbs (13 kg) were sold (Dr. C. Valdivia, IBTA/SR-CRSP, unpublished data). Cross-bred sheep were superior wool producers compared to Criollo sheep (see Table 5.17 for statistics on wool production). Shearing took one adult about 20 to 30 min per sheep (Sherbourne et al 1995). Most households sheared one or two sheep each morning before the animals were taken to graze, and sometimes sheared a couple more later in the afternoon. It usually took a household one to two months to complete the shearing each year. The prevalence of using a piece of tin to shear sheep belies the fact that thousands of modern hand shears were distributed on the central Altiplano starting in 1966, and hundreds of courses were offered so that local residents could learn proper shearing techniques (Dr. James Thomas, Utah State University, personal observation). This raises the question of why such apparently simple technology was not sustainable.

Control for external parasites (e.g., dipping) was done after shearing. There were public dipping facilities at SJL that cost about 20 centavos (or USD 0.05) per sheep (Sherbourne et al 1995).

Milking took less than one hour each morning and was usually done seasonally. Twenty-seven of 39 households milked sheep, but home consumption dominated as only five households sold milk. Cross-bred sheep were superior milk producers compared to Criollo sheep (see Table 5.18 for sheep milk-production statistics).

Tail docking (removed by cutting) was an annual task that took less than one day. Tail docking was believed to improve subcutaneous fat distribution and speed-up the breeding cycle for females (Section 5.3.3: *Management and productivity of sheep*).

Sixty percent (or 27) of the 45 households surveyed in 1993 reported selling live sheep (Valdivia et al 1996). Nineteen of these 27 households sold an average of 11 head that year. More than 50% of the sheep sold were by the senior female of the household, while about 30% were sold by the senior male and senior female together. Less than 10% were sold only by the male household head, and in these cases the men were mostly widowers (Valdivia et al 1996). The money from sales of sheep and sheep products was typically spent on food, household goods and school supplies (Valdivia et al 1995).

Plate 4.5. *Sheep shearing at San José Llanga.* Photograph: Christian Jetté

Eighty-eight percent (or 40) of the 45 households surveyed in 1993 reportedly consumed sheep, with an average of six eaten per household per year (Valdivia et al 1996). Hides of consumed sheep were sold.

The average sale price of sheep in 1994-5 was about 89 Bolivianos or USD 20.84 (Céspedes et al 1995b). Roughly 44% of the sale price was profit. The total cost of production was about 50 Bolivianos, with 86% of this cost occurring as labour and 11% as feed (Céspedes et al 1995b). Prices varied with size and breed of sheep (Sherbourne et al 1995). Smaller (i.e., <50 kg LW) Criollo animals typically sold for 30 to 50 Bolivianos (i.e., USD 7.00 to 11.76). Larger (i.e., >50 kg LW) Criollo animals sold for 60 to 80 Bolivianos (i.e., USD 14.12 to 18.82), with improved stock going for up to 150 Bolivianos (i.e., USD 35.29).

The network of marketing channels for live sheep in 1994-5 is depicted in Figure 4.4 based on records for 45 families (Rodriquez 1996). The majority of sheep sold were an annual offtake of year-old males destined for slaughter. Figure 4.4 illustrates that the marketing channels for live sheep produced at SJL were diverse in terms of local (i.e., Patacamaya, Lahuachaca, Chijmuni) and distant (i.e., La Paz) destinations. Nearly 60% of live sheep were marketed through "large" or "small" traders or middlemen. Traders were categorised as "large" if they procured 10 or more sheep per transaction. Only about 10% of sales occurred directly from producers to consumers (Figure 4.4). Thirty percent of purchases were made by other local producers. This all is interpreted to suggest that the sheep market at SJL was fairly well-developed in terms of a complex structure of buyers and consumers. A well-developed structure should contribute to the reliability of market opportunities given local ecological or economic perturbations (Dr. C. Valdivia, IBTA/SR-CRSP, personal observation).

Prices for live sheep were recorded throughout July1995 at the main market in Patacamaya town by Céspedes et al (1995). Temporal fluctuation in sheep prices was marked (Figure 4.5). Prices were lowest (i.e., between 80 and 85 Bolivianos per head) during the first half of the dry season (i.e., June through August), but then increased by about 40% to a peak of 112 to 124 Bolivianos per head by the late dry and early wet periods (i.e., October and November). From December through April prices then varied between 95 to 105 Bolivianos per head before rising once again in May. There were probably several factors influencing price dynamics for sheep, but it was particularly noteworthy that an increase in price was observed before festive periods such as All Saints (November 1), Christmas, New Years, Epiphany and Easter (Céspedes et al 1995). In a few cases the marketed volume of sheep appeared to increase in response to higher prices (especially in December), but this was not consistent (Figure 4.5). To explain why supply of sheep was not consistently related with price it is useful to recall that sheep have traditionally been the commodity most often used for routine income generation (Dr. C. Valdivia, IBTA/SR-CRSP, personal observation). Campesinos at SJL have indicated that their weekly average use of cash for food purchases is on the order of 70 Bolivianos (range:

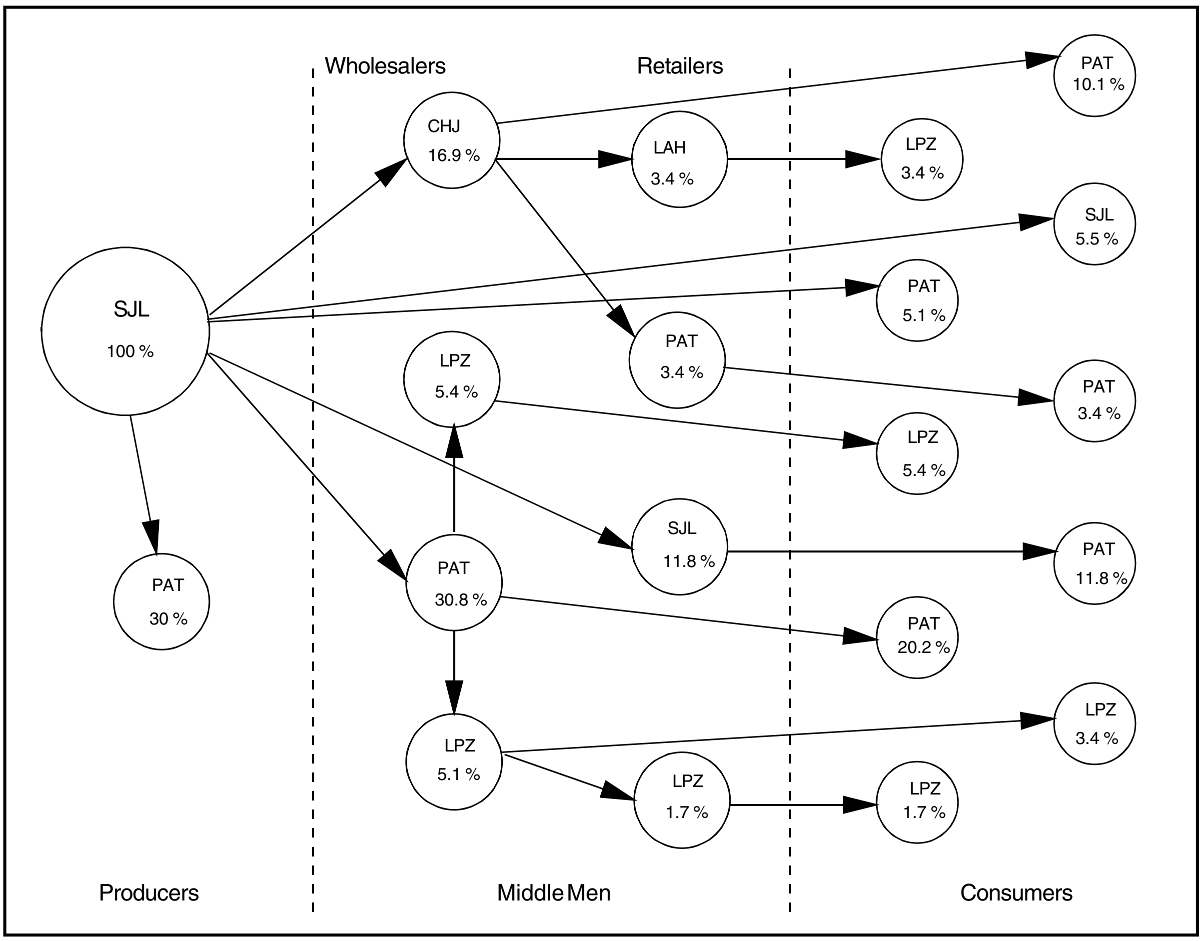

Figure 4.4. *Network of marketing channels for live sheep produced at San José Llanga during 1994-5. This diagram is based on a total of of sheep sold by 45 families. SJL = San José Llanga; PAT = Patacamaya; CHJ = Chijmuni; LPZ = La Paz; and LAH = Lahuachaca. Wholesalers differ from retailers in that wholesalers procured a minimum of 10 head per transaction.* Source: Rodríguez (1996)

20 to 120 for N=28 households; Murillo and Markowitz 1995, 15), and a regular demand for cash is what should primarily drive sheep sales, regardless of prices offered. We speculate that a higher price was important in eliciting a higher sale volume of sheep in December, but other coincident factors were also influential. For example, the fact that lambs of the year tended to be born between July and September, and hence were weaned and ready for market by December, was fortuitous because the timing coincided with marketing animals when higher holiday prices were offered. In addition, the campesinos reportedly strategised to cull some sheep by the end of the dry season (i.e., October through December) to ensure that sufficient forage resources would be available for the new crop of lambs in the up-coming year (see Section 5.3.3: *Management and productivity of sheep*). Other factors in the timing of sheep sales included advent of the school year and seasonal needs to buy food for the household. For example, sheep were often sold to pay for school supplies, uniforms and school fees, and this should have contributed to relatively more sales in the month of March (Figure 4.5; Valdivia et al. 1995). In addition, in the aftermath of a poor year for crop production, stocks of stored potatoes and other home-grown foods could have begun to run low for many poorer and middle-class households during the subsequent growing season. Sheep sales could be used for families to buy pasta and other goods from the market during the period between April to July. In 1994-5, however, this was probably not a major factor since crop yields in 1994 were near-average (Dr. C. Valdivia, IBTA/SR-CRSP, personal observation). Finally, breed of sheep influenced prices received. Genetically improved sheep commanded higher

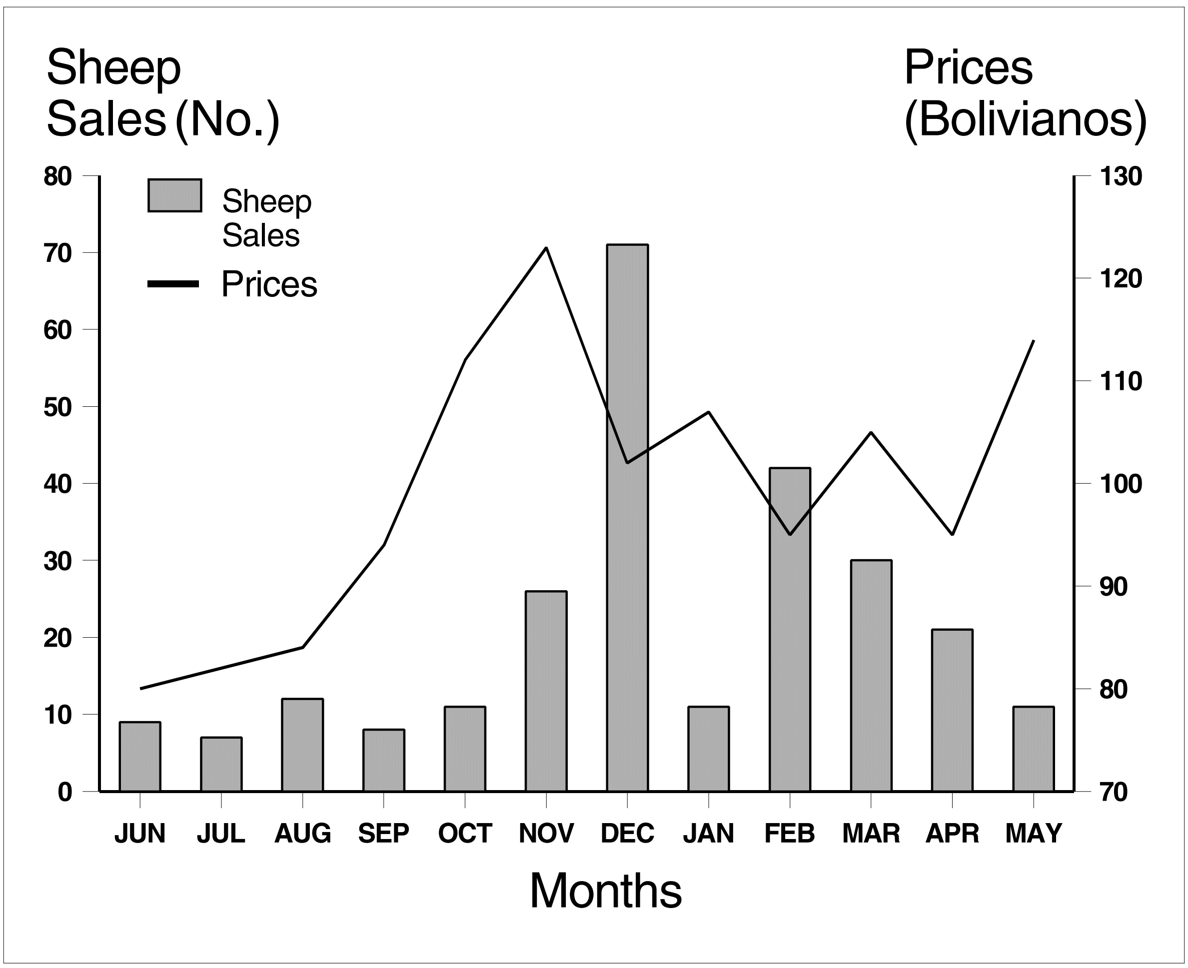

Figure 4.5. *Monthly pattern of sheep sales and average prices for live sheep at San José Llanga during 1994-5. The histogram is based on sheep sales for 45 families.* Source: Céspedes et al (1995)

prices (roughly double) compared to those received for Criollo animals (Villanueva 1996; see also Section 5.3.3: *Management and productivity of sheep*).

As will be reviewed later in this chapter, income from sheep production was very important to the household economy. Income from sheep sales was used to purchase food, miscellaneous household goods, and school supplies. Sheep thus had a link to household food security (Chapter 6: *Household socioeconomic diversity and coping response to a drought year at San José Llanga*). Income from sheep sales also tended to be controlled and spent by women.

Manure has always been an important output of livestock production, especially for mixed agropastoral systems like the one at SJL. Sheep manure has been traditionally used as a crop fertiliser at SJL, with small amounts added by hand at the base of young potato plants (Section 3.3.4.1: *Sustainability of the alluvial terrace*). Various surveys were conducted in which use of manure was evaluated (Valdivia et al 1995, 1996; Dr. J. de Queiroz, IBTA/SR-CRSP, personal communication). In 1993, 37 of 45 surveyed households at SJL regularly collected sheep manure. The average amount of manure produced per household per year may have been on the order of 6.3 metric tonnes (MT) on a fresh-weight basis. The average amount of manure collected was on the order of 4 MT per year (or at least 60% of production), with 85% of collected manure coming from sheep. Most households collected manure from corrals where the animals spent about half of their time (Section 5.3.1: *Grazing management, livestock activity and travel*). Of the 4 MT collected, 2.6 MT were reportedly sold, 1.4 MT were used as a fertiliser on cultivated fields, and the remainder was accumulated for unspecified future use. Advantages and disadvantages of manure use as a fertiliser, given the current widespread availability of chemical fertilisers, is reviewed in Section 3.3.4.1: *Sustainability of the alluvial terrace*.

Another study of manure production, use and nutrient export by Ciro and de Queiroz is cited by Norton (1994, 66-18). This study involved measurement of fecal production and evaluation of the N and P content of manure (see Section 4.2: *Methods*). Results indicated that manure production averaged about 0.72 kg per sheep per day on a dry-matter (DM) basis. This equated to about 21.6 kg DM per head per month or 1015 kg DM per flock per month for an average flock size of 47 head. The total accumulation per flock over eight months was on the order of 8120 kg DM, and slightly over half (52%) would have been deposited in the corrals. This implies that up to 4222 kg DM of sheep manure could be available to the household for potential use as a crop fertiliser (especially for potatoes) or as a means to generate cash income. Extrapolating to a full year the total amount of manure DM would be about 6.3 metric tonnes. For the 100 households at SJL in 1994, the total sheep manure production in corrals would add to 630 metric tonnes.

The average concentrations of N and P present in fresh feces was 2.02 and 0.67%, respectively. The average concentrations of N present in dried feces was 1.38%, indicating that some N was volatilised in the drying process (Norton 1994, 17). After volatilisation, about 87 kg of N and 29 kg of P were therefore deposited by 47 sheep in a given corral over eight months—this corresponded to the nutrient content of about four and one-half 50-kilogram bags of urea, a commercial fertiliser widely used at SJL. On an annual basis this equates to 130 kg of N and 43 kg of P per corral per year. For 100 households at SJL, this added to a grand total of 13 metric tonnes of N and 4.3 metric tonnes of P accumulated in corrals each year. In October, 1994, one 50-kg bag of urea could be locally purchased for 100 Bolivianos (or USD 21.40). The market value of the N in the sheep manure deposited in corrals over eight months was about USD 98.40. On an annual basis this equated to about USD 148.00 worth of manure-N per household, or USD 14 800 for the community as a whole (Norton 1994, 17).

Norton (1994) summarised a variety of statistics pertaining to use of manure as a fertiliser for potato crops by 32 households interviewed by Ciro and de Queiroz. Considering that 52% of the 100 households regularly applied manure to their potato crops, Norton reported that perhaps only 7.7% of the 630 MT of sheep manure captured in corrals ended-up on cultivated fields in 1993-4. It was presumed that most of the remaining 586 MT was sold because there was little evidence of long-term manure accumulation, and the cold, dry ambient conditions greatly constrain decomposition. The net result was that roughly 12 MT of N and 4.0 MT of P may have been exported from SJL each year. In terms of urea N, this equated to exporting about 650 bags of urea with a value of about USD 13 600 (Norton 1994). Traders probably routinely bought manure from communities like SJL and sold it for use as a fertiliser to vegetable producers and related enterprises located close to the large markets of El Alto and La Paz.

Even though sheep manure may have constituted a useful option for generating cash for the campesinos, it is likely that they were not getting paid full market value by traders. Norton (1994) noted, again based on interviews of 32 households by Ciro and de Queiroz, that the campesinos sold a 46-kg bag of sheep manure to traders for an average of <1.00 Bolivianos (e.g., USD 0.11). Thus, the total cash generated by the community by selling 586 MT of manure was only USD 1401 per year, a meager 10% of the true commercial value in terms of urea content alone.

Cattle management and smallholder dairying. Although Criollo cattle have been present at SJL for hundreds of years, and largely used for ploughing with some milk as a by-product, smallholder dairying based on Holstein (Friesian) and Brown Swiss animals and their crosses with Criollos has been a relatively new enterprise at SJL that started in 1989 with the introduction of the PIL (Programa de Industrialización Lechera) marketing system. The PIL is introduced in Section 2.4.2: *Local society*. Not surprisingly, cattle with improved genetics have a higher value than Criollo cattle (Sherbourne et al 1995). Adult Criollo cattle can go for 1000 to 1500 Bolivianos, respectively (i.e., USD 235.00 to 353.00). An adult Holstein or Brown Swiss cross can go for 2700 to 4000 Bolivianos (i.e., USD 635 to 941). Compared to Criollo stock, the exotic breeds and their crosses are considered to be more vulnerable to stress induced by disease or malnutrition, and thus the exotic breeds and their crosses tend to receive the most attentive management at SJL (Dr. C. Valdivia, IBTA/SR-CRSP, personal observation).

Only very general aspects of cattle husbandry, with a focus on labour allocation and costs of production, will be reported here. Readers are referred to Chapter 7: *Patterns of technology adoption at San José Llanga* for other details concerning the advent and spread of smallholder dairying at SJL.

About half of the households at SJL kept improved dairy cows, although the level of commercial involvement markedly varied. About half of the households having improved dairy cattle sold milk to the local branch of PIL (Illanes et al 1995). Some households also produced and sold replacement dairy heifers (Sherbourne et al 1995). The prevalence of dairy cattle varied among the six settlements or neighbourhoods, which in turn reflected varied access to cultivated forage resources (see Figures 3.3, 3.4, 3.5 and 5.1 and Table 5.3). The average number of all cattle owned for households involved in cattle production was five head in 1992-3 (Valdivia et al 1996).

The major management activities for cattle including herding, breeding, milking, cut-and-carry forage feeding, manure collection and marketing were shared by most household members regardless of gender (Sherbourne et al 1995). Like sheep, cattle grazed by day and returned to the family corral at night. Herding cows was generally considered more the purview of boys and men, and was regarded as much easier work than herding sheep since cattle could be staked out and left alone all day. All breeds of cattle could be herded with other livestock species for grazing depending on labour availability (Plate 5.1a). Seasonal patterns of use of grazing sites by cattle are shown in Figure 5.2b, and had some general similarities to site use by sheep in that fallow fields were used more in the wet season and rangelands and alfalfa fields were used more in the dry season. Watering of cattle from ponds, rivers or shallow wells occurred once or twice per day. Milking took place in the morning. Milk yields ranged from 3 to 12 litres per head per day for Criollo versus improved animals, respectively (Illanes et al 1994). Families involved with PIL had to deliver milk to the office in the main plaza where the milk was weighed and recorded. Grazing was the main mode of feeding cattle. Cattle feeding via cut-and-carry methods was rare and tended to occur during the evening in the later stages of the dry season (i.e., June through October) when forage was less available (Plate 4.6). Breeding was natural or through artificial insemination (Sherbourne et al 1995). Payment for renting a breeding bull was 40 Bolivianos (i.e., USD 9.41) while the artificial insemination charge was 15 Bolivianos (i.e., USD 3.53). Payment was also in-kind (i.e., a live sheep to rent a breeding bull).

Dairying has rapidly become an important source of cash for the campesino community at SJL. In 1993, 50% of the households at SJL sold milk (Dr. C. Valdivia, IBTA/SR-CRSP, unpublished data). The number of improved cattle has been steadily increasing in the early 1990s. Cash from milk sales was used to purchase food and farming inputs (Sherbourne et al 1995). Revenue from live cattle sales was many times over what is obtained for live sheep sales (above). Income from live cattle sales was therefore used differently than income from sheep (or crop) sales in that the larger volume

Plate 4.6. *Resident of San José Llanga cutting alfalfa to feed dairy cattle.* Photograph: Christian Jetté

of money gave an opportunity to cover improvements (i.e., replacement animals) for the cattle herd, major education expenses and investment capital for emigration and land puchases outside of the community (Valdivia et al 1996). Cattle manure (*bosta*), which was higher in fibre than sheep manure, was traditionally used as a source of household cooking fuel as it was rarely applied as a fertiliser to crops (Céspedes et al 1995). Cattle manure was occasionally sold as fuel (Dr. C. Valdivia, IBTA/SR-CRSP, unpublished data).

Sales of live cattle typically take place at the Sunday fair in the Patacamaya market. The network of marketing channels for live cattle in 1994-5 is depicted in Figure 4.6. In contrast to sheep marketing (Figure 4.4), a much greater proportion of cattle sales (85%) occurred in the absence of middlemen, allowing producers to control a fuller measure of profit. Cattle that were sold were destined for breeding or slaughter (cull cows) in local markets of Patacamaya, Umala and Santiago de Collana.

The average sale price for cattle in 1994-5 was about 1392 Bolivianos or USD 326.00 (Céspedes et al 1995b). Roughly 40% of the sale price was profit. The total cost of production was about 810 Bolivianos, with 61% of this cost occurring as feed and 36% as labour (Céspedes et al 1995b).

Compatibility of dairying with sheep production. As mentioned above, smallholder dairying using introduced cattle breeds and their crosses was a relatively recent activity at SJL. Dairying at SJL has become very popular because it has increased possibilities for more frequent generation of household income. Because smallholder dairying was relatively new and animal production resources at SJL were relatively scarce, researchers wanted to investigate: (1) The degree to which smallholder dairying complemented or competed with sheep production; and (2) whether women benefitted in terms of labour or income from the addition of dairying to the household portfolio. A more detailed analysis of these issues is presented in Section 5.3: *Results and discussion,* Chapter 6: *Household socioeconomic diversity and coping responses to a drought year at San José Llanga,* and Chapter 7: *Patterns of technology adoption at San José Llanga.* To briefly summarise here, dairy cattle appeared to be highly complementary to sheep in both ecological and economic terms.

In Chapter 5 it is concluded that the current grazing management system at SJL is effective at exploiting the high and inherent ecological complementarity between sheep and cattle. Scope for inter-species competition was very low with regard to grazing resources such as native forage and crop residues. Sheep could apparently be easily sold, so when resource restrictions occur at SJL potential competition between sheep and cattle could be minimised through sheep sales (Section 5.3.3: *Management and productivity of sheep*).

In Chapter 7 it is postulated that sheep and cattle production have exhibited economic synergisms. Over the past 30 years, for example, it has appeared that incremental improvements in sheep production systems have facilitated more recent adoption of smallholder dairying at SJL. Subsequent expansion of dairying has then, in turn, benefitted production of improved sheep.

Data from five case-study households concerning gender- and age-related labour domains for sheep and cattle production are displayed in Table 4.4. These results indicate that males and females across households typically shared cattle-management tasks such as herding, feeding, and manure collection. Females, however, tended to perform milking chores while males exclusively dealt with breeding and marketing. Compared to women in households where only sheep were produced, women in households with sheep and dairy cattle had more daily tasks in total, but to some degree the burden of added tasks was shared with males. In terms of use of the added income from dairying, it was unclear if benefits to males and females differed (Dr. C. Valdivia, IBTA/SR-CRSP personal observation). Men were the formally acknowledged members of the local PIL association. Women delivered the fresh milk daily to the

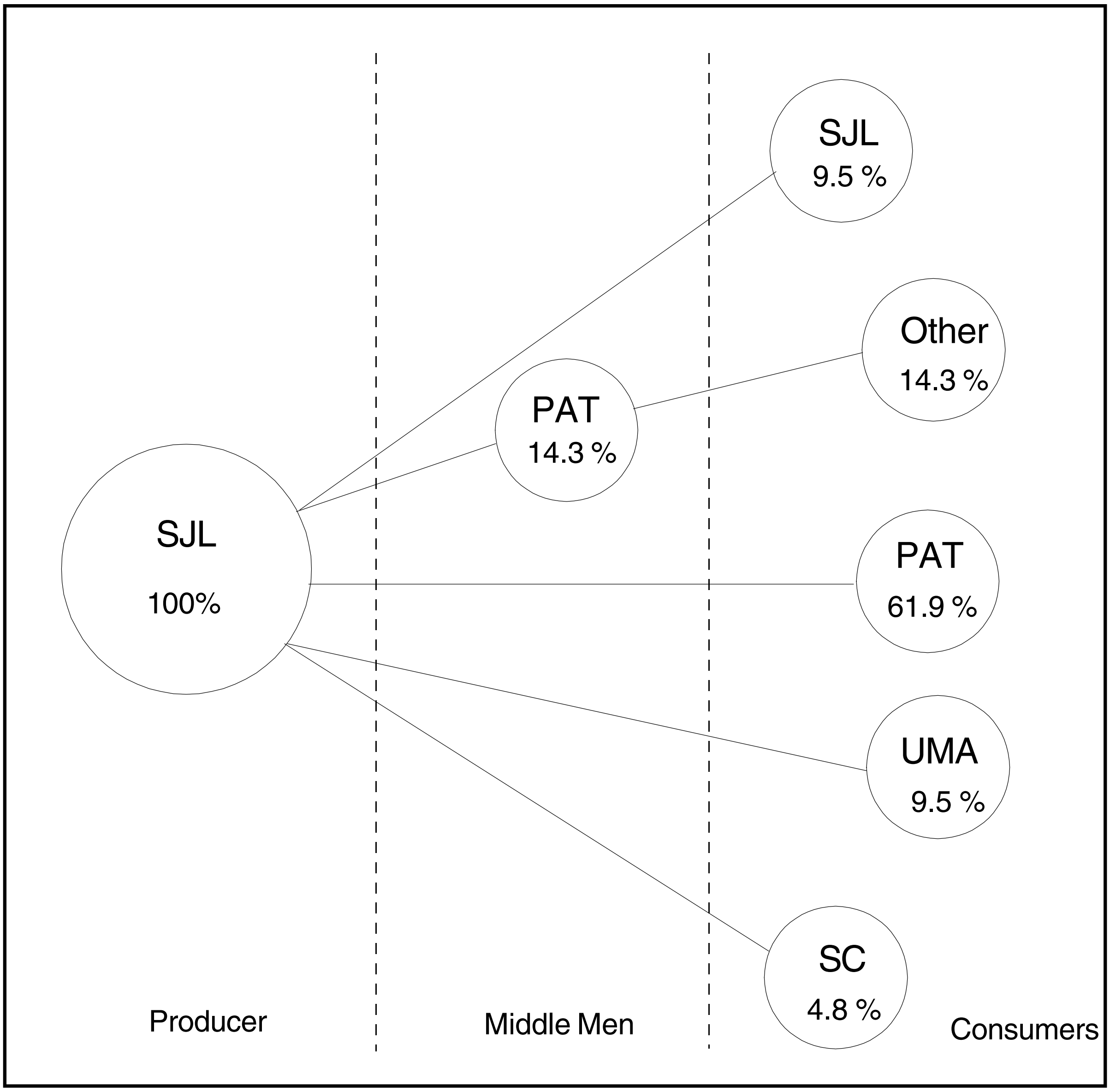

Figure 4.6. *Network of marketing channels for live cattle produced at San José Llanga. This diagram is based on cattle sales for 21 families between February and August of 1995. SJL = San José Llanga; PAT = Patacamaya; UMA = Umala; and SC = Santiago de Collana.* Source: Rodríguez (1996)

collection centre, but men collected the bi-weekly payments (Illanes et al 1995). There was some evidence that income from dairying tended to substitute for income generated from off-farm employment, and this has implications for gender-related work relationships (Céspedes et al 1995; Sherbourne et al 1995). In other words, households at SJL which focused on dairying tended to retain the male head of household (MHH) at home rather than having him seek off-farm employment. When the MHH was employed off-farm, more domestic and agricultural production tasks and short-term decisions consequently fell in the domain of the FHH. In this light it has been postulated that the net effect of dairying at the household level has more positive consequences for women than not having dairying (Sherbourne et al 1995).

Non-agricultural activities. Here we define non-agricultural activities to include off-farm employment that occurs locally and as a result of long-distance emigration. Non-agricultural activities as defined here also include production and

Table 4.4. *Labor allocation[1] according to gender and age for livestock enterprises of five households at San José Llanga during 1992-3.* Source: Valdivia et al (1996).

	Household									
	1		2		3		4		5	
Task	Sheep	Cattle	Sheep	Cattle	Sheep	Cattle	Sheep	Cattle	Sheep	Cattle
Herding	2,4	1	4	2	2,3	1	2,3,4	2,3,4	2	1
Milking	2	2	4,2	–	2,5	–	2	2	2,4	2,4
Shearing	1,2	NA	2	NA	1,2	NA	2,5	NA	1,2	NA
Dipping[2]	1,2	NA	2	NA	1,2,5	NA	1,5	NA	1,2	NA
Breeding[3]	NA	1,5	NA	1	NA	1	NA	1,5	NA	1
Feeding[4]	NA	1,2	NA	1,2	NA	1,2	NA	1,2	NA	1,2
Manure[5]	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2
Tail Docking[6]	1,2	NA	1,2	NA	1,2	NA	2,5	NA	1,2	NA
Selling	2	1	2	1,2	1	1	2,5	1	1,2	1
Buying	NA	–	NA	–	NA	–	NA	1	NA	1

[1]Where tabular entries are coded as: 1 (male household head); 2 (female household head); 3 (son); 4 (daughter); 5 (other); NA (not applicable); – (applicable but not observed or recorded).

[2]Where dipping was performed with sheep as a treatment against external parasites.

[3]Where sheep breeding was largely unmanaged compared to cattle breeding.

[4]Where cut-and-carry feeding was carried out for cattle but not sheep.

[5]Where "manure" represents collection, use and sale of manure.

[6]Where tail docking was performed on lambs to improve growth characteristics.

sale of handicrafts and fuel wood and rental of land. Wages is income derived from permanent or seasonal off-farm employment by persons who live at least part of the time at the household. Remittances is income derived from off-farm employment by persons who typically no longer reside at the household.

Off-farm employment can be an important mechanism to reduce variation in household income due to general climate or market fluctuations and household-specific challenges. Off-farm employment also provides a means to help households make more efficient use of their labour resources. The campesinos of SJL were typically able to find off-farm employment due to their proximity to towns (i.e., Patacamaya) and large urban centres (i.e., La Paz and El Alto). The need for off-farm employment can increase when crops fail as a result of drought (see Chapter 6: *Household socioeconomic diversity and coping response to a drought year at San José Llanga)*. Céspedes et al (1995) found that off-farm employment contributed 10% of total household income for a sample of 43 households at SJL.

Off-farm employment was sought by households from all wealth strata at SJL, but off-farm wages in absolute terms significantly decreased ($P<0.05$, $R^2= 0.65$, N = 43 households) as cash income from other activities such as dairying increased (Céspedes et al 1995). The multiple regression model was:

$$y = (-0.162)\ CI + (0.114)\ IKI$$

where Y is off-farm wages, CI is cash income, and IKI is in-kind income. This implies that dairying can at least partially substitute for the need to find off-farm income. This, in turn, suggests that dairying has ramifications for maintaining integrity of the household at SJL.

Off-farm employment most commonly involved male heads of household (MHH), who comprised 75% of the 25 persons recorded as employed off-farm (Céspedes et al 1995). In contrast, female heads of households (FHH) comprised 8%. Sixty percent of jobs were outside of SJL and were dominated by manual labour. The 25 people were variously employed as agricultural workers outside of SJL (36%), truck drivers (12%), traders (16%) and urban-based workers (44%). Two people working as school teachers earned 34% of all reported wage income, which indicated that the distribution of wages by household was highly skewed. For most households wage income was truly a minor contribution to total income during this year (Céspedes et al 1995).

A common shrub called *thola* (*Parastrephia lepidophylla*; Plate 3.5) is a dominant species on range sites having a lower water table—*thola* is particularly common in fallow fields on the alluvial terrace. *Thola* was regularly collected as household fuel by the campesinos, and it was also sold to traders who then exported it out of SJL in large trucks (Plate 3.11b). Typically, the *thola* plants were harvested when they were over 1 m tall. The entire crown and most of the roots were extracted using a pick and shovel (Dr. J. de Queiroz, IBTA/SR-CRSP, personal observation). *Thola* was harvested when campesinos were preparing to till fallow fields prior to planting potatoes. The importance of *thola* harvest has led some to believe that *thola* should be considered as another multiple-use output of the cropping system (Dr. J. de Queiroz, IBTA/SR-CRSP, personal observation). The value of *thola* as a cash crop, however, is debatable given results from economic surveys. Only six families (or 13% of the sample) reportedly sold *thola* in 1993 and only derived a small amount of income (next section).

Handicrafts were largely comprised of woolen products knitted by adult women in the household. Woolen products such as hats and sweaters contributed in-kind products for household consumption as well as a source of cash income.

4.3.3.2 Household income synopsis

The numbers of households at SJL involved in various income-earning opportunities are summarised in the far-left column of Table 4.5. There was a fairly broad range of household involvement in different enterprises. Potato production was the only enterprise that all 45 sampled households engaged in, followed by production of grain barley, sheep and alfalfa by over 80% of households. About 42% of sampled households participated in selling cow's milk to PIL, and less than one-third produced wheat, *cañawa* or peas.

The summary of income is clarified by segregating income according to cash and in-kind components as well as by source. The distribution of cash and in-kind income from all sources for surveyed households is shown in detail in Table 4.5 and at a more general level of resolution for total, in-kind and cash income, respectively, in Figure 4.7 (a-c). The statistics in Table 4.5 were calculated based on the actual number of households engaged in any given enterprise, and not aver-

Table 4.5. *Sources of cash and in-kind income for 45 campesino households at San José Llanga in 1993.*[1] Source: Drs. E. Dunn and C. Valdivia (IBTA/SR-CRSP, unpublished data).

Source	Households Involved (no.)	Total Source Income for all Sampled Households[2]	Mean Total Source Income Per Household[2]	Overall Source Contribution to Mean Total Income Per Household	Percentage of Mean Total Source Income Per Household as:	
					Cash Income	In-kind Income
Agriculture						
Crops						
Food crops						
Potato	45	9210	205	15%	12%	88%
Quinoa	35	1270	36	2%	31%	69%
Barley	39	1798	46	3%	9%	91%
Faba bean	18	538	30	1%	1%	99%
Wheat	13	388	30	1%	5%	95%
K'ara	36	768	21	1%	0%	100%
Oats	16	1016	64	2%	11%	89%
Peas	2	29	15	<1%	<1%	100%
Cañawa	9	113	13	<1%	10%	90%
Sub-total	45	15 132	336	25%	12%	88%
Forage crops						
Alfalfa	37	9233	250	15%	2%	98%
Barley	34	2324	68	4%	12%	88%
Oats	21	4969	237	8%	9%	91%
Sub-total	43	16 526	384	27%	6%	94%
Total crops	45	31 600	702	51%	9%	91%
Livestock						
Cattle						
Milk	25	462	18	1%	8%	92%
Milk-PIL	19	4158	219	7%	100%	0%
Cheese	22	540	25	1%	23%	77%
Manure	31	230	7	<1%	60%	40%
Live animals	19	9219	485	15%	100%	0%

Continued on following page

Source	Households Involved (no.)	Total Source Income for all Sampled Households[2]	Mean Total Source Income Per Household[2]	Overall Source Contribution to Mean Total Income Per Household	Percentage of Mean Total Source Income Per Household as:	
					Cash Income	In-kind Income
Sub-total	34	14 609	430	24%	94%	6%
Sheep						
Live animals	38	6579	173	11%	65%	35%
Wool	30	385	13	1%	25%	75%
Skins	34	204	6	<1%	61%	39%
Milk	14	601	43	1%	20%	80%
Manure	32	324	10	1%	78%	22%
Sub-total	38	8093	213	13%	60%	40%
Total livestock	38	22702	643	37%	79%	21%
Total agriculture	45	54302	1207	88%	38%	62%
Non-agriculture						
Wages	32	6072	190	10%	100%	0%
Other	20	1035	52	2%	100%	0%
Total non-agriculture	32	7107	137	12%	100%	0%
Grand total income	45	61 409	1365	100%	46%	54%

[1]Based on interview data.

[2]Bolivianos. During the time of this survey 4.05 Bolivianos equaled 1 USD.

aged across the 45 households per se. Figure 4.7 (a-c), in contrast, gives means as calculated across all 45 households, whether or not all 45 households were actually engaged in a given activity. Such portrayals of an average, albeit fictitious, household in Figure 4.7 (a-c) are useful to convey a general picture for the cantón, but can inadequately illustrate divergence in household production strategies and specialisation. Some aspects of variation in household income are covered below, while divergence in strategies and specialisation is dealt with in Section 6.3.1: *Socioeconomic groups.* Finally, it is important to note that cash income was probably estimated more accurately than in-kind income (Dr. C. Valdivia, IBTA/SR-CRSP, personal observation). For example, the value of in-kind values such as animal traction, use of *thola* as a household fuel, and the role of livestock as a means to store capital and thus serve as an insurance commodity were not adequately quantified (Dr. C. Valdivia, IBTA/SR-CRSP, personal observation).

The average annual household income (± SE) from all sources in 1992-3 was 1365 Bolivianos (USD 321). Agricultural sources contributed about 88% of total income. Total income was almost evenly split between cash (46%) and in-kind (54%) sources [Figure 4.7 (a-c)]. The major agricultural components for total income were crops (52%) and livestock (37%). The major contributing commodities for total income were (in descending order): Cattle, alfalfa, forage oats, sheep and potatoes (Table 4.5).

The average annual in-kind income of 737 Bolivianos was dominated by enterprises such as forage crop production (47%) and food crop production (40%; Figure 4.7b). The average annual cash income of 628 Bolivianos was dominated by enterprises such as cattle production (49%), wage-generation (21%) and sheep production (17%) (Figure 4.7c).

The data above confirm that the household economies of SJL were indeed mixed in terms of agriculture and pastoralism. They also indicate a moderate degree of market integration for households involved in dairying. The data illustrate points addressed in the previous discussion, namely, that each major agricultural enterprise (i.e., food crops, sheep and cattle) play varied roles for households along an economic continuum. Simply, food crops were largely produced for subsistence, cattle were largely produced for market to generate cash, and sheep production had a dual subsistence and cash-generation function. For example, 91% of the total income value of food and forage crops was consumed by households, with only 9% sold (Table 4.5). Only 20% of households sold potatoes and 11% sold *quinoa* (Sherbourne et al 1995). This is a near-reversal of the pattern observed for cattle production in which 94% of production was sold as milk and live animals and 6% was used by the household, the latter mainly in the form of manure, cheese and animal traction. Table 4.5 shows that 19 households sold milk to PIL. It also shows that 19 families were selling live animals. These may come from both the families with improved cattle as well as those with Criollo cattle that dedicated to sales of live animals, as they did not have access to forages for feed required by improved animals. Sheep production showed a near-even split between consumptive use and cash generation, with 40% of the total income from sheep consumed in the form of meat, wool, hides, milk and manure and 60% comprising cash income, mostly from sales of live animals, wool and manure. This analysis clearly demonstrates that smallholder dairying has increased the level of market integration for households at SJL relative

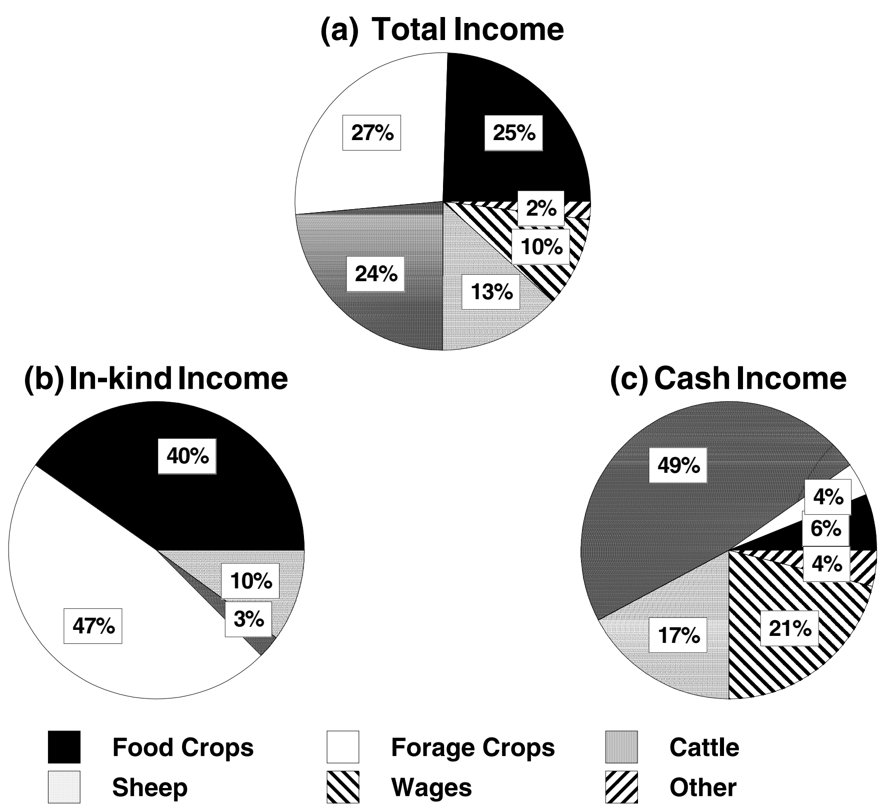

Figure 4.7 (a-c). *Sources of total, cash and in-kind income for 45 campesino households at San José Llanga during 1993.* Source: Dr. C. Valdivia (IBTA/SR-CRSP, unpublished data)

to the more traditional enterprises of food crop production and sheep husbandry.

During our period of observation, non-agricultural activities appeared to comprise only relatively minor, and opportunistic, sources of income (Tables 4.5 and 4.6). This was despite the prevalence of emigration in the community. Wages and remittances comprised only about 10% of total income generated. Other ancillary sources of income such as sales of fuel wood, manure and handicrafts made up <2% of total income value (Tables 4.5 and 4.6). Assuming the interview data are accurate, the remittance information suggests that the net flow of capital tends to leave, not enter, SJL. The data on income from sales of fuel wood and manure belie the impressions elsewhere that shrub cutting or manure export are economically important to SJL residents in terms of cash income generation. Although the scope of off-farm income and remittances at SJL appeared to be relatively narrow—at least during the time of this research—in terms of income the system at SJL is still "open." In Chapter 3 (*Ecology and natural resources at San José Langa*) it was argued that in terms of the livestock grazing system, SJL tended to be a "closed" system. Different socioeconomic and ecological dimensions of the SJL system, therefore, vary with respect to their connectiveness to the outside world.

Household stratification: Life-cycle stage and income. The degree to which households can generate income varies according to the number, extent and types of enterprises that households are engaged in. The breadth and depth of enterprises is, in turn, related to the resources of land, capital and especially labour marshalled by households (Valdivia et al 1996) Resource control and acquisition can be affected by many forces, but it is commonly a function of the stage of a family life cycle that a given household happens to be in. Younger couples starting a family, or older couples approaching retirement, would not be expected to be at their peak productive potential. In contrast, families in which the husband and wife are middle aged and where youths and children provide a diverse labour pool are cases expected to have the greatest potential for production and income generation (Valdivia and Jette 1996). One proxy for

Table 4.6. *Sources of non-agricultural income[1] for 45 campesino households at San José Llanga in 1993.* Source: Céspedes et al (1995).

Source[2]	Total Source Income	Percentage of: Non-Agric. Income	Percentage of: Grand Total Income[3]
Wages	25 805	86	10
Remittances	850	3	<1
Rent collection	385	1	<1
Fuel wood sales	536	2	<1
Handicrafts sales	2530	8	1
Total	30 106	100	12

[1]Where income is expressed in Bolivianos and the exchange rate was 4.25 Bolivianos per USD.

[2]See text for description of income sources.

[3]Where grand total income included all agricultural and non-agricultural sources. Also see Table 4.4.

Table 4.7. *Grouping of 45 campesino households at San José Llanga by income quintiles and associated socio-economic features in 1993.* Source: Dr. C. Valdivia (IBTA/SR-CRSP, unpublished data).

		Other Socio-economic Features[1]			
Quintile[2]	Total Income	Income used for Consumption	Mean Age of Household head	Household Size	Labour Pool
First	589a[3]	488a	59.7a	1.6a	1.6a
Second	2273ab	1538b	61.5a	2.2ab	1.8a
Third	3682b	2322b	46.3b	3.8bc	2.7bc
Fourth	7837c	4973c	47.2b	6.6d	4.1c
Fifth	15 079d	7291d	42.1b	5.3cd	3.3bc

[1]Where household size and labour pool are expressed as adult equivalents. Age of household head is in years. Income is in Bolivianos, and 4.05 Bolivianos equaled 1 USD.

[2]With nine households per quintile, ranked on the basis of total (i.e., cash plus in-kind) income.

[3]Entries within the same column accompanied by the same letter (a,b,c,d) were not significantly different according to a one-way ANOVA and an LSD test at $P \leq 0.05$.

assessing the stage of household life cycle is the age of the household head (Deere and de Janvry 1981). We used the age of male and female household heads as an indicator for stage of the household life cycle when assessing sources of variability for total household income.

The inadequacy of portraying households at SJL on the basis of grand means is illustrated by Table 4.7, which reveals the high degree of economic stratification in the community. The top quintile (20% or nine households) had an average total income 25-times higher than that of the bottom quintile. For the top quintile, the proportion of total income that was derived from in-kind sources was also less than half of that for the bottom quintile. Low income tended to be associated with situations in which the household heads were elderly and labour pool diminished (Table 4.7). Sharp differences also existed in the absolute levels of household consumption, reflecting relative differences in standard of living.

4.3.3.3 Household assets and land use

Assets are defined as property that may be used to pay debts. Assets vary in liquidity. The best example of liquid household assets at SJL is livestock. Livestock are the main form of wealth accumulation on the Altiplano (C. Jetté, IBTA/SR-CRSP, personal observation). While in many other settings land can also be considered an asset, in SJL this is not the case because a true land market was absent. Land at SJL also varied in the degree to which access was controlled. In general, lands which were more valuable for crop production or grazing had controlled access, while the least productive range was communal access. Since the land is inherited, even though official titles do not exist, this contributes to the process of differentiation that ensures that some families continue their control of the high value areas. Regulations can also vary with year, as communal land use increased overall during drought compared to a year having normal or above-normal precipitation (Cala 1994). Livestock owned and degree of controlled access to land were two indicators of wealth for households at SJL.

There was high variability in livestock and land holdings among income quintiles at SJL. Livestock holdings and controlled access to land tended to markedly increase with increases in income (Table 4.8). The greatest single source of value for livestock assets was cattle. Second was sheep. We did not account here for the value of donkeys that were owned by the family, and used mostly for transport within the community. For land access, households in the top income quintile had controlled access to over seven times the land area as did households in the bottom income quintile. Households having more controlled access to land tended to have a larger proportion of area planted to forages, and, to a lesser extent, food crops (Table 4.8). Households in lower income quintiles tended to have a higher percentage of land that was temporarily accessed.

In SJL, profits from cattle sales were often invested in land at Patacamaya town and the city of El Alto (Dr. C. Valdivia, IBTA/SR-CRSP, unpublished data). We have little information on the other forms of asset transfer and diversification for SJL, however. The residents of SJL have poor access to formal financial institutions. The Agricultural Bank of Bolivia closed in 1991. Other forms of credit delivery as farming inputs (i.e., fertilisers, seeds, etc.) managed by NGOs have failed in recent years (Rojas 1995). Recent experience with hyper-inflation in the 1970s would be expected to discourage campesinos from keeping significant portions of their assets as cash (Section 2.2.2.3: *National highlights of social history: 1951 to 1996*). Campesinos have been observed, however, to keep cash in the form of US currency (Dr. C. Valdivia, IBTA/SR-CRSP, personal observation). In recent years private financial institutions have opened in Patacamaya town and the nearby community of Lahuachaca. These offer individual and group loans at high rates of interest (Dr. C. Valdivia, IBTA/SR-CRSP, personal observation). It is expected that campesinos with livestock are less in need of credit than crop farmers. This has been confirmed by a survey conducted at Lahuachaca by Rojas (1995).

4.3.3.4 Gender, livestock and household welfare

Production, distributive and consumptive activities within campesino households have been shaped by a gender-based division of roles. Fender (1997) did an analysis to determine the degree to which female-controlled enterprises contributed to household welfare. Household survey data on income and expenditures in 1993 were used in a regression analysis. Welfare expenditures were defined to include payments for food, clothing, health care, and education. The total number of welfare expenditures were analysed as a function of income from female-managed enterprises such as sheep production. This is an important finding with respect to policy formulation (see Chapter 8: *Conclusions and recommendations*).

4.3.4 Non-market factors in resource access

Previously in this chapter and elsewhere (Chapter 7: *Patterns of technology adoption at San José Llanga*) community dynamics at SJL have been described. A process of increased market involvement began in the 1950s and has continued with incentives to produce more marketable potatoes, increased production of improved sheep and the advent of subsidised dairying. Emphasis on various commodities waxes and wanes largely as a function of market opportunities. This section is devoted, however, to reviewing the variety of non-market mechanisms that help households secure primary factors of production. The examples presented illustrate that despite a steady increase in market involvement for buying and selling goods, the primary means of accessing land, labour and capital remain largely traditional and governed by non-market relationships.

4.3.4.1 Land and labour resources

Although most households at SJL had gained permanent access to crop land and high-value grazing land through inheritance, there were other means that allow households to gain temporary access to land that facilitates expansion and diversification of production in an opportunistic manner. Such mechanisms contributed to miti-

Table 4.8. *Grouping of 45 compesino households at San José Llanga by income quintiles and the associated asset holdings in land (ha) and livestock (value in Bolivianos accompanied by average number of head in brackets) in 1993.* Source: Dr. C. Valdvia (IBTA/SR-CRSP, unpublished data).

		Assets[1]					
		Crop land			Livestock		
Quintile	Total Income[4]	Controlled	Other Access	Total Used	Sheep	Cattle	Total
First	589 a[5]	3.7 a	0.8 a	4.5 a	71 a (1.3)	318 a (0.2)	389 a
Second	2273 ab	8.9 ab	0.8 a	9.7 ab	796 ab (11.7)	2888 b (2.0)	3684 b
Third	3682 b	16.5 b	1.0 a	17.5 b	1297 bc (22.9)	6010 c (4.1)	7308 c
Fourth	7837 c	19.0 b	1.3 a	20.3 b	2217 cd (33.7)	5947 c (4.0)	8165 cd
Fifth	15 079 d	29.9 c	2.0 a	31.9 c	2165 cd (31.9)	7963 c (5.3)	10 128 d

[1]Where land represents a productive but non-liquid asset and livestock represent liquid assets.

[2]Where controlled land implies private access and other accessed land implies shared or temporary access.

[3]Where Criollo and improved breeds and their crosses are added together by species.

[4]Where total income includes cash income plus in-kind income.

[5]Entries within the same column accompanied by the same letter (a, b, c, d) were not significantly different according to a one-way ANOVA and an LSD test ($P \leq 0.07$). At the time of this survey 4.05 Bolivianos equaled 1 USD.

gating some of the wealth inequality among households. The current prominence and utility of such social arrangements was due to recent high rates of emigration out of SJL. Since the late 1970s it has been estimated that the number of households at SJL has declined by about 18% (see Section 4.3.1: *Human population and resource base*). This has consequently released a significant amount of resources at SJL for use by people who have elected to stay.

Crop land owned by households has typically been inherited via a male lineage (Cala 1994). Females can inherit land from their parents if the family does not have male descendants, or if the mother passes on land that she owns. Sometimes females can receive small parcels of land as gifts from male relatives. Examples of land endowments for various households have been previously depicted (Figures 4.1 and 4.2 and Table 4.1).

There were several ways that a household could increase its access to controlled land. One covert option was for a household to trespass their livestock onto grazing lands held by others. Cursory trespassing could occur when animals must be herded across privately held grazing parcels in order to reach other communal lands—skilled shepherds merely ensure that their hungry stock travel slowly through such areas (Ramos et al 1995; see Section 5.3.1: *Grazing management, livestock activity and travel*). Alternatively, households could make formal arrangements among themselves to temporarily use or share crop land or grazing land. Table 4.9 illustrates that in 1991-2 almost one-quarter of crop land in production was used under the auspices of a shared or temporary agreement. Households which possessed <35 ha of crop land were the ones which typically took advantage of such arrangements, thereby increasing their land base by over 70% (Cala 1994). Specifically, the temporary arrangements included: (1) Loans (66% of transactions in 1991-2); (2) rentals (30% of transactions); and (3) *waqi* and *al partir* (i.e., systems of shared tasks and benefits at 4% of transactions). The following discussion highlights key findings of Cala (1994).

In most cases, land loans occurred when one resident emigrated and left his or her land under the care of a close relative, usually a sibling. This care-taker was expected to keep the land in good condition, make sure that boundaries would not change, and treat the owner to products of the land (usually mutton and potatoes) when the owner returns for a visit. The care-taker benefits from access to land and products of the land. Typically, as the length of time the emigrant has been gone increases, the formality of these obligations also increases. Similarly, the formality of obligations increases with increased divergence in the social or kin relationship between emigrant and care-taker.

Rental agreements were more formal than land loans. Renting usually involved a three-year agreement in the case of arable parcels and the arrangements typically gave the renter full rights of use for cultivation and grazing of crop residues. Shorter-term arrangements existed for the use of *alfafares* (perennial alfalfa fields) and privately held range sites, giving the renter use rights for a few weeks to a full year. During the time of our study most rental payments were made in cash, but traditionally *chuño* (freeze-dried potatoes) and sheep used to be given as payments. Some tenants continued to pay using in-kind considerations as a measuring-stick; for example, market prices for *chuño* were used as a basis for determining rent. Fluctuations in market prices, however, caused contention and most people preferred other arrangements for compensation.

Waqi and *al partir* were traditional arrangements where the owner of an arable parcel and a counterpart shared cultivation of the parcel, dividing up responsibility for performing tasks and providing inputs—ploughing, weeding, seeding, fertilising, etc, as they wish. In the case of *waqi* the owner generally ploughs the land and the counterpart furnishes seeds and fertilisers and takes charge of the sowing. The resulting crop is then divided up between the owner and the counterpart. In the case of *al partir* the counterpart agrees to plough an entire parcel for the owner and in exchange obtains full rights to half of the ploughed land. Each half is managed independently over the period of the agreement. *Al partir* is typically preferred to *waqi* because *al partir* requires less haggling on fewer details. *Waqi* and *al partir* were used infrequently as observed by Cala (1994). Not surprisingly, *waqi* and *al partir* are most likely to be used by households that are poor in land, that have a dearth of emigrating relatives, and that are typically unable to pay for rental arrangements in cash or in-kind. And though both emigrants and care-takers benefit from land-sharing arrangements, Cala (1994) speculated that the sustained maintenance of the land could suffer. Care-takers were reluctant to make long-term improvements on land they will use for only a few years at most. Renters, for example, typically preferred to fertilise potatoes with purchased urea-

Table 4.9. *Access to crop land (ha) for 31 campesino households at San José Llanga during 1991-2.* Source: Adapted from Cala (1994).

		Crop Land Access					
		Permanent		Temporary		Total	
Size Class[1]	n	Mean	Sum[2]	Mean	Sum[2]	Mean	Sum[2]
Small	21	15	317	11	230	26	547
Large	10	59	594	6	60	65	651
Total	31	29	911	9	290	38	1178

[1]Where the "small" size class were those households having access to <35 ha of crop land in total while the "large" size class were those operations having access to >32 ha of crop land in total.

[2]Where the "sum" is the total area for a given size class of type of land access. For example, the 21 households in the small size class had permanent or temporary access, overall, to 317 ha or 230 ha of crop land, respectively.

based fertilisers which were relatively easy to transport and apply compared to manure. Purchased fertilisers, however, may not be as beneficial for maintenance of soil productivity (see Section 3.3.4.1: *Sustainability of the alluvial terrace*).

4.3.4.2 Livestock resources

The campesinos of SJL begin to accumulate animals very early in their lives. When turning three years of age a child receives one or two sheep as a gift from his or her godparents in a haircutting ceremony called *rutucha*. These sheep become part of the household flock, but the offspring and other products of the sheep belong to the child. Children and youths may also obtain sheep as a reward for their work as shepherds from their parents or close relatives. Despite the occurrence of livestock gifts in childhood, inheritance and dowry are the most important external sources of livestock for herd building in a campesino's lifetime. As household heads grow older and their children mature and marry, household heads progressively give their sheep and cattle to the new households of their children. Both men and women at SJL received animals from their parents, and this pattern has been observed elsewhere in the Andes (Palacios 1988; West 1988). Marriage is a special opportunity to build livestock assets. Espejo (1994) surveyed 32 households at SJL and found that the majority of female (94%) and male (87%) heads of these households had received sheep around the time of their wedding. Likewise, 81% of women and 72% of men had also received at least one cow. The distribution of animal numbers received as inheritance (including dowry) is depicted in Table 4.10. On average, women obtained one cow and 10 sheep as a wedding gift, while men received one cow and nine sheep (Espejo 1994). A majority of households therefore started up with about two cows and 10 to 20 sheep, including animals acquired by either spouse before marriage.

In 1993, the 32 households surveyed by Espejo (1994) owned an average of 34 sheep and five cows (Table 4.10). This indicated, on average, that households experienced a 125% net increase in sheep and a 150% net increase in cows. Espejo (1994) found a significant, positive correlation between the number of sheep inherited at marriage (x) and the number of cows that a household eventually owned by 1993 (y).

As with land, there were social mechanisms at SJL which allowed households to significantly increase the number of livestock they managed. The survey of Espejo (1994) demonstrated that

Table 4.10. *Number of sheep and cattle inherited by 32 campesino households at San José Llanga.*[1] Source: Adapted from Espejo and Jetté (1995).

Sheep		Cattle	
Number Inherited	Number of Households	Number Inherited	Number of Households
≤9	3	0	1
10 to 20	17	1	11
21 to 30	10	2	19
≥31	2	≥3	1

[1]See text for descriptions of inheritance systems.

more than a third of the sheep and 17% of the cattle tended by any given household on average, were actually owned by someone else. Nearly 60% of sampled households managed sheep that belonged to other people. These findings were confirmed by another community livestock census in 1994 (Dr. C. Valdivia, IBTA/SR-CRSP, unpublished data). As a result of such practices the mean numbers of sheep and cattle that were managed, but not necessarily owned, by the average family increased to 47 and seven head, respectively. In most cases of livestock sharing the agreements involved sheep of emigrant families. Since cattle were a far more valuable resource than sheep, emigrants were less likely to leave cattle with care-takers, and when this occurred the care-taker was normally a closer relative of the emigrant compared to what typically occurred with sheep. The duration of livestock sharing agreements varied but typically lasted from 12 to 15 months (Espejo 1994). Emigrants could leave their sheep with care-takers either on a less formal *gratuito* basis or through a more formal *al partir* agreement. In a *gratuito* arrangement the caretakers were typically close kin of the emigrants. Care-takers could benefit from the use or sale of all routine sheep products and could also use the land resources of emigrants (i.e., *alfalfares*, crop lands and range-lands) in support of sheep production. *Al partir*, in contrast, gave the care-taker a fixed proportion of lambs born to the flock in return for management services (Espejo 1994). This agreement was made between parties who were more distant relatives or neighbors—the owners were often emigrants and care-takers were often younger couples who wanted to build up their flocks. A typical agreement of *al partir* would be one where the care-taker manages some 25 sheep (mostly ewes) for an emigrant owner. The care-taker could receive half (about 10) of the lambs born over the course of a year. The need to re-negotiate terms with care-takers and monitor the well-being of the flock creates an important incentive for emigrants to periodically visit the community (Markowitz and Jetté 1994). The practice of leaving animals in the care of others was ubiquitous at SJL, which indicates the utility of the practice. Nonetheless, tensions arose from poorly defined arrangements (Espejo 1994). For example, finding a good care-taker for one's livestock was not always easy, especially for those who lacked close relatives in the community. Would-be care-takers may not be satisfied with the outcome of animal production and remuneration agreements, and hence demand additional compensation.

4.3.4.3 Other labour resources

A lack of labour can constrain the ability of a household to make efficient use of crop and livestock resources, participate in community development projects, and benefit from off-farm employment. The labour pool of a household typically includes all members older than five years. While certain work roles are linked to gender and age, labour allocation tends to be flexible and opportunistic. There was no single task that fell exclusively to males or females. Flexible task allocation enabled households to cope with varied seasonal demands on their time. There were also social mechanisms by which households could temporarily increase their labour supply to facilitate the execution of tasks which must be timed relative to weather or other demands such as cutting-and-carrying forages or planting crops. Nearly all households at SJL reported using some sort of extra-familial assistance (Markowitz and Jetté 1994). These include *ayni* (various forms of labour exchanges), *minka* (hiring labour with payment either in cash or in-kind) and *prestado de hijo* (borrowing a child).

Ayni is a form of social reciprocity involving a trade of services. A neighbour aids another with a given task with the expectation that an equivalent service will be returned in the future. Households were more likely to perform *ayni* with other households with which they were closely related. A more informal form of *ayni* called *yanapa* (Carter and Albó 1988) frequently occurred at SJL among close relatives, especially between females dealing with animal management duties. Sisters, for example, rotated days herding sheep. Another form of labor exchange which allows people lacking cash to acquire animal traction services is called *yunta-ayni*. Renting draft cattle at SJL could be expensive, costing the equivalent of three days of adult labour. A household needing the services of draught oxen could make payment by providing future labour to the person who owned the oxen.

*Minka (*also called *jornal)* entails hiring labour for a payment on the order of 5 to 7 Bolivianos (about USD 1.40) per day according to the task at hand. Payment could also be made in-kind-- for example, giving a basket of potatoes for assisting with a harvest. The campesinos of SJL most commonly resorted to using *minka* during labour-intensive periods of crop harvest and planting. Since the cantón of SJL has more arable crop land than most surrounding communities, people from neighbouring hamlets would send their teen-aged children to assist with the harvest at SJL, especially during bumper-crop years (Markowitz and Jetté 1994).

Prestado de hijo was the sharing of child labour with relatives or fictive kin referred to as *compadres*. Children old enough to be responsible herders (i.e., ages 9 to 15) could be dispatched to assist another household for up to two weeks. While this assistance was typically provided without compensation to close relatives, compensation in the form of food or school supplies was required from a *compadre*. In recent years compensation has often occurred in the form of a small payment to the child, usually on the order of one Boliviano (or USD 0.25) per day.

4.3.5 Credit

To satisfy a household's pressing needs for food, health or social commitments, reciprocal relationships of the *ayni* type appearred to be the main way to obtain financial help from a relative or friend (Dr. C. Valdivia, IBTA/SR-CRSP, personal observation). Sometimes loans were requested from a trucker, merchant or wealthier neighbour, but the implicit rates of interest could be very high. In another case the association of milk producers at SJL had lotteries in 1991-2 for members to win Brown Swiss or Holstein crossbred cows. As one condition of winning, a recipient of a cow had to give another member of the association the first-born calf.

4.4 Conclusions

We concluded that the community at SJL is evolving. In general terms, the trajectory of the community in social and economic aspects appeared rather positive. The people had a strong base of social capital and food security. They have embraced formal education and several types of new technology that have diversified the local economy and contributed to economic growth. Problems may persist, however, in some aspects of human nutrition and public health. Equity in terms of improved access of young women to more formal education was also an issue. The increasing dependence on smallholder dairying, despite its subsidised nature, may be worrisome. The community was almost polarized in terms of stratification of household wealth, but the significance of this for system dynamics and equity remained unclear. High rates of migration were not new to SJL. The fact that emigration has been promoted by recent circumstances may be beneficial in the long run in terms of community development and resource allocation.

Households have selectively incorporated new technologies and activities that complement traditional options. This has created a mix of market-driven relations in parallel with non-market traditions. Non-market traditions, underlain by a fabric of social capital, helped to secure access of households to land, labour and capital in situations that the market could not otherwise guarantee. Social relations that redistribute production resources probably reduced risk exposure for emigrants and care-takers alike.

SJL is a strong community when measured in terms of the networks of sharing and reciprocity, that have been maintained through the years. These networks are indicative of a large amount of social capital. The analysis on land, labour and animals show how through the use of these networks some of the large differences in assets are attenuated. The value of this social capital was also revealed by recent efforts undertaken by the leadership to improve living standards in terms of local access to education, potable water, electricity and modern sanitation practices. The desire for an improved standard of living was paramount among emigrants. While such efforts may not stem high rates of emigration, they make SJL a more desirable place to live and probably encourage the maintenance of linkages among rural and urban components of the system.

Various commodities in the agropastoral system play varied socioeconomic roles. With the rare exception of marketable surpluses for land-wealthy households, food crop production serves a subsistence function. Dairy cattle served to increase cash incomes and diversify assets and enhance market integration. Sheep served both subsistence traditions and a need for income generation. Improved sheep were important for food security because they could be sold to buy food. Criollo sheep were also important for food security, but more in the sense of their role as a regular source of inexpensive protein in human diets. These patterns indicate that economic diversification and market linkages can permit economic growth in a risky and fragile environment.

Traditional gender roles were evident in the agropastoral system, but flexibility occurred that permitted opportunism in incorporating new endeavours. One of the critical roles of small ruminants in the system is how they were sold to provide funds for welfare expenditures, a function articulated by female household heads.

4.5 Literature cited

AOAC (Association of Official Analytical Chemists). 1980. *Official Methods of Analysis*. 13th edition. AOAC, Washington DC, USA. 1016 pp.

Cala E. and Jetté C. 1994. *Posesión y Control de Tierras en una Comunidad del Altiplano Central.* IBTA/SR-CRSP (Instituto Boliviano Technología Agropecuria/Small Ruminant Collaborative Research Support Program) IBTA 138/Boletín Técnico 07/SR-CRSP 09. La Paz Bolivia. 37 pp.

Cala E. 1994. *El Sistema de Tenencia de Tierras en la Comunidad San José Llanga.* BA tesis, Universidad Mayor de San Andrés, La Paz, Bolivia. 147 pp.

Caro D. 1992. The socioeconomic and cultural context of Andean pastoralism. In: Valdivia C. (ed), *Sustainable Crop-Livestock Systems for the Bolivian Highlands*. *Proceedings of an SR-CRSP (Small Ruminant Collaborative Research Support Program) Workshop, held at Lubbock, Texas, USA, 14-17 May 1991.* University of Missouri, Columbia, Missouri, USA. pp. 71-92.

Carter W. and Albó X. 1988. La comunidad *Aymara:* un mini-Estado en conflicto. En: Albó X. (comp), *Raíces de América. El Mundo Aymara.* Alianza Editorial. Madrid, España. pp. 451-492.

Céspedes J., Aguilar V. y Rodríguez L. 1995b. *Caracterización Económica de la Producción Ovina en San José Llanga.* IBTA/SR-CRSP (Instituto Boliviano de Tecnología Agropecuria/ Small Ruminant Collaborative Research Support Program) IBTA 174/Boletín Técnico 42/SR-CRSP 40, La Paz, Bolivia. 36 pp.

Céspedes J., Dunn E. y Valdivia C. 1995a. *Impactos de la Introduccion de Leche en el Ingreso Familiar.* IBTA/SR-CRSP (Instituto Boliviano de Tecnología Agropecuria/ Small Ruminant Collaborative Research Support Program). IBTA 144/Boletín Técnico 12/SR-CRSP 14, La Paz, Bolivia. 43 pp.

Cotlear D. 1989. *Desarollo Campesino en los Andes. Cambio Tecnológico y Transformación Social en los Comunidades de la Sierra del Perú*. IEP (Instituto de Estudios Superiores), Lima, Perú. 325 pp.

Deere C. and de Janvry A. 1981. Demographic and social differentiation among northern Peruvian peasants. *The Journal of Peasant Studies* 8(3):335-366.

Ellis F. 1993. *Peasant Economics and Agrarian Development*. Second edition. Cambridge University Press, Cambridge, UK. 309 pp.

Espejo R. 1994. *Prácticas Socioeconómicas de Tenencia y Adquisición de Ganado.* BA tesis, Universidad Mayor de San Andrés, La Paz, Bolivia. 213 pp.

Espejo R. y Jetté C. 1995. *Rol Socioeconómico de la Ganadería en una Comunidad Agropastoril del Altiplano Central*. IBTA/SR-CRSP (Instituto Boliviano de Tecnología Agropecuria/Small Ruminant Collaborative Research Support Program). IBTA 152/Boletín Técnico 20/SR-CRSP 18, La Paz, Bolivia. 25 pp.

Eyzaguirre J.L., Cuesta M., y Céspedes J. 1995. *Estructura de la Produccion y Eficiencia de la mano de Obra. Estudio de Caso: Comunidad San José Llanga*. IBTA/SR-CRSP (Instituto Boliviano de Tecnología Agropecuria/Small Ruminant Collaborative Research Support Program). IBTA 178/ Boletín Técnico 46/SR-CRSP 44, La Paz, Bolivia. 36 pp.

Fender K. 1997. *Empowerment Within the Household: A Study of Income Allocation in Bolivia*. MS Thesis, University of Missouri, Columbia, Missouri, USA. 187 pp.

Huanca J., Markowitz L. y Jetté C. 1995. *El Proceso de Cambio Tecnológico. Perspectiva de los Productores de una Comunidad Agropastoril*. IBTA/SR-CRSP (Instituto Boliviano de Tecnología Agropecuria/Small Ruminant Collaborative Research Support Program). IBTA 158/ Boletín Técnico 26/SR-CRSP 24, La Paz, Bolivia. 25 pp.

Illanes P., Cuesta M. y Céspedes J. 1995. *Adopción de Tecnología en la Producción Lechera. Estudio de Caso de la Comunidad San José Llanga*. IBTA/SR-CRSP (Instituto Boliviano de Tecnología Agropecuria/Small Ruminant Collaborative Research Support Program). IBTA 147/ Boletín Técnico 15/SR-CRSP 17, La Paz, Bolivia. 35 pp.

INE/DHS ((Instituto Nacional de Estadísticas/ Demographic and Health Sureveys). 1994. *Encuesta Nacional de Deomografía y Salud 1994.* La Paz Bolivia. 226 pp.

INE (Instituto Nacional de Estadístacas). 1993. *Censo 1992. Resultados Finales*. vol 2, 4 y 5. INE, La Paz, Bolivia. 233 pp.

Jetté, C. 1993. *A diachronic analysis of changing resource use patterns on the central Bolivian highlands*. Presentation at the Small Ruminant Workshop, 7-9 September. San Juan Puerto Rico. 11 pp.

Le Tacon P., Vacher J., Eldin M. y Imaña E. 1992. Los riesgos de helada en el Altiplano Boliviano. En: *Actas del VII Congreso Internacional Sobre Cultivos Andinos.* IBTA/ORSTOM/ CIID (Instituto Boliviano de Tecnología Agropecuria/Institut Français de Recherche Scientifique Pour le Développement en Coopération/Centro Internacional de Investigación y Desarrollo Canada). La Paz, Bolivia. pp. 287-291.

Markowitz L. y Jetté C. 1994. *Estrategias Sociales Hacia la Sostenibilidad en Los Andes. Un Estudio de Caso del Altiplano Central*. IBTA/SR-CRSP (Instituto Boliviano de Tecnología Agropecuria/ Small Ruminant Collaborative Research Support Program). IBTA 139/ Boletín Técnico 08/SR-CRSP 09, La Paz, Bolivia. 33 pp.

Medicanelli X., Jimenez R. y Quiton M. 1993. *Historia Demográfica de Aroma - Umala -San José*. IBTA/SR-CRSP (Instituto Boliviano de Tecnología Agropecuria/Small Ruminant Collaborative Research Support Program), Imprenta papiro. La Paz, Bolivia. 130 pp.

Montes de Oca. 1989. *Geografía y Recursos Naturales de Bolivia*. Editorial Educación del Ministerio de Educación y Cultura. La Paz, Bolivia. 574 pp.

Murillo C. and Markowitz L. 1995. *Food and Nutrition in San José Llanga, an Agropastoral Community in the Central Altiplano of Bolivia*. IBTA/SR-CRSP (Instituto Boliviano de Tecnología Agropecuria/Small Ruminant Collaborative Research Support Program). IBTA 173/ Boletín Técnico 41/SR-CRSP 39, La Paz, Bolivia. 37 pp.

Norman D. 1992. Household economics and community dynamics. In: Valdivia C. (ed), *Sustainable Crop-Livestock Systems for the Bolivian Highlands. Proceedings of an SR-CRSP (Small Ruminant Collaborative Research Support Program) Workshop, held at Lubbock Texas, USA, 14-17 May 1991.* University of Missouri, Columbia, Missouri, USA. pp. 39-70.

Nolan M. 1994. Sociological analysis of small ruminant production systems. In: Johnson S. (ed), *SR-CRSP Annual Report 1994*. Management Entity, SR-CRSP (Small Ruminant Collaborative Research Support Program), University of California, Davis, California, USA. pp. 27-45.

Norton B. 1994. Range ecology. In: Johnson S. (ed), *SR-CRSP Annual Report 1994.* Management Entity, SR-CRSP (Small Ruminant Collaborative Research Support Program), University of California, Davis, California, USA. pp. 3-20.

Orlove B. 1987. Stability and change in highland Andean dietary patterns. In: Harris M. and Ross E. (eds), *Food and Evolution: Toward a Theory of Human Food Habits.* Temple University Press, Philadelphia, Pennsylvania, USA. pp. 481-515.

Palacios F. 1988. Pastores de llamas y alpacas. En: Albó X. (comp), *Raíces de América. El Mundo* Aymara. Alianza Editorial. Madrid, España. pp. 133-155.

Ramos A., Prieto G. and de Queiroz J. 1995. *Relaciones de Presión de Pastoreo, Productividad y Disponibilidad de Forraje en Áreas de Pastoreo del Cantón San José Llanga*. IBTA/SR-CRSP (Instituto Boliviano de Tecnología Agropecuria/Small Ruminant Collaborative Research Support Program). IBTA 153/ Boletín Técnico 21/SR-CRSP 19, La Paz, Bolivia. 35 pp.

Reardon T., Delgado C. and Matlon P. 1992. Determinants and effects of income diversification amongst farm households in Burkina Faso. *Journal of Development Studies* 28(2):264-296.

Rojas R. 1995. *Mercados Financieros Rurales en la Región Andina. Zona de Estudio: La Paz.* CEP (Centro de Estudios y Proyectos). La Paz, Bolivia. 34 pp.

Rosenzweig, M. and Binswanger H. 1993. Wealth, weather risk and the composition and profitability of agricultural investments. *The Economic Journal* 102:56-78.

Sherbourne J., Dunn E., Valdivia C. and Nolan M. 1995. *Agropastoral Production Systems, Intra-Household Resource Allocation and Household Members Domains: Five Case Studies from the Community of San José Llanga*. IBTA/SR-CRSP (Instituto Boliviano de Tecnología Agropecuria/Small Ruminant Collaborative Research Support Program). IBTA 171 /Boletín Técnico 39/SR-CRSP 37, La Paz, Bolivia. 50 pp.

SVEN (Boletín del Sistema de Vigilancia Epidemiológica Nutritional). 1987. *Población de Referencia para Bolivia. Cuadernos de Vigilancia Nutritional, 3*. DNNA/MPSSP (Dirección Nacional de Nutrición y Alimentación/Ministerio de Previsión Social y Salud Pública).

Valdivia C. and Jetté C. 1996. *Peasant Households in Semi-Arid San José: Confronting Risk Through Diversification Strategies*. IBTA/SR-CRSP (Instituto Boliviano de Tecnología Agropecuria/ Small Ruminant Collaborative Research Support Program). IBTA 181/ Boletín Técnico 181/SR-CRSP 47. La Paz, Bolivia. 24 pp.

Valdivia, C., Dunn E. and Sherbourne J. 1995. *Cash Crops and Food Production: Dairy and Sheep Household Diversification Strategies in the Crop-Livestock Systems of San José Llanga, Bolivia.* IBTA/SR-CRSP (Instituto Boliviano de Tecnología Agropecuria/Small Ruminant Collaborative Research Support Program). IBTA Boletín Técnico 165/31, La Paz, Bolivia. 35 pp.

Valdivia C., Dunn E. and Jetté C. 1996. Diversification as a risk management strategy in an Andean agropastoral community. *American Journal of Agricultural Economics*. 78:1329-1334.

Valencia S. y Jetté C. 1995. *Estrategias de Reproducción Familiar y Tenencia de Recursos, en una Comunidad del Altiplano Occidental*. IBTA/SR-CRSP (Instituto Boliviano de Tecnología Agropecuria/Small Ruminant Collaborative Research Support Program). IBTA 172/ Boletín Técnico/SR-CRSP 40, La Paz, Bolivia. 40 pp.

Van Haeften R. 1996. *Peru Food Security Strategy.* LAC Tech Bulletin No. 16. Washington, D.C.

von Braun J., Hotchkiss D. and Immink M. 1989. *Nontraditional Export Crops in Guatemala: Effects on Production, Income and Nutrition*. IFPRI (International Food Policy Research Institute). Research Report 73. IFPRI, Washington, D.C., USA. 99 pp.

West T. 1988. Rebaños familiares y propietarios individuales: Ritual ganadero y herencia entre los Aymaras de Bolivia. En: Ochoa J. (comp), *Pastores de Llamas y Alpacas*. Cuzco, Perú. pp. 191-201.

Chapter 5

The grazing livestock of San José Llanga: Multiple-species resource use and the management and productivity of sheep

El ganado doméstico en San José Llanga: Uso del recurso multi-especies y el manejo y productividad de las ovejas

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Summary

In this chapter the focus is on the livestock and forage components of the agropastoral system. We broadened our mission, however, to study cattle and donkeys in addition to small ruminants (i.e., sheep) to better understand how the entire system functioned.

Work was largely descriptive and was carried out during 1992-3, a year of near-average precipitation. We first wanted to find out what forage resources and site types at San José Llanga (SJL) were most important for livestock as well as general aspects of grazing management. This information would give us insight as to whether or not forage resources were being efficiently used and the degree to which livestock species might complement, or compete with, each other in ecological terms. We also wanted to evaluate the nutritional value of forages and grazed diets throughout a production year to assess nutritional risks for animal productivity. Finally, a baseline study of sheep productivity and management was conducted across six settlements. We wanted to quantify rates of mortality and morbidity, aspects of health and breeding management, fertility of flocks and patterns of lamb growth.

Methods included mapping of extensive grazing areas using interviews of campesinos and direct observations of livestock. Herded livestock were accompanied by observers who quantified diets using bite-count methods and systematically recorded activity patterns and site use. Ecological similarity among livestock species, as well as quantification of forage resources at the plot level of resolution, were quantified using various indices. Sheep management and productivity was assessed by observing flocks held by households in six settlements. The total number of sheep for these studies was over 400 and represented three breeds [i.e., Criollo, improved (a 50% cross between Criollo and Targhee, Corriedale or Merino), and highly improved (>50% cross)]. Statistical analyses for ecological or production studies typically employed Analysis of Variance (ANOVA).

Virtually all of the cantón was grazed in 1992-3. Livestock grazed by day and were corralled at night. Livestock grazing was typically directed by herders, and animals traveled an average of 6 to 8 km per day in their search for forage throughout the year. The general pattern was for livestock to graze fallow fields in the cropping matrix during the rainy season followed by increased use of rangeland sites as crops grew and the dry season began. The diversity of site use increased as the dry season progressed. Animals eventually returned to the cropping matrix to graze crop stubble. They also made strategic use of high-value alfalfa pasture in the transition between the late dry and early wet seasons, a time when animals were most likely to be under nutritional stress. Alfalfa plots were especially important for cattle. The overall grazing pattern was most affected by the seasonal cultivation cycle and the periodic inaccessibility of parts of the fluvio-lacustrine plains because of flooding. This later feature created a natural and *de facto* deferred grazing system for many range sites whereby grazing was delayed to dry periods when plants had become senescent and were less-likely to be damaged by over-utilisation.

At a finer scale of resolution, herders employed various methods to ensure that forage was efficiently used. A managed form of grazing succession was observed whereby cattle were given

priority to forage on some range sites, followed by sheep or donkeys. Clever and dynamic herding was critical for resource management given the complex juxtaposition of land types (i.e., crop fields, fallow, range, pasture, etc.) and variable forms of land access (i.e., more controlled access for crop fields, pasture and higher-value range versus less controlled or open access for fallow and lower-value range). Herding skills were observed to be particularly important for "land-poor" households that had a dearth of private access rights and were forced to rely more on less-controlled grazing resources subject to increasing competition as the year progressed. Herders strived to keep animals out of cropped fields while exploiting fallow and had to ensure that their animals "trespassed lightly" over range sites controlled by others when traveling to graze elsewhere. Households varied in terms of the quality of herding labour. Female teenagers could control more animals and were much better herders than young children of either sex. Skilled herders successfully guided their animals to exploit remnant, high-value patches of forage as the year progressed. Such tactics helped livestock mitigate against seasonal fluctuations in forage quality and abundance by keeping diet quality and intake at reasonably high levels, even during dry periods. This, in turn, enabled animals such as lambs to gain adequate weight despite precipitous declines in available resources.

In terms of feeding ecology, sheep, cattle and donkeys consumed a variety of grass and forb taxa, with scant use of shrubs. The dietary profiles for the year were: (1) Sheep, 50% grass, 47% forbs, and 4% shrubs; (2) cattle, 70% grass, 30% forbs, and 0% shrubs; and (3) donkeys, 73% grass, 26% forbs, 1% shrubs. Forbs were consumed more in the rainy season and grasses were consumed more in the dry season. The diversity of forages was greatest in the fallow fields, largely due to the prevalence of annual forbs. Livestock species used many sites in common throughout the year. Distinctions among livestock species emerged more in terms of the forage species that were used. Sheep diets were the most distinctive, and cattle and donkey diets were more similar to each other. The distinctiveness of sheep diets was largely due to their consumption of grasses and forbs that were low to the ground and hence less accessible to larger livestock species. In a purely ecological sense, this implies that cattle and donkeys would be the most likely competitors for forage given scarcity of resources.

Dynamics and baseline features of forage quality were typical of seasonal rangeland environments, with few exceptions. Forbs (10% CP on average during the year) often had the highest nutritive value. Grasses (7.1% CP on average) were lower in protein and mineral content than forbs but higher in fibre content. Current annual growth of shrubs (8.3% CP on average) was often intermediate between that of grasses and forbs, but nutritive value for shrubs was probably complicated by secondary compounds and other factors. Forage quality rapidly increased at the advent of the wet season and declined in the dry period. While in some cases early senescence of forage could be promoted by hard frosts early in the dry season, it is likely that persistence of green material in selected grasses was promoted by landscape; namely, some higher-value range sites were subtended by high water tables that provided moisture for deeper-rooted taxa throughout much of the year.

Diet quality dynamics for all livestock species exhibited patterns typical of seasonal rangeland environments. Diet quality increased quickly with the advent of the rainy season, leveled-off for a few months, and then gradually declined as the dry season progressed. Variation among species in diet quality was not pronounced, however. All species had a dietary level of crude protein (CP) on a dry-matter (DM) basis that exceeded the 7% minimum threshold for six months (November to April) in the case of sheep and donkeys or eight months (November to June) in the case of cattle. Peak values for all species were around 12 to 13% CP in December and January. The fact that suitable levels of diet quality occurred for several months after the end of the rainy season was not merely an artifact of livestock selectivity, but was strongly influenced by landscape features and herding management. Strategic use of alfalfa pasture by all livestock, but especially higher-value cattle, late in the dry season kept diet quality at reasonable levels late in the production year. Sheep in the dry season were able to find tiny green shoots in otherwise senesced bunch grasses on range sites, and many of these grasses probably had persistent access to ground water. As previously noted, this all occurred within a framework of clever herding.

A survey of sheep flocks across six settlements at SJL revealed that 22% of animals were males (mostly immatures), and nearly half were <1 year old. Criollo animals made up 60% of all animals, while improved animals were 26% and highly improved were 14%. There was a marked variation in the breed composition of flocks across households and settlements. Some settlements had only 5% Criollo animals while others had 95% Criollo animals. This variation was attributed to settlement differences in terms of access to alfalfa pastures and other cultivated forages, as the improved and highly improved animals have higher nutritional requirements. Settlements having a higher endowment of lower-value range appeared to have a higher proportion of Criollo animals in their flocks.

Analysis of sheep production parameters across six households residing in six settlements produced indicative results regarding possible production problems and variation in production systems throughout the cantón. Overall, there was an average ram:ewe ratio of 1:15, but this was highly variable. Mortality rates for lambs (N=266) and adult sheep (N=297) were 5.2 and 1.7%, respectively, in 1992-3. Lamb deaths were due to diarrhea while deaths of adult sheep were due to accidents and unspecified diseases. Highly improved lambs made up the highest proportion of lamb deaths, although sample size was small. Morbidity rates in flocks were high, as 46 to 78% of animals were variously burdened with diarrhea, conjunctivitis, scabies and internal parasites. Breeding was not controlled and lambs were born throughout the year. Castration, nutritional supplementation or forced weaning of lambs typically were not practiced. Fertility rate, calculated as the number of lambs born per ewe, varied from 75 to 145% across household flocks. Twinning appeared to be more common in improved or highly improved animals compared to Criollo, but again sample size was relatively small.

Compared to Criollo animals, the highly improved sheep were 27% heavier at birth and had a 78% faster average daily gain over the first 150 days of life. Highly improved lambs weaned themselves about one month sooner than Criollo lambs. Improved sheep tended to be intermediate between Criollo and highly improved in these respects. No effects of breed, however, were observed in terms of overall productive efficiency at 150 days, which corrected for basic differences in live-weight. Some variation among breeds was noted in terms of commodity production. Highly improved sheep produced nearly 60% more wool than Criollo animals. Highly improved sheep also tended to yield more milk, but this was reflected more in terms of lactation persistence rather than average daily yield. Because sheep milk was not a fundamental product for households, patterns were more difficult to detect compared to wool.

On average, 16% of each flock was culled in 1992-3, and this equated to an average of 31 head per household. Of the culled animals three-fourths were sold as live animals, 17% were slaughtered for home consumption at a rate of one head/household every 2.5 months. The other 7% were culled due to injury or disease. Sheep were typically sold when they were at least one year old. Sales of sheep were driven by the need for income to purchase food, in particular. The end of the dry season was a time of highest need to buy food, and this coincided with higher holiday demand for lambs in the marketplace. Besides routine sales, households planned to off-load much of the current year's lamb crop to provide sufficient resources for the next year's lamb crop.

Firm conclusions regarding resource use, management, and the sheep production system at SJL are risky given data were only collected for one year having near-average levels of precipitation. Rangeland production systems are known for their variability, and what appears true in one year may be woefully incorrect in the next. Estimates of animal production parameters can also be extremely imprecise for the same reasons. In addition, a comprehensive approach would include a thorough analysis of cattle production and management, a dimension we were unable to cover during our study period. Despite these dilemmas, we feel that we can still forward some useful concluding remarks.

First, it is clear that the grazing management system at SJL was remarkably efficient. Land and labour resources appeared to be fully utilised. Native and improved forages were effectively combined to reduce nutritional risks for livestock. Landscape features have encouraged a *de facto* deferred system of grazing that contributes to sustainable levels of resource use. We therefore see little scope to improve grazing management per se given the existing social and economic framework.

Second, in terms of ecological niches, we see sheep and cattle, the vital species in this production system, to be highly compatible. Should common forage resources be diminished during a dry season or drought, we see ample opportunity for potential competition to be mitigated through human interference, whether it be intensified management (i.e., cut-and-carry feeding, etc.) of cattle and/or quickly disposing of extra sheep in the marketplace. The observation that some households attempt to balance sheep numbers with forage resources using an annual sales strategy reveals consciousness concerning carrying capacity and risk.

Third, in terms of sheep production, it was clear that introduced bloodlines have made a substantial impact at SJL over the course of the past 30 years. New breeds have been effectively mixed into the traditional system and probably offer marked boosts in terms of commodity outputs. However, one of the most important findings was that the ability of a household to use improved breeds depends on ability to grow improved forages. This, in turn, depends on location within the cantón.

Fourth and lastly, our assessment of sheep productivity resulted in a variety of insights. The exceptionally low rates of sheep mortality, perhaps the key parameter in such systems, are promoted by hands-on care from the campesinos. Despite this general attentiveness, there are high rates of animal morbidity.

Resumen

Este capítulo está enfocado hacia los componentes de ganado y forraje en el sistema agropastoril. Sin embargo nuestra misión fue ampliada para un mejor entendimiento de como el sistema completo funciona al incluir en el estudio el ganado vacuno (vacas y toros) y equino (asnos), además de los pequeños rumiantes (ovejas).

Este trabajo fue descriptivo en su mayoría y se llevó a cabo durante 1992-3, un año de precipitación casi normal. Nuestro primer interés fué conocer que tipo de recursos forrajeros y sitios de pastizales eran de mayor importancia en San José Llanga (SJL) para el ganado, pero además nos interesaban los aspectos generales del pastoreo. Este tipo de información nos daría una visión de si los recursos forrajeros estaban siendo utilizados eficientemente, y hasta que grado el ganado podría estar complementandose o compitiendo, en términos ecológicos. Por otro lado, quisimos evaluar el valor nutricional de los forrajes y las dietas a través de la producción annual, para así evaluar los riesgos nutricionales para la productividad animal. Finalmente, un estudio base de la productividad de los ovinos y su manejo fue llevado a cabo en las seis sub-unidades de la comunidad. También quisimos cuantificar las tasas de mortalidad y morbilidad, los aspectos de salud y las prácticas de manejo, así como la fertilidad del rebaño y los patrones de crecimiento de los corderos.

Los métodos incluyeron el mapeo de las áreas de pastoreo intensivo usadas por los campesinos y observaciones directas del ganado. Observadores acompañaron el ganado arreado para la recolección cuantificada de las dietas basandose en el método del conteo de mordiscos y el registro sistemático de los patrones de actividad y uso de los sitios de pastizales. Usando diversos índices se cuantificó la similaridad ecológica entre las especies, así como la cuantificación de los recursos forrajeros con resolución a nivel de cuadrante. El manejo de ovejas y su productividad fue determinada a través de la observación de rebaños pertenecientes a familias en las seis sub-unidades de la comunidad. El número total de ovejas para estos estudios fue por sobre los 400 animales de tres razas [Criollo, mejorada (cruza 50% Criollo y Targhee, Corriedale o Merino), y altamente mejorada (cruza por sobre el 50%)]. Se usó el Análisis de Varianza (ANOVA) para el análisis estadístico en los estudios ecológicos o de producción.

Virtualmente todo el cantón fue pastoreado en 1992-3. El pastoreo fue hecho durante el día y los animales fueron mantenidos en corrales por la noche. El pastoreo del ganado fue típicamente dirigido por los pastores. Los animales viajaron un promedio de 6 a 8 km por día en busca de forraje a través del año. El patrón general del pastoreo se basó en los campos de descanso, en una matriz de campos de agricultura, durante la estación húmeda seguido por un aumento en el uso de los campos nativos de pastoreo, en la medida que los pastos crecían y la estación seca comenzaba. La diversidad del uso de sitios se aumentó en la medida que la estación seca progresaba. Así, de a poco, los animales fueron llevados a los campos de agricultura para el pastoreo de los residuos agrícolas. Ademas se hizó un uso estratégico de los valiosos pastizales de alfalfa en el período de transición entre las estaciones seca y húmeda, que fue la época de mayor estress nutricional para los animales. Los campos de alfalfa fueron de especial importancia para el ganado vacuno. En general el patrón de pastoreo fué afectado principalmente por el ciclo de cultivo estacional y la falta de acceso a las zonas planas fluviales y lacustres a causa de encontrarse inundadas. Esta característica creó un sistema de pastoreo natural y *de facto* en muchos de los sitios donde el pastoreo fué atrasado por períodos secos cuando las plantas

estaban en senescencia y tenian menos posibilidades de ser sobre-utilizadas por el pastoreo.

A una escala más fina de resolución, los pastores usaron varios métodos para asegurarse de que el forraje fuera eficientemente utilizado. Se observó una forma de manejo de la sucesión por el pastoreo en donde se le dió prioridad para pastorear en algunos sitios al vacuno, seguido por ovinos y equinos. Dada la compleja contiguidad de los tipos de tierra (campos agrícolas, de descanso, de pastoreo, pastizales, etc.) y la diversa forma de acceso a estas tierras (mayor control para el acceso a las campos agrícolas y pastizales de alto valor versus un menor control o acceso abierto para los campos de descanso o pastizales de bajo valor) se necesitaba un pastoreo diestro y dinámico, el que fue crítico para el manejo de estos recursos. Por otro lado, se observó que la destreza de pastoreo fue de particular importancia para aquellas familias de "tierras-pobres" con limitado acceso a tierras privadas y que han sido forzados a una mayor dependencia de los recursos de pastoreo menos controlados y sujetos a un aumento en la competencia a través de los años. Estos pastores hacian el esfuerzo de mantener los animales fuera de los campos agrícolas mientras explotaban los campos en descanso, a la vez que tenían que asegurar que sus animales "traspasaran ligeramente" campos controlados por otros cuando viajaban a pastorear a otros lugares. Las familias variaban en cuanto a su calidad de labor de pastoreo. Las mujeres jóvenes (entre 11 y 19 años) mantenían mejor control sobre los animales, por ejemplo, mucho mejor que los jovencitos (menos de 11 años) de ambos sexos. Los pastores diestros guiaron exitosamente sus animales para explotar las áreas de forraje de alto valor a través del año. Tales tácticas ayudaron al ganado a aliviar las fluctuaciones estacionales de la calidad y abundancia del forraje a través de la mantención de una dieta alta en calidad y en ingesta a niveles relativamente altos, aún en los períodos secos. Esto, en turno, permitió a animales tales como los corderos a ganar un peso adecuado a pesar de las tremendas bajas en recursos disponibles.

En términos de ecología de pastoreo, ovinos, vacunos y equinos, consumieron una variedad de pastos y hierbas, con limitado uso de las arbustivas. Los pérfiles de dieta a través del año fueron (1) ovinos (50% pastos, 47% hierbas, y 3% arbustivas); (2) vacunos (70% pastos, 30% hierbas, y 0% arbustivas); y (3) equinos (73% pastos, 26% hierbas, y 1% arbustivas). Las hierbas fueron consumidas principalmente en la estación húmeda en tanto que los pastos fueron consumidos en las estación seca. La diversidad de los forrajes fue más alta en los campos de descanso debido en parte a una mayoría de hierbas anuales. Las especies de ganado usaron muchos sitios en común a través del año. La distinción entre las especies aparece principalmente en términos de las especies forrajeras usadas. Las dietas de los ovinos fueron diferentes a las otras especies de ganado, en tanto que las de vacuno fueron similares a las de equinos. La diferencia en las dietas de los ovinos se debió principalmente al consumo de pastos y hierbas cortas y por ende menos accesibles a los animales de talla mayor. En un sentido puramente ecológico, esto implica que el vacuno y los equinos podrían competir por forraje dada una escasez de recursos.

La dinámica y las carácteristicas básicas de la calidad del forraje, con pocas excepciones, fueron típicas de los pastizales estacionales. Las hierbas (10% PC promedio durante el año) a menudo tuvieron el valor nutritivo más alto. Los pastos (7% PC en promedio) fueron más bajo en proteína y contenido mineral que las hierbas, sin embargo no así en el contenido de fibras. El crecimiento anual de las arbustivas (8.3% PC en promedio) estuvo entre el promedio de los pastos y las hierbas, pero el valor nutritivo de las arbustivas fue obstruido debido a los componentes secundarios y otros factores. La calidad del forraje aumentó rápidamente con la llegada de la estación húmeda y bajó rápidamente con la llegada de la estación seca. En algunos casos las plantas pasaron a un estado senescente a causa de heladas tempranas durante la estación seca, en tanto que en algunos casos el que las plantas se mantuvieran activas se debió al sitio del pastizal donde éstas se encontraban. Por ejemplo, algunos sitios considerados de mejor calidad, fueron sostenidos por la superficialidad de las aguas subterráneas, las que proveían humedad a través del año, para aquellas plantas con raíces más profundas.

La dinámica de la calidad de las dietas de las especies ganaderas exhibieron los patrones típicos de pastizales estacionales. La calidad de la dieta aumentó rápidamente con la llegada de las primeras lluvias de la estación húmeda, se mantuvo por algunos meses y luego bajó gradualmente, en la medida que se entraba a la estación seca. La variación entre las especies en cuanto a la calidad de la dieta no fue pronunciada. Todas las especies tuvieron un nivel de proteína cruda (CP) en base a la materia seca (MS) que excedía el mínimo umbral (7%) por lo menos en seis meses en el caso de las ovejas y los asnos (Noviembre a Abril), o por lo menos por ocho meses en el caso de las vacas (Noviembre a Junio). Los valores más altos para todas las especies fue de 12 al 13% de PC en Diciembre y Enero. El hecho de que existieran niveles adecuados en la calidad de la dieta hacia fines de la estación húmeda no se debió a un artefacto de la selectividad del ganado, sino que mas bien fue influenciado por las caracteristicas de los sitios del pastizal así como también el manejo de los animales. El uso estrátegico de la alfalfa por todo el ganado, pero especialmente el vacuno, altamente preciado, hacia fines de la estación seca mantuvo la calidad de la dieta a razonables niveles hacia fines de la producción del año. Durante la estación seca, las ovejas encontraron pequeñas plántulas entre los pastos en senescencia, esto a pesar de que los pastos tenian acceso a aguas subterráneas. Como se mencionó previamente, todo esto ocurrió gracias al diestro manejo del ganado.

En un questionario en relación a los ovinos que se usó en seis sub-unidades de SJL, se determinó que el 22% de los animales eran machos (en su mayoría inmaduros), y casi la mitad eran <1 de edad. La mayoria eran animales criollos, 60%, en tanto que los mejorados un 26% y solo un 14% eran altamente mejorados. Se encontró que había una marcada variación en la composición de las razas en los rebaños en las diferentes familias de la comunidad. Algunas sub-unidades tenían solo un 5% de animales criollos en tanto que en otras se encontraba un 95% de criollos. Esta variación se atribuyó al acceso de las sub-unidades a la alfalfa y a otras áreas de pastizales cultivados, dado que los animales mejorados y los altamente mejorados necesitan de un requerimiento nutricional más alto. Las sub-unidades que parecen tener una cantidad mayor de áreas de baja calidad tienen una proporción mas alta de criollos en sus rebaños.

Un análisis de los parámetros de producción de seis familias en las sub-unidades indicaron posibles problemas en la producción y en la variación de los sistemas de produccíon a través del cantón. En general, existió una tasa carnero:oveja de 1:15, sin embargo ésta fue bastante variable. La tasa de mortalidad de corderos (N=266) y de ovejas adultas (N=297) fue de un 5.2 a 1.7% respectivamente en 1992-3. La muerte de los corderos se debió a diarrea en tanto que la muerte de las ovejas adultas se debió a accidentes o a enfermedades indeterminadas. Los corderos de las razas altamente mejoradas tuvieron una proporción más alta de mortalidad, aunque el tamaño de muestra fué bajo. Las tasas de enfermedad en los rebaños fueron altas, 46 al 78%, esto debido a problemas con diarrea, conjunctivitis, parásitos internos y externos. La reproducción no fue controlada y los corderos nacieron a través del año. Típicamente no se practicó la castración, la suplementación nutricional, o el destete forzado de los corderos. La tasa de fertilidad, el número de corderos nacidos por oveja, varió entre el 75 a 145% en los diferentes rebaños de las familias. Aunque el tamaño de la muestra es pequeño, el número de gemelos nacidos pareciera ser mayor entre las ovejas mejoradas o altamente mejoradas.

Los animales mejorados fueron un 27% más pesados al nacer que los criollos, además tuvieron un crecimiento mas rápido por día de hasta un 78% durante los primeros 150 días de vida. Los animales altamente mejorados se destetaban solos hasta un mes antes que los criollos. En tanto que los animales mejorados se ubicaban entre los altamente mejorados y los criollos con respecto al destete. Pero en cuanto a la eficiencia de productividad observada no existía un efecto dado por las razas a los 150 días, los que fueron corregidos por las diferencias en peso vivo. Ciertas variaciones entre las razas fueron registradas en términos de producción. Los animales altamente mejorados produjeron hasta un 60% más lana que los criollos. Ademas los animales altamente mejorados tuvieron un producción de leche mayor, lo que se reflejó en una persistente lactación en vez de un promedio de producción diaria. Dado que la leche de oveja no fue un producto de importancia para las familias, los patrones fueron mucho más difícil de detectar comparados con la producción de lana.

Hasta un 16% de las ovejas fueron utilizadas en 1992-3, esto equivale a 31 cabezas por familia. Tres cuarto de estos animales fueron vendidos vivos, un 17% fueron carneados para su uso en casa, a una tasa de 1 por familia cada 2,5 meses. El resto, 7%, fueron eliminados a causa de accidentes o enfermedades. Típicamente las ovejas fueron vendidas al año de vida. Las ventas de ovejas fueron hechas más que nada ante la necesidad de comprar comida.

Hacia fines de la estación seca fue la mayor necesidad de comprar comida. Esta venta coincidía con una mayor demanda de corderos en el mercado debido al incremento de fiestas. Aparte de la venta de rutina, las familias planearon la venta de los corderos de año a modo de obtener suficientes recursos hasta la próxima cosecha de corderos.

Dado que los datos fueron obtenidos por solo un año y que ese año fue un año promedio en cuanto a precipitación, las conclusiones son riesgosas con respecto al uso del recurso, manejo y sistemas de producción en SJL. Es conocido que los sistemas de producción de pastizales son variables, y lo que aparece como verdadero en un año puede ser deplorablemente incorrecto el año siguiente. La estimación de los parametros de producción animal pueden ser imprecisos por la misma razón. Más aun, en un estudio comprensivo del sistema se debería incluir el ganado vacuno, lo que no pudimos hacer durante nuestro período de estudio. A pesar de estos dilemas, creemos que podemos hacer algunas conclusiones.

Primero, está muy claro que el sistema de manejo de pastoreo en SJL fue extraordinariamente eficiente. Los recursos de mano de obra y de tierra pareciera ser que fueron utilizados al máximo. Tanto los forrajes nativos como mejorados fueron efectivamente combinados a modo de reducir los riesgos nutricionales del ganado. Las características de la tierra han impulsado a un sistema de pastoreo con descanso que contribuye al uso del recurso a niveles sostenibles. Es por ello es que vemos una mínima necesidad en cuanto a mejoramiento del manejo de pastoreo dado las condiciones socio-económicas de la comunidad.

Segundo, en relación a los nichos ecológicos, vemos que tanto el ovino como el bovino son las especies vitales y altamente compatibles para este sistema de producción. En caso de que los recursos forrajeros disminuyeran durante la estación seca o épocas de sequía, vemos un alto potencial de competición que necesita ser corregido por la intervención humana, ya sea a través de la intensificación del manejo del vacuno (por ejemplo cortar y llevar alimento a los animales, etc.) y/o vendiendo ovinos en el mercado. En la comunidad se nota una preocupación por la capacidad de carga de animales en la tierra y riesgo dada la observación de algunas familias que usan la estrategia de balancear el número de ovejas con los recursos forrajeros usando ventas anuales.

Tercero, en términos de producción de ovejas, está claro que la introducción de razas puras en los últimos 30 años han tenido un impacto de importancia en SJL. Nuevas razas han sido mezcladas efectivamente en el sistema tradicional y ofrecen un marcado empuje en términos de materia producida. Sin embargo, uno de los puntos de mayor interés hallados en esta investigación fue que la posibilidad de que una familia tenga animales mejorados dependerá de la abilidad de producir forrajes mejorados. Esto sin embargo dependerá de la ubicación geográfica dentro del cantón.

Cuarto y último, nuestra investigación en relación a los ovinos resultó en una serie de observaciones. La excepcional baja mortalidad de animales, tal vez un parámetro clave en tales sistemas, es debido al extremo cuidado de los animales por los campesinos. A pesar de la gran atención que le dan a sus animales, existen altas tasas de enfermedades en los animales.

5.1 Introduction

The main objective of the joint IBTA/SR-CRSP project in Bolivia was to assess the overall role of small ruminants in the ecological and economic sustainability of an agropastoral system. Prominent was a mandate for us to investigate: (1) Whether small ruminants were important contributors to environmental degradation; and (2) whether there were feasible improvements in management that could mitigate negative impacts of small ruminants on natural resources and increase efficiency of animal production (see Chapter 1: *Project objectives and research approach*). These issues are important in light of recent controversy concerning environmental degradation of the world's rangelands. On one hand people and livestock are blamed (Sinclair and Fryxell 1985; Cloudsley-Thompson 1988) while on another hand climate, or change in climate, is cited as a key factor (Rasmusson 1987; Ellis and Swift 1988). If livestock are not to blame then efforts to de-stock traditional pastoral systems could be in error (Behnke and Scoones 1991).

Our research was focused on the Cantón of San José Llanga (or SJL) for reasons discussed in Chapter 1: *Project objectives and research approach*. Circumstances at SJL required that we re-orient some aspects of livestock research, however, from the original plans. One re-orientation involved studying the role of introduced small ruminants (i.e., sheep) rather than the role of indigenous small ruminants (i.e., camelids such as llama and alpaca). While it was philosophically desirable that we focus on camelids since they are unique to the Andean zone, the campesinos at SJL no longer raised camelids. As in many other communities of the central Altiplano, llama were traditionally used at SJL for production of meat and fiber, wealth generation and storage, and portage. Alpaca, in contrast, were never produced at SJL because the environment is unsuitable. San José Llanga lacks the moist bofedal (i.e., wetland) habitat needed for alpaca production (Section 3.3.2: *Description of natural resources*). The arrival of domesticated sheep and equines over 400 years ago, expansion of markets for sheep and cattle, dismemberment of the *Ayllu* system of regional land use by the Spanish, access to mechanised transport, and urban bias against products such as llama meat all contributed to elimination of llama at SJL (C. Jetté, IBTA/SR-CRSP, personal communication; see Section 2.3.2: *Regional historical highlights*).

The second re-orientation involved embracing a broader livestock research perpective than merely a focus on small ruminants. It was apparent that sheep were a mainstay of livestock production at SJL, but the campesinos also highly depended on Criollo cattle for draught power and milk production, donkeys for portage and Friesian (Holstein) cattle for small-scale dairying. Although sheep clearly dominated livestock composition on a numerical basis, in terms of biomass there was more equity among species. For example, in 1992 the total number of grazing livestock at SJL was around 5625 head with 5000 sheep (89% on a numerical basis), 500 cattle (9%) and 125 donkeys (2%; Dr. I.M. Ortega et al, IBTA/SR-CRSP, unpublished data). If Tropical Livestock Units (TLUs) based on metabolic weight are considered [i.e. , where one sheep = 0.1 TLU, one bovine = 0.7 TLU, and one donkey = 0.5 TLU (Jahnke 1982, 10)], the percentages shift to 55% sheep, 38% cattle and 7% donkeys. We therefore decided to investigate resource use and interactions among several grazing livestock species since we hypothesised that sheep, cattle and donkeys were having a variety of direct and indirect effects on the performance of each other (Plate 5.1a-c). For example, initial surveys were interpreted to indicate that these species used similar ecological resources and probably had to compete to some degree for limited nutrition and health inputs.

Our initial questions for work in this chapter included: What were the quantities and types of

a

b

c

Plate 5.1 (a-c). *Livestock incorporated in studies of feeding ecology and resource use at San José Llanga: (a) Mixed group of Criollo cattle and sheep on rangeland; (b) Holstein heifer on alfalfa pasture; and (c) donkey.* Photographs: (a) Jim Yazman, (b) Christian Jetté, and (c) Lita Buttolph available grazing and other feed resources at SJL, and were they being efficiently used by the campesinos? Was the seasonal nutrient content of diets and intake of forage sufficient to support desired levels of livestock production? Similarly, were sheep production statistics at SJL "reasonable" given pervasive managerial and ecological constraints? Work described in this chapter is therefore more descriptive and diagnostic with regards to animal feeding ecology and production. Later in this volume some managerial, technical and policy innovations are addressed which could alleviate some problems of animal production and risk management at SJL and similar communities (see Chapter 8: *Conclusions and recommendations*).

Finally, while our work was limited to grazing livestock, other livestock are raised at SJL which were not investigated at all. These may be important to some households and include poultry and a few swine.

5.2 Methods

Material in this chapter primarily draws upon BS-thesis work and other field studies completed by seven Bolivian undergraduates (see Section 5.5: *Literature cited* and Chapter 1: *Project objectives and research approach*). Thesis work was targeted to address specific topics which would contribute to an overall understanding of the structure and function of the SJL agropastoral system. Such studies were variously conceived, designed and supervised by resident scientists of the IBTA/SR-CRSP project with ancillary guidance and participation by Bolivian co-investigators and U.S.-based principal investigators. A justification and general methods for major studies concerning grazing management, livestock feeding ecology and nutrition, and sheep production are given below.

5.2.1 Grazing management

Grazing management is a foundation of rangeland science. A range manager controls the intensity, frequency and season of defoliation of range plants. This is achieved by selecting stocking rates and making decisions as to when and where animals should forage (Heady 1975). If the intensity or frequency of defoliation is too high, plants may lose vigour or even die. If plants are too heavily grazed during seasons when they are actively growing and setting seed, plant reproduction can be jeopardised. Alternatively, plants can be grazed to a very high degree during cold or dry seasons when aboveground tissues are senescent with little if any damage to future productivity (Heady 1975). Some plant communities are far more tolerant of heavy grazing than others. High root:shoot ratios, prostrate morphologies, and low-growing apical meristems are features which confer grazing tolerance in range plants (Briske 1991). Reliable access to ground water may give plants more regrowth capacity under heavy grazing compared to situations where plants are dependent on seasonal rainfall. These fundamentals are briefly noted here because all are relevant to understanding the grazing system of SJL. Being a physically closed system in terms of grazing resources, the campesinos are under some pressure to make wise and efficient use of limited forage each year. Many species of dominant range plants at SJL reviewed in Chapter 3 (*Ecology and natural resources of San José Llanga)* exhibit morphological features consistent with adaptation to heavy grazing. Native perennial forages growing on geomorphological units such as the fluvio-lacustrine plain have easy access to ground water; in contrast those annuals growing on fallow fields of the alluvial terrace are more dependent on rainfall. All range plants at SJL are growing in a highly seasonal environment in terms of moisture and temperature. This defines alternating periods of plant growth and dormancy. Many choices are therefore presented to campesinos when they are in the process of deciding when and where animals should forage.

For an overall, preliminary picture of grazing activities at SJL, Massy and Cáceres (IBTA/SR-CRSP, unpublished data) used interviews of campesinos, in combination with casual observations, to produce a map showing where sheep, cattle and donkeys foraged in the cantón during a near-average rainfall year. Attention was given to associate specific sites with use according to livestock species, foraging intensity (i.e., high, medium or low) and season(s) (i.e., rainy season, dry season or both). There were 13 sites recognised in total; these included three sites on land primarily used to cultivate food crops, two types of cultivated alfalfa pasture, and eight types of rangeland.

This work of Massy and Cáceres was augmented by a systematic, observational study of site use, daily behaviour patterns and travel effort of livestock throughout a representative year (Victoria 1994; Victoria et al 1995). In this work livestock herds from 12 households were selected for day-long observation. The 12 households represented about 10% of all households in the cantón, and were chosen from a sub-group of 56 households that were the formal collaborators with the project. Study households were evenly distributed throughout the six settlements that comprised the cantón [see settlement features in Victoria (1994, 39), Chapter 3: *Ecology and natural resources of San José Llanga* and Section 4.3.1.1: *Settlements*]. Observations were made for 12 days per month from April, 1992, to March, 1993. Observation days were spread evenly among sheep, cattle and donkeys with four days per species per month. The livestock species were often mixed together, so behaviour of one species was not independent of that for another. The average size of observed herds was 91 head (range: 44 to 154 head). Herds were heavily dominated by sheep on a numerical basis, with only a few (from three to eight) Criollo or cross-bred cattle and fewer (from 0 to 2) donkeys. Animals were herded, so management objectives were likely a strong influence on patterns of site selection. Sites included a wide variety of crop lands (fallow fields and post-harvest crop stubble), cultivated alfalfa pasture, and range. Annual precipitation during the study period was 388 mm (Peña 1994), which was near the long-term average of 406 mm (Section 3.3.1: *Climate*). Herds were followed from the time they left corrals in the morning until their return at night. A student accompanied the herd [and herder(s), who were typically women or children] and collected data on site use and animal behaviour (i.e., foraging, traveling, resting, watering, etc.) at five-minute intervals. Travel distances were measured using a pedometer worn by the student, and the overall daily travel route was mapped. Data were analysed in a completely random design using a General Linear Model Analysis of Variance (ANOVA). Dependent variables included factors such as daily average foraging time, daily average travel distance, and proportion of daily foraging time spent in various sites. Independent variables included month (season) and livestock species. Previous studies elsewhere indicate that season affects activity budgets of grazing animals (Arnold and Dudzinski 1978). For example, during rainy (growing) periods when forage is abundant, foraging time and travel efforts commonly decrease while the reverse can occur during dry periods. Patterns may deviate from this, however, because of influences of daylength, management (i.e., corralling and how far animals must trek to water) as well as forage abundance and distribution. Larger species can spend more time feeding per day than smaller species. In contrast to foraging time and travel, however, there were fewer expectations about how livestock would use the landscape, and in this regard the study was more exploratory and descriptive. Seasonal similarity in site use among pairs of livestock species was analysed using an ANOVA. Fisher's Least Significant Difference (LSD) test was used to separate means of all ANOVAs when main effects or interactions were significant (SAS 1988). Work of Flores (1995) is reviewed later in the context of his study of site and season effects on forage intake by sheep. In the course of this work he made some observations on multiple-species grazing management, and these will be cited to provide some details lacking in Victoria (1994) or Cáceres (1994).

A third approach for site use involved more detailed observation of how sheep flocks of five households, which varied in resource endowments, utilised grazing resources. This work was directed later in the project during 1993-4 (also a near-average rainfall year) by Dr. J. de Queiroz et al. (IBTA/SR-CRSP, unpublished data) and is reported in Norton (1994), Ramos (1995) and Ramos et al (1995). The approach for this study differed from methods above in that a very precise hypothesis was tested, namely, that households having reduced access to land would be forced to apply more grazing pressure to that land in order to meet household needs. Thus, overgrazing would be a function of the imbalance between land access and flock size, and should also be reflected in lower levels of animal productivity per head. The study design therefore relied on some basic socio-economic information that had not been available at the beginning of the project. First, it was apparent that campesino households varied according to wealth, the number of livestock they owned, enterprise diversity, labour pool and access to land. While some of the lower-quality range was indeed under communal tenure, resources such as higher-value alfalfa pasture, prime rangeland and cropping plots were under private access (see Section 4.3.3: *Household production system*). Five households were chosen that varied in terms of access to resources. Labour pools varied in terms of the ratio of teenagers versus young children (Table 5.1) and in terms of access to various types of forage (Table 5.2). Access to prime range, cropping plots, fallowed fields and cultivated alfalfa varied, respectively, by up to six-fold, four-fold, 14-fold and 20-fold among households.

Each of the five household flocks were followed by a student for two sample days in a wet season (December to March) and one sample day in a wet-to-dry transition season (April to August; note that the critical late dry season was not included). Important herding decisions (such as those concerning where animals foraged and how long they remained in any given parcel) were recorded by interviewing herders. The test of the hypothesis required a means to measure animal performance for each household and a way to reflect the overall quality and quantity of forage encountered by household flocks during their day-long foraging trajectories. Animal performance was measured by obtaining live weights of the same five to 10 sheep from each family flock on a monthly basis. For forage quality and quality an index was devised that integrated the results of two equations. The first equation yielded a plot forage index (I_{fp} or "an index of forage encountered on a parcel basis") which reflected quantity and quality of patches that were grazed for >15 min. It has the following formula:

$$I_{fp} = \sum_{i=1}^{n} \frac{(B_i)(V_i)}{V_i}$$

where B_i is the biomass of species i and V_i the forage value of species I. The n stands for the total number of species in a given parcel. Values for B_i were obtained by double-sampling of vegetation (Bonham 1989). To arrive at values of V_i for the different forage species 13 (female) herders were interviewed and asked them to rate key species on a scale of 1 to 10 in which the lowest value was ascribed to *Astragalus garbancillo*, a toxic species deemed useless as forage, and a value of 10 to alfalfa. The second equation created a second daily forage index (I_{fd} or "an index of forage encountered on a daily basis") which integrated all I_{fp} on a given day along with the time (T_i) spent feeding in parcel i. Here the n stands for the total number of parcels encountered on a given day:

$$I_{fd} = \sum_{i=1}^{n} \frac{(I_{fpi})(T_i)}{T_i}$$

The index I_{fd} was found to be normally distributed and was subject to parametric statistical analysis. A two-way ANOVA was conducted with I_{fd} as the dependent variable. Households (five) and sampling dates (12) were independent variables. The null hypothesis was that I_{fd} would not significantly vary due to household or sampling date. Sheep weights (dependent variable) were analysed in a similar fashion (Ramos 1995). An alternative hypothesis was that the land-poor households would have lower values of I_{fd}, especially as the dry season progressed. As previously shown, households varied along several axes. This presented a potential problem in interpreting what "household effects" really were. To identify which household factors were most important in defining variability of I_{fd} a multiple regression analysis

Table 5.1. *Variation among five campesino households in terms of labour resources. Households were used in a study of the effects of how variation in household resource endowments influenced household-level grazing strategies at San José Llanga.* Source: Norton (1994).

Household	Labour Resources		
	Children[1]	Teenagers[2]	Adults[3]
1	1	2	2
2	5	0	2
3	5	1	2
4	3	1	2
5	3	1	2

[1]Less than 10 years old.
[2]Between 10 and 19 years old.
[3]Over 19 years of age.

Table 5.2. *Variation among five campesino households in terms of forage resources (hectares) and numbers of adult sheep. Households were used in a study of the effects of how variation in household resource endowments influenced household-level grazing strategies at San José Llanga.* Source: Norton (1994).

Household	Forage Resources[1]				Adult Sheep[2]
	Rangeland	Fallow	Food Crop	Alfalfa	
1	7.0	7.0	1.8	5.0	85
2	3.5	9.0	1.3	0.3	23
3	12.0	60.0	3.3	0.5	48
4	18.8	101.0	0.8	3.0	72
5	11.2	30.0	4.0	3.0	64

[1]Where rangeland was unimproved, rain-fed grazing sites; fallow was area in the crop matrix rested from cultivation and used for grazing; food crop was area in the crop matrix under cultivation used for grazing crop residues; and alfalfa was area under sub-irrigated forage production.

[2]All adult sheep were not necessarily owned by the family – some were managed for others.

was also carried out using I_{fd} as a function of household features such as amounts of land owned, flock size and numbers and ages of herders.

5.2.2 Seasonal dynamics of livestock diets: Composition, quality and intake

By virtue of their varied body sizes and gut morphophysiologies, the sheep, cattle and donkeys of SJL should exhibit marked differences in the forage plants they consume (Janis 1976; Kay et al 1980; Hofmann 1988). For example, sheep have small bodies and small mouths with mobile lips, but they also have relatively large rumens. This paradox typically allows sheep to be more selective feeders than larger ruminants in terms of diet composition and nutritive quality but, like cattle, sheep can also tolerate fairly high levels of dietary fiber. Sheep are known world-wide to be adaptable mixed feeders in terms of their use of grasses, forbs and woody browse (Coppock et al 1986a; Hofmann 1988). In contrast to sheep, cattle have broader muzzles, wider tongues and lips and a much larger body size. This all tends to force cattle to be less selective feeders, particularly when their feeding time is constrained by night corralling or widely scattered distributions of forage. Cattle therefore tend to feed on more abundant plants like grasses, which also have a higher fiber content more suited to their digestive processes. Cattle have been observed, however, to make opportunistic use of palatable, low-fiber forbs or current-annual growth of shrubs if available (Coppock et al 1986a). As a cecal digester, donkeys have the ability to process the least digestible forages (if necessary) by passing more material per unit time; a strategy not open to most ruminants (Janis 1976). Like cattle, donkeys tend to consume material higher in fiber but can be highly opportunistic in diet selection (Coppock et al 1986a).

Based on animal features above, it would be expected that livestock diets at SJL are distinct and little inter-specific dietary overlap (or potential for forage competition) exists. However, if the plant community lacks diversity, or if no effort is made to herd animals to different locations, diet overlap and potential for competition could be pervasive. Understanding the scope for diet overlap and competition among livestock is important. If forage resources are shared during a critical bottleneck period, one species could suffer reduced productivity because of another species. This then affects economic returns to households. Ideally, if households are to effectively mitigate risks they should want to hold a combination of livestock species that are complementary in terms of ecological requirements and economic attributes. In some cases, however, one species could actually facilitate foraging of another by clearing undesirable vegetation; this has been suggested to occur between cattle and goats on savanna (Pratt and Gwynne 1978, 164) and between sheep and cattle in management of poisonous plants in the Intermountain West (Dr. D.L. Coppock, IBTA/SR-CRSP, personal observation).

Given these justifications, work was undertaken to quantify livestock diets and diet selection in important foraging sites (Cáceres 1994; Flores 1995). The bite-count technique was used (Hobbs et al 1981; Coppock et al 1986a; Ortega 1991). This method involves close observation of a foraging animal (i.e., the observer should keep within 50 cm of the feeding interface, especially if grazing rather than browsing is involved). Bites of specific forage types are recorded (usually on a hand-held tape recorder) for a specified length of time to create a diet profile; proportions of different forages in diets can be approximated further by multiplying bite numbers by estimated average dry weights of bites. Bite weights are usually subjectively estimated using hand-plucked samples that mimic bites observed to be taken by the foraging animal. Despite the chance for imprecision, the bite-count method is usually the technique of choice when logistics are difficult and where animals travel long distances and are relatively tame; this was the case at SJL. Ortega et al (IBTA/SR-CRSP, personal communication) found that bite counts can give comparable results to those obtained by use of esophageal fistulation, especially if the analysis is limited to forages which comprise >2% of the diet. Lack of sanitation at SJL, as well as other logistical problems, precluded consideration of esophageal fistulation which requires post-operative maintenance (Dr. I.M. Ortega, IBTA/SR-CRSP, personal observation).

Bite-count data were collected in different ways by each student. The work of Cáceres (1994) was carried out for a 12-month period from April, 1992, to March, 1993. She observed sheep, cattle and donkeys foraging across nine site types. Four site types consisted of different ages (i.e., successional phases) of fallow in the agricultural fields (or CADES), while the other five site types were grass-dominated communities on the rangelands (or CANAPAS); for a general review of site types see Chapter 3: *Ecology and natural resources of San José Llanga*. The work plan of Cáceres (1994) consisted of six consecutive days of bite counting separated by 15-day intervals; throughout the year she therefore had 24, six-day observation periods overall with two per month. She also blocked her observations by season for analysis; November through March was considered the rainy season (with 10, six-day observation periods) while April through October was considered the dry season (with 14, six-day observation periods). Data were collected as follows: On a work day the student scanned the landscape and selected a group of animals for observation that belonged to a collaborating household and occupied a foraging site of interest; effort was made to stratify observations across the six settlement zones of the cantón (above). If sheep were to be watched, the student selected one sheep from the group and collected data for 100 bites on this animal before moving on to observe nine more sheep for 100 bites each at the same location. The sample unit was the 100 bites for a given sheep. If cattle or donkeys were to be watched, a total of three animals were consecutively watched with 200 bites per animal. For each six-day observation period data were collected for 50 sheep, 15 cattle and 15 donkeys (Cáceres 1994, 30). For the entire study this added to 120 000 bites for sheep, 72 000 bites for cattle and 72 000 bites for donkeys. Statistical comparisons of livestock use of different types of forage plants was achieved by using bite-count data in a completely randomised design with a General Linear Model ANOVA; livestock were independent variables and percent use of various plant categories were dependent variables. Fischer's LSD test was used for mean separation when main effects or interactions were significant (SAS 1988). In addition, a canonical discriminant analysis was used as an exploratory tool to reveal extent of diet similarity among pairs of livestock species according to foraging sites and season. Similarity indices between pairs of livestock species were calculated on the basis of overlap in consumption of plant species.

Work of Flores (1995) was conducted in nearly the same time period as that for Cáceres (1994).

Like Cáceres, Flores (1995) was interested in studying complementarity among livestock species in terms of forage selectivity, but in addition he studied forage intake, diet nutritive quality and aspects of grazing management. He focused his observations on four plant communities of the rangelands (CANAPAS) and did not work in agricultural fields (CADES). The four rangeland plant communities were selected because of their importance to livestock based on social survey and empirical observations. The communities were: (1) Grassland patches dominated by *Calamagrostis curvula* and *Muhlenbergia fastigiata;* (2) grassland patches dominated by *Hordeum muticum*, *M. fastigiata* and *Distichlis humilis*; (3) a mixed grassland/ shrubland association dominated by large bunchgrasses (*Festuca orthophylla*) and evergreen shrubs (*Parastrephia lepidophylla* or *thola); a*nd (4) another mixed grassland/shrubland dominated by *P. lepidophylla, Atriplex triandrum* and *Distichlis humilis*. These plant communities are described in Section 3.3.2.4: *Land cover*. We will only review a couple aspects of the work of Flores (1995) here that pertain to grazing management of sheep and dietary overlap among livestock species. Focusing on adult female sheep, Flores (1995) used 10-min sampling periods to collect bite counts for one sheep, followed by 30 min in which other site-specific forage data (such as estimating bite weights of representative, hand-plucked samples) were collected. This, in turn, was followed by another 10-min observation for another sheep and so forth. Considering one 10-min period as a sample unit, Flores (1995) collected data for 230 total sample units spread across the four plant communities and three seasons; seasons included the rainy season (December to February), dry season (June to August) and late dry-season (September to November). Flores calculated a diet similarity index for pairs of species on the four site types over three seasons; this approach utilised the index of Kulczynsky cited in Martín et al (1988). This index varies from 100 for complete similarity to 0 for complete complementarity (Flores 1995, 11-12). Flores was only able to make observations where animals were routinely taken to feed, therefore balanced designs were not possible. In the rainy season livestock were observed on the higher elevation (i.e., grassland/ shrubland) sites while in both dry periods livestock were observed on the grassland sites; this led to a piecemeal analysis. A 2x2 factorial ANOVA was used to analyse forage intake (g/head/day) and daily foraging time (hours/head/day) for grassland sites in dry periods (i.e., sites and periods were the factors). For the rainy season a completely randomised design was used with site as the lone independent variable. One hypothesis for the dry season was that forage intake would decrease in the late dry period, it was less clear what would happen to daily feeding time. Similarity indices were not statistically analysed, but Flores considered index values >50 to indicate potential for forage competition.

The studies of foraging behaviour also gave us an opportunity to evaluate nutritional quality of livestock diets. It was anticipated that dietary nutritive value for livestock would vary markedly according to season, and perhaps also due to animal species. For example, it is well-known that growing (rainy) seasons on rangelands are times of higher forage nutritive value because plants are phenologically young and actively growing (Van Soest 1994). Compared to mature plants, growing plants have a higher proportion of leaf to stem and more cell solubles relative to fibrous cell wall. Forages eaten during growing seasons therefore often have the highest levels of CP and lowest proportion of total (neutral detergent) fiber compared to materials selected during the rest of the year. Conversely, brown, senescent plant materials characteristic of dry seasons are typically lower in CP and higher in total fiber. Increases in total fiber are often due to a gradual lignification of plant cell walls; lignin is a structural agent virtually indigestible by ruminants (Van Soest 1994). Differences among animal species in diet quality are due to variation in animal selectivity; selectivity, in turn, is related to such disparate factors as animal body size, mouth morphology and herding management (Heady 1975; Hofmann 1988). Other factors aside, smaller-bodied sheep with their smaller mouths should be able to acquire a higher diet quality than that for cattle or donkeys overall (Coppock et al 1986b). Another question to be answered was: Was the nutritive quality of livestock diets adequate for desired levels of animal performance? This was a difficult issue to address in a rangeland setting because forage intake needs to be measured along with diet quality; we were unable to conduct intake studies of adequate accuracy for this purpose because of logistical constraints. Where animals have free (*ad libitum*) access to forage, diet quality can give a fairly reliable indication of potential performance of ruminants because diet quality factors are then the prime determinants of rate of digestion and hence forage intake and animal productivity (Van Soest 1994). In a rangeland setting, however, diet quality alone is not sufficient to predict performance because other constraints on forage intake are often operating. For example, herd management, water intake and highly variable standing crops of forage can all affect rates of forage intake (Coppock 1985). Despite these limitations, diet quality can give some indication of production constraints and thus need for range improvements or tactical animal supplementation (Coppock 1994). Typically, if dietary CP values are <7% on a dry matter (DM) basis, quality constraints on intake for ruminants could occur. Similarly, if lignin content >12% of DM, or total fiber >70% of DM, intake for ruminants could also be compromised.

Bite counts are often augmented with chemical analyses of hand-plucked forage samples for the purpose of estimating diet quality. Chemical values for each forage item are multiplied by the respective proportions of forage in the diet (i.e., number of bites times average bite weight) to come up with weighted averages for the overall diet (Hobbs et al 1981; Coppock et al 1986b). Attempts to reconstruct nutritive quality of livestock diets from bite counts were performed by Flores (1995) and Lopéz (1994). Both students collected forage samples in a similar fashion, but Flores (1995) collected materials during feeding observations while Lopéz (1994) used diet profiles from Cáceres (1994) and collected forage from representative sites and at representative times long after bites had been counted. In the studies of Lopéz (1994) and Flores (1995), hand-plucked forage samples were oven-dried at 55 °C for 72 hr and ground using standard procedures (AOAC 1990). Samples were analysed at the A&L Agricultural Laboratories in Lubbock, Texas, USA, for crude protein (CP), digestible crude protein (DCP), Acid Detergent Fiber (ADF), Total Digestible Nutrients (TDN), phosphorus (P), potassium (K), and calcium (Ca), also according to procedures in AOAC (1990). Crude protein is commonly used as an indicator of forage value; DCP can be particularly important when browse is consumed because compared to that for grasses, nitrogen of browse is more commonly located in fiber and tannins and less accessible for digestion. Acid detergent fiber is the holocellulose fraction of total fiber and the main substrate for fermentation of carbohydrates. Minerals like K were assessed because the central Altiplano is regarded as K-deficient for grazing livestock (Dr. H. Alzérreca, IBTA/CRSP rangeland ecologist, personal observation).

Flores (1995) did not perform a statistical analysis on his diet quality data; thus, some of his results are referred to here for illustration purposes only. In contrast to Flores (1995), Lopéz (1994) followed the bite-count design of Cáceres (1994) reported above in designing her work. Lopéz (1994; 121, 125, 129) reconstructed diet profiles and diet quality parameters for 60 sheep, 60 donkeys and 50 cattle diets throughout a 12-month period. She collected plant materials twice per month for chemical analysis. Lopéz (1994) used a completely random design with a two-way ANOVA for statistical analyses; diet quality parameters were dependent variables and livestock species and seasons (rainy, dry) were the two independent variables (SAS 1988). Effects of foraging sites (i.e., CADES versus CANAPAS) were not analysed because site use was not balanced among livestock species and seasons. In addition to diet quality, Lopéz (1994) did considerable work analysing nutritive dynamics of individual forage species. Data were analysed using a two-way ANOVA with nutritional parameters as dependent variables and forage classes (i.e., grasses, forbs or shrubs) and seasons (i.e., rainy, dry) as independent variables. Lopéz (1994, 58-96) presented dozens of graphs showing nutrient dynamics of individual species. These details are not reviewed here.

5.2.3 Management and productivity of sheep

A core focus of SR-CRSP projects world-wide has been the study of management and productivity of small ruminants under indigenous conditions. Knowing a baseline situation allows key production constraints to be identified. This, in turn, helps clarify interventions and economic implications of improving animal production.

A descriptive analysis of sheep management and productivity was undertaken at SJL during 1992-3 by Villanueva (1995). Preliminary resource surveys at SJL early in 1992 indicated that the cantón should be stratified into six zones for animal production studies. Each zone is represented by a settlement and has a unique endowment of natural resources. The settlements included *Callunimaya, Inkamaya, Espiritu Willq'i, Barrio, Savilani* and *T'olatia* (see Section 2.4.2: *Local society,* Figure 5.1 (a,b) and Figures 3.3, 3.4 and 3.5 which show the distribution of settlements in relation to geomorphology, soil types and land cover). Table 5.3 gives a summary of numbers of households and livestock in the six settlements.

Villanueva proceeded to work with one flock of sheep from six, randomly selected households—there was one household from each of the six settlements. This resulted in a grand total of 438 sheep at the beginning of the study, with a mean of 38 ewes per household (range: 20 to 66). Flocks varied markedly in terms of genetic composition. The local Criollo sheep was typically most common, but crosses of Criollo with introduced Targhee and Corriedale were also frequent in some settlements. Targhee, Corriedale and Merino blood had been brought into the SJL system via projects based at the Patacamaya Experiment Station during the 1960s (Chapter 7: *Patterns of technology adoption at San José Llanga*).

The objectives of the work by Villanueva (1995) were to: (1) Describe the basic sheep management practices of the campesinos, with a focus on breeding and health; (2) quantify production parameters such as overall rates of fertility, natality and mortality; and (3) quantify growth rates of lambs. She had a general emphasis on determining how sheep breeds influenced management and productivity. Villanueva conducted her studies from April, 1992, through March, 1993. She made routine observations of management practices when she visited households and conducted interviews with flock managers. Management practices of specific interest included: (1) Sheep breeding control; (2) tail docking; (3) weaning intervention; (4) sheep identification; (5) castration; (6) shearing; and (7) use of dipping baths for external parasites and vaccination against disease. It was not known the degree to which the campesinos of SJL used "progressive" management practices, despite their proximity to the Patacamaya Experiment Station. Some of the less-obvious advantages of using "progressive" management practices will be briefly mentioned here. For example, breeding control can be effectively used to not only produce lambs with a desirable genetic make-up, but have them born at the time(s) of year when forage is more abundant and/or nutritious. Breeding control can also help produce lambs at the right time to take advantage of seasonal market prices. Tail docking can alter fat distribution in sheep by eliminating the option for deposition in the tail and thereby increasing subcutaneous fat content of the carcass. Forced weaning of lambs at an appropriate

Table 5.3. *Numbers of households and livestock for six settlements at San José Llanga in 1992.* Source: Villaneuva (1995, 27).

Settlement	Number of Families	Total Animals		
		Cattle	Sheep	Donkeys
Espíritu Willq'i	8	26	489	13
Inkamaya	27	76	1191	27
T'olatia	22	84	724	20
Savilani	22	66	831	17
Barrio	35	87	630	18
Callunimaya	11	44	300	13
Total	115	383	4165	108
Percentage[1]	--	8.2	89.5	2.3

[1]Percentage that all individuals of a given species made up of all cattle, sheep and donkeys (or 4656 head).

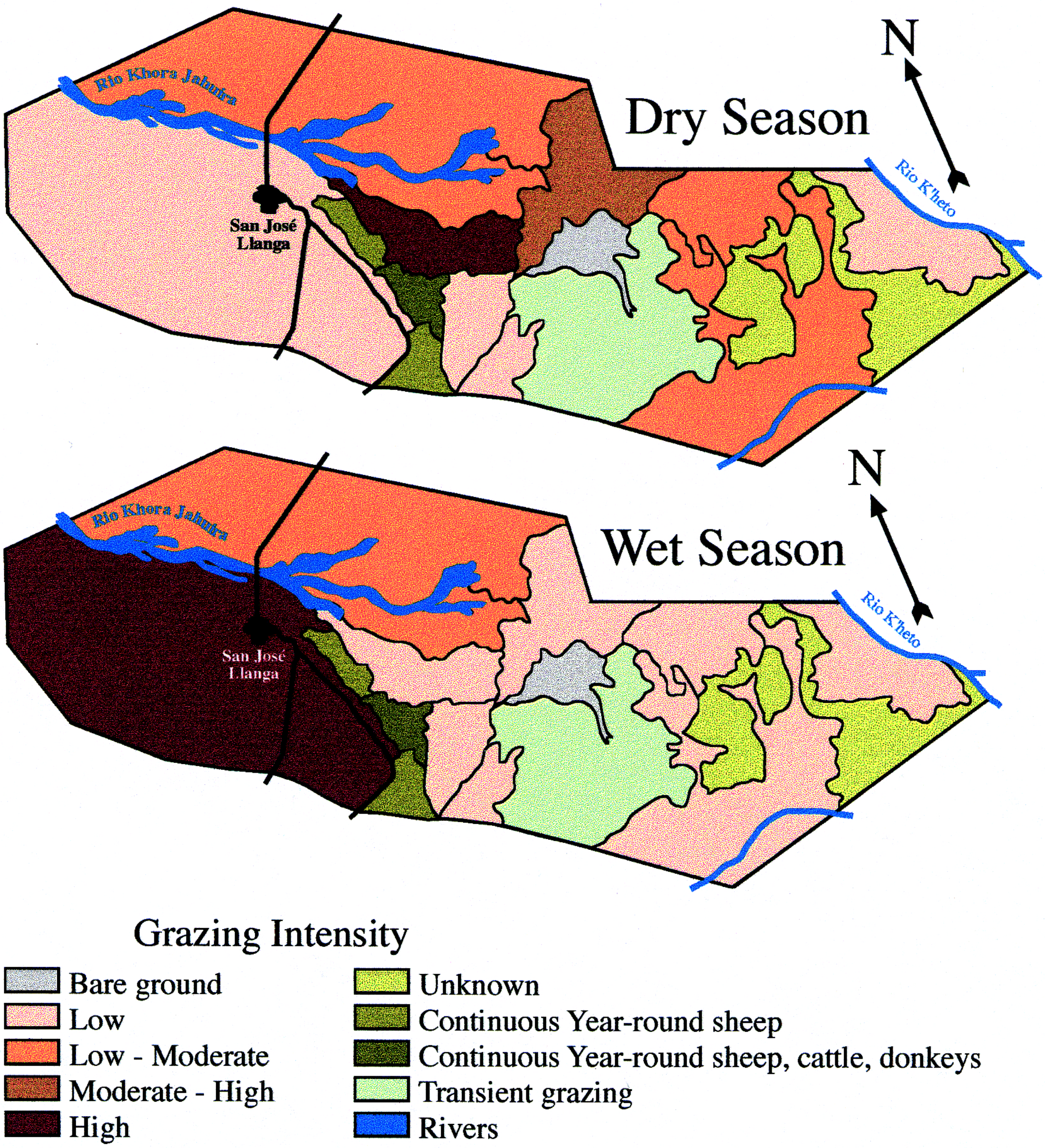


Figure 5.1(a,b). Maps of livestock grazing intensity throughout the Cantón of San José Llanga during the: (a) Dry season and (b) wet season of 1992-3. Source: Maps produced by Dr. I. M. Ortega from information collected by Massy and Cáceres (IBTA/SR-CRSP, unpublished data)

age and time of year can improve condition of ewes by allowing them to cease lactation. Marking of individual animals increases the likelihood that animal performance can be tracked. Castration improves weight gain and fat deposition in males. Villanueva (1995) recorded dates when births of lambs occurred and measured liveweights of ewes at parturition. She also recorded liveweights of lambs at birth and 60 and 150 days of age, age and liveweights of lambs at weaning, and sales and deaths for all sheep. Health assessments focused on internal parasites, and this was evaluated through analysis of fecal samples. Fresh fecal samples were collected in July (dry season) and February (wet season) for analysis of internal parasites using microscopy. Eggs and other evidence of various parasite species were tabulated per cubic centimeter of feces and coded into 12 abundance classes based on numbers ranging from 25 to 1600 eggs per unit (Villanueva 1995, 32).

Villanueva (1995) used a variety of statistical methods. She employed descriptive approaches to talley frequencies and calculate means. She also used the General Linear Models (PROC GLM) approach in SAS for ANOVA (SAS 1988) to analyse effects of sex, breed, household and season on production parameters listed above. It is important to note that household was confounded with settlement (or zone). A lack of replication for households within settlements meant that effects of settlement per se could not be statistically evaluated. Three seasons were used for the ANOVA: (1) The main wet season (i.e., November to February); (2) the wet-to-dry transition (i.e., March to June); and (3) the main dry season (i.e., July to October). For the analysis of internal parasites a factorial ANOVA was used to assess effects of household, age of sheep, and season (SYSTAT 1992).

5.3 Results and discussion

5.3.1 Grazing management, livestock activity and travel

The resource-use maps generated from interviews of campesinos and observations conducted by Massy and Cáceres are depicted in Figure 5.1(a,b). These maps illustrate that: (1) Virtually all of the cantón receives some grazing during the year; (2) fallowed sites in the agricultural fields (CADES) are grazed intensively in rainy periods and lightly in dry periods; (3) transient, low and moderate levels of grazing dominate on rangeland sites (CANAPAS) in rainy periods, but this shifts to include a higher degree of moderate and high grazing pressure in dry periods; and (4) several rangeland sites immediately to the west of settlements and the agricultural fields are subjected to continuously heavy grazing year-round. These findings are consistent with perspectives previously generated in Chapter 3 (*Ecology and natural resources of San José Llanga*), namely, that grazing of fallow fields coincides with a time when annual forages are most abundant on these sites; conversely, that grazing of rangelands is lower in rainy seasons, which may also be related to localised flooding and muddy conditions of the fluvio-lacustrine plain; and a relatively small proportion of rangeland sites constitute "sacrifice zones" of impact, and appears to comprise locations where contemporary, grazing-induced changes in vegetation are most evident.

A more-detailed presentation of data collected by Massy and Cáceres is presented in Table 5.4; this breaks down site types further and therefore offers more resolution. The important summary points of Table 5.4 can be organised according to types of foraging sites as follows. For the agricultural lands there are two complementary patterns of use; peak use of fallow for grazing is relatively brief at the height of the rainy season and trails off thereafter; stubble on cropped fields is subsequently grazed from harvest through the middle of the dry season. Although there is always some low level of grazing on the alfalfa fields, grazing on these sites tends to increase during the transition from the end of the dry season into the early wet season (i.e., October through December). For the rangelands, salt-affected shrublands are only used on a transient basis for grazing throughout the year. Valuable patches of *Hordeum*, *Calamagrostis* and *Festuca/Hordeum* appear to be avoided to a large extent in rainy periods because of localised flooding; this effectively creates a situation where these plant communities become part of a *de facto* deferred grazing scheme with the highest levels of use occurring during dry periods when plant tissues are dormant and therefore less susceptible to damage. Two types of *Distichlis* sites are discriminated on the basis of proximity to settlements; one is a sacrifice zone while the other to the east typically receives only light use; a similar pattern also occurs for *Festuca* sites (Table 5.4).

Some results on seasonal use of various habitats by livestock for foraging from work by Victoria (1994) are depicted in Figure 5.2(a-c). These data

Table 5.4. *Spatial and temporal distribution of livestock grazing*[1] *throughout the Cantón of San José Llanga during 1992-3.* Source: Produced by Dr. H. Alzérreca from Massy and Cáceres (IBTA/SR-CRSP, unpublished data).

Grazed Site	Grazed material	Season												Features of grazed sites
		Wet				Dry								
		Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	
Crop lands	Crop Residues	n/a	M	L	L	M	H	H	H	M	M	M	L	Crop residue, regrowth & annuals
	Young Fallow	H	H	H	H	M	L	L	L	L	L	M	M	1-5 yr fallow-annuals & perennials
	Old Fallow	M	M	M	L	L	L	L	L	L	M	L	M	>6 yr fallow-shrubs & bunch grasses
Pasture	Alfalfa (subirrigated)	M	L	L	L	L	L	L	L	L	L	M	H	Roots under each of subsurface water
	Alfalfa (irrigated)	H	L	L	L	H	L	L	L	L	L	L	M	With surface saline water
Rangelands	*Anthobrium* spp. *Salicornia* spp.	P	P	P	P	P	P	P	P	P	P	P	P	Saline sites (soils & water)
	Hordeum muticum	L	–	–	–	M	M	H	H	H	H	H	M	Flooded during rainy season
	Distichlis humilis (1)	–	–	–	L	L	L	ML	ML	ML	L	L	--	Flooded and far from households
	Distichlis humilis (2)	CH	CH	CH	CH	CH	CH	CH	CH	CH	CH	CH	CH	Close to household - Sacrificed area sheep
	Calamagrostis curvula	L	–	–	L	L	M	M	H	H	H	H	M	Flooded during rainy season
	Festuca dolichophylla	CH	CH	CH	CH	CH	CH	CH	CH	CH	CH	CH	CH	Close to household - sacrificed area, cattle, sheep, burros
	Festuca dolichophylla *Hordeum muticum*	L	–	–	L	L	M	M	H	H	H	H	M	Flood during rainy season (short term)
	Anthobrium *Salicornia* *Distichlis* spp.	L	L	L	L	L	L	L	L	L	L	L	L	Not important for grazing

[1]Where grazing intensity is coded as: H= heavy; M= moderate; L= light; C= continuous; P= opportunistic grazing; – = flooded; n/a = not applicable

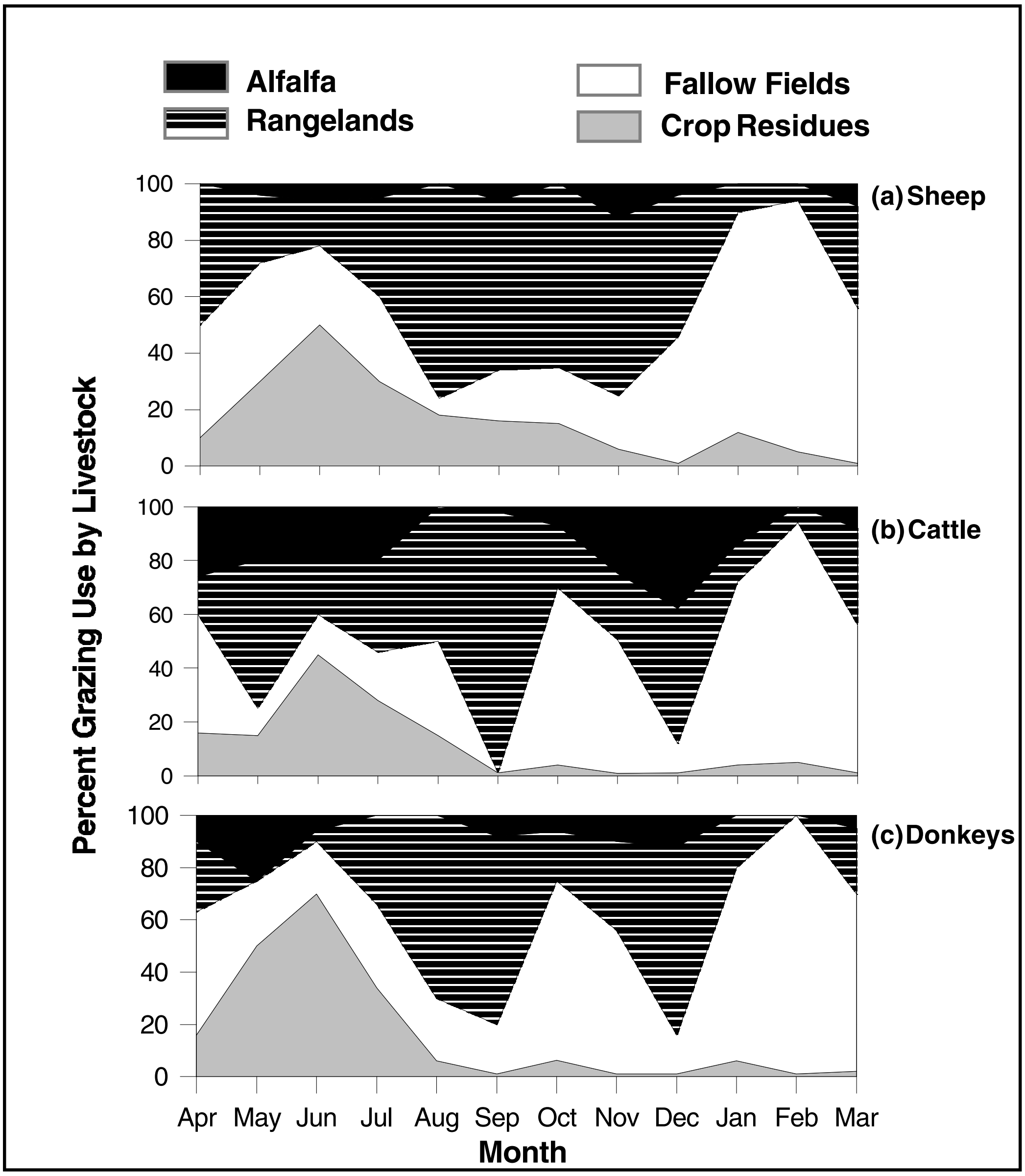


Figure 5.2 (a-c). *Percent of feeding time spent by livestock on four types of grazing sites throughout the Cantón of San José Llanga during 1992-3: (a) Sheep; (b) cattle; and (c) donkeys. Each monthly data point is based on 12 days of observation for each livestock species. The rainy period is approximately from November through March while the dry season occurs from April through October.* Source: Victoria (1994)

largely confirm the interview-based information from Massy and Cáceres (above). They also provide more insights, including the apparently higher relative use of alfalfa fields by cattle in the early dry-seaon, late dry-season and early rainy-season. In contrast to sheep, cattle and donkeys also appeared to make greater use of fallow fields in the late dry-season. The higher reliance of cattle on alfalfa fields makes sense given the higher value placed on cattle by the campesinos compared to sheep or donkeys, and it may also reflect a greater vulnerability of cattle to stresses imposed by the local environment. Victoria et al (1995, 17-19) report more detailed results with regards to use of fallow fields <5 years old versus those >6 years old; in general the younger fallow dominated by ephemeral forbs was exploited to the greatest degree by all livestock during the middle of the rainy season. In contrast, older fallow dominated by mature bunch grasses and *thola* shrubs was used relatively more by all livestock as the dry season progressed. Despite the appearance of meaningful variation in Figure 5.2(a-c), the results of an ANOVA applied to the data indicated that significant differences ($P<0.05$) across 30 paired species comparisons across five site types and two seasons occurred only twice, namely between cattle and sheep, and cattle and donkeys, during the wet season on alfalfa fields (Victoria et al 1995, 20).

Despite improvements over information generated by Massy and Cáceres, the work of Victoria (1994) was still conducted at a crude level of resolution. Observations by Flores (1995, 28-32), however, are useful to further fill gaps concerning detailed patterns of grazing management. Flores (1995) noted that each livestock species used rangeland patches (CANAPAS) in a defined sequence; cattle were always the first species to graze a site and they were followed by sheep and donkeys either separately or together. After a site was initially selected by herders, cattle would be staked out (usually at the end of a 4-m rope). Cattle were then allowed to consume all the forage they wanted; they usually fed on taller grasses (see below). When the cattle were done they were moved elsewhere and sheep and donkeys were brought in to finish-up the site. This highly managed system at SJL appears to superficially resemble natural "grazing successions" among native herbivores in East African savannas (Bell 1971) in which the larger, less selective grazers (zebra, buffalo) consume the highly fibrous vegetation and thus allow more efficient patch exploitation of highly nutritious short grasses and forbs sought by the smaller-bodied grazers (e.g., gazelles). There are many important differences, however, between this Andean system and that of East Africa that undermine such a comparison (Dr. D.L. Coppock, IBTA/SR-CRSP, personal observation). First and foremost, the vegetation at SJL is not comprised of a high density, structurally complex sward like that of East African savannahs; therefore cattle are not required to graze it so that sheep can exploit it later. The vegetation is layered at SJL and sheep do feed on the shorter grasses (below), but the taller grasses are not dense enough to obstruct access to the short grasses by sheep. It is more likely that cattle get grazing priority at SJL because of their high economic value to campesinos and greater vulnerability to stress in this harsh environment compared to sheep or donkeys (Dr. H. Alzérreca, rangeland ecologist, personal observation). Regardless of motivation, the prevalence of this form of "grazing succession" at SJL is a further testament to the generally high level of efficiency with which the campesinos exploit forage resources.

Victoria (1994) and Victoria et al (1995) also reported results for livestock behaviour and travel efforts; we will only highlight a few findings here. In terms of general daily activity patterns, all livestock left their corrals between 0900 and 1000 h in the morning and returned between 1700 and 1811 h in the evening. There were no differences ($P>0.05$) among species in daily time outside of corrals ($\bar{x}$= 8.2 h), but considered across species animals spent more time ($P<0.05$) outside of corrals in the rainy season ($\bar{x}$ = 9.0 h) compared to that in the dry season ($\bar{x}$ = 8.0 h). All species significantly varied ($P<0.05$) across the year in terms of percentage of uncorralled time spent foraging; donkeys (68%) were highest followed by sheep (66%) and cattle (59%). Considered across livestock species, animals spent a higher proportion of time feeding (66%) in the rainy season compared to the dry season (62%); significant increases for species due to season occurred for sheep (62 to 70%) and donkeys (65 to 72%). The second most time consuming activity was travel; across all livestock species there was slight, but significant ($P<0.05$) variation in terms of percent of uncorralled time spent traveling (from 24% for cattle to 27% for sheep). Travel time across all species declined slightly from the dry ($\bar{x}$ = 27%) to rainy periods ($\bar{x}$ = 24%). Cattle and sheep travelled from 6.1 to 8.1 km/day throughout the year. There were significant effects ($P<0.05$) of month on daily travel; cattle ranged from 5.5 to 9.7 km/day from the middle of the rainy season to later stages of the dry season, while sheep varied from 6.3 to 8.4 km/day along a roughly similar time frame (Victoria et al 1995, 22).

There are relatively few comparative data for behaviour and travel of livestock in indigenous rangeland systems. The average foraging time of 5.5 h/head/day for livestock at SJL calculated throughout the year is similar, but slightly lower, than figures reported for African pastoral systems where nightly corralling is practised, but is only 52% of the 10.5 h/head/day average reported for temperate and subtropical systems where fenced pastures allow night feeding (Coppock et al 1988). Average overall travel time (2.2 h/head/day) and travel distance (7.4 km/head/day) observed at SJL are considerably lower than figures reported for pastoral cattle and small ruminants in arid Africa or even Australia (i.e., up to 3.4 h/head/day and 8 to 15 km/head/day). Travel time and distance travelled for livestock in temperate and subtropical systems having fenced pastures and water development, however, are much lower at about 1hr/head/day to travel 5 km/head/day (Coppock et al 1988). Victoria (1994) and Victoria et al (1995) recommended that range improvements in vegetation and water development be considered to mitigate what they viewed as excessive losses of energy and time to livestock travel. In rangeland systems, dry seasons can be times of increased or decreased foraging efforts of livestock relative to that in rainy seasons. Time and distance for foraging can increase in dry seasons, for example, if diminishing forage and water resources are widely scattered (Coppock et al 1988). In addition, once a threshold of search time is exceeded, however, foraging time can then start to decline and energy is conserved (Arnold and Dudzinsky 1978). Despite the observation that livestock of SJL exhibited generally high efforts for travel and had fewer hours available for feeding compared to livestock in more-developed systems, it is notable that temporal shifts in livestock activity budgets and travel were relatively minor. Indeed, the general similarity in foraging time and travel throughout the year is, in part, a reflection of efficient management by the campesinos which included active herding and use of deferred grazing in many cases (see results below pertaining to houshold grazing management).

Norton (1994, 7-10) is cited here for his summary of the analysis of grazing pressure and animal performance at a household level of resolution conducted by Ramos (1995); results are also reported in Ramos et al (1995). Examination of daily "grazing trajectories" of family flocks revealed that resource endowment affects resource use; this was best illustrated by contrasting a "land-poor" household with a "land-wealthy" household [review Tables 5.1 and 5.2 and see Figure 5.3 (a,b)]. The sheep owned by the land-poor household relied on grazing in poor-quality, older fallow fields for most of the nine-month study period. This occurred because such fields are under rules of free access; the sparse cover of desirable forage required highly skilled herding and large amounts of walking to enable sheep to efficiently locate the best patches of forage. By February and March, however, the flock had to walk more each day to find grazing and used some of the younger fallow fields (Figure 5.3a). By June and August sheep were taken to feed on cultivated alfalfa fields and distant patches of *Hordeum muticum*. In contrast, the land-wealthy family initially grazed their flock more on rangeland sites and the higher quality, younger fallow fields with less daily time devoted to walking (Figure 5.3b). By June and August the flock was also taken to feed on cultivated alfalfa fields. The distinct strategies followed by these two households illustrate how different households utilise available resources to seize opportunities and compensate for limitations imposed by things such as shortages of labour or land. The land-poor family is able to maintain a large flock (i.e., 85 head) despite that it owns little land; it does so by making intensive use of communal (or pseudo-communal) resources such as the older fallow fields. Effective use is further enhanced by the household having two, highly skilled teen-aged herders. In contrast, the land-wealthy family opts to exploit high quality range nearer to the homestead; in part this compensates for young, less experienced herders. The land-wealthy family is thus labour-poor, and adjusts by keeping a relatively smaller flock (i.e., 48 head).

The ANOVA for the daily grazing index (I_{fd}) over the nine months of the study revealed that the value of the index was not significantly affected (P>0.05) by household, but there were significant effects of time (P<0.05), namely, index values tended to be higher later in the season (August) than earlier in the season (December/January). At first glance these results appear to contravene common sense, but closer scrutiny reveals that this result could stem from rational grazing strategies (Figure 5.4). December and January of 1993-4 were characterised by torrential rains and flooding at SJL. This restricted grazing to well-drained, higher elevation areas (primarily fallow fields and/or gramadales, depending on household land resources). Mud and rain also forced families to graze flocks closer to homesteads. The surprising increase in the I_{fd} index that occurred in August was associated with grazing crop residues, dried alfalfa fields and distant patches of range that were out of reach during the rainy season due to flooding and muddy conditions. Such patches of range were essentially under deferred use.

The wisdom of the household grazing strategies is reflected by flock performance (Figures 5.5 and 5.6). The average weight gain curve for young lambs closely followed the grazing index I_{fd}. In spite of the relatively low value of grazing in January,

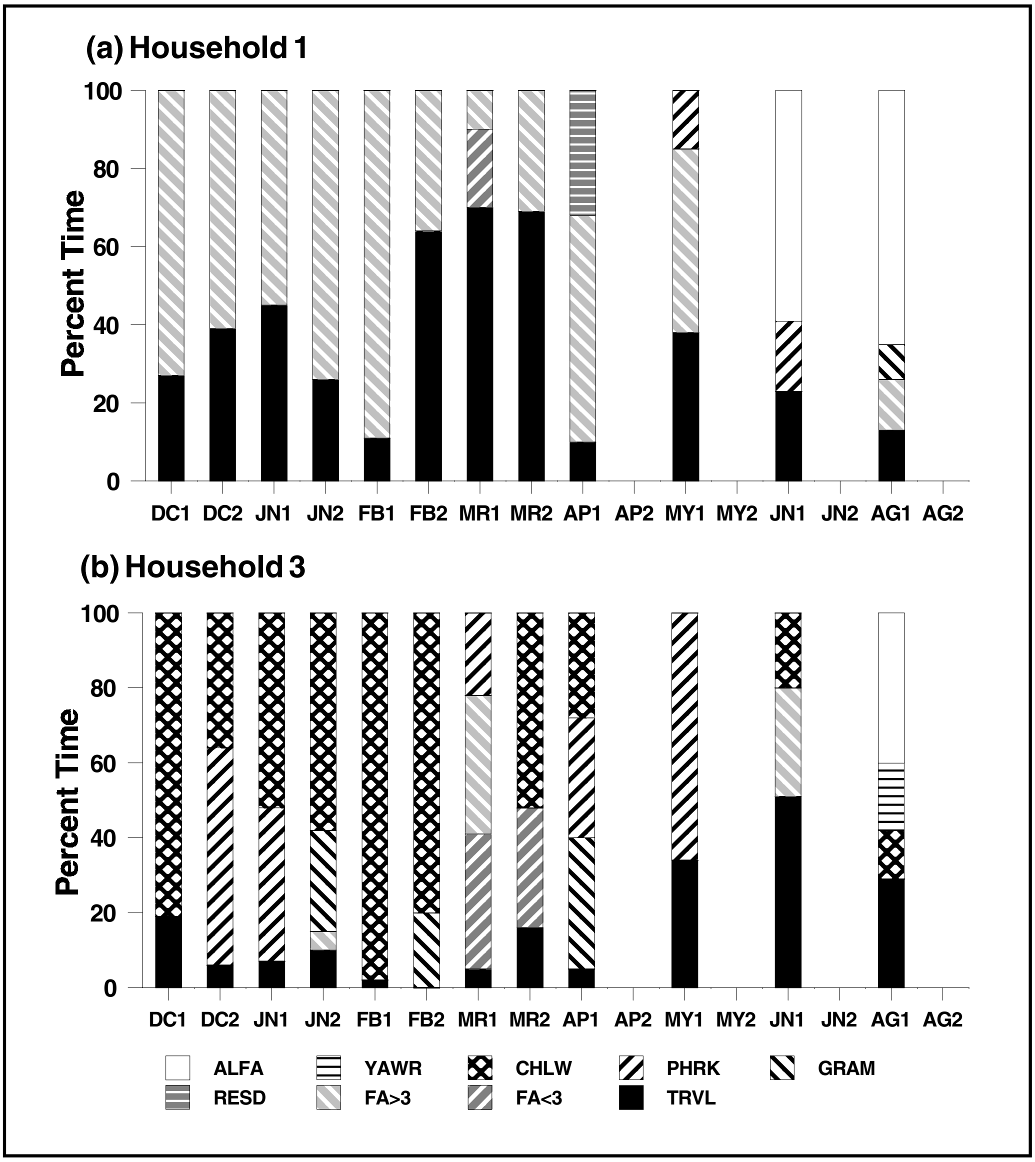


Figure 5.3 (a,b). *Grazing strategies (percent of time) for sheep flocks held by: (a) a land-limited family, and (b) a family well-endowed with land from December, 1993, through August, 1994. Activities are coded as TRVL (traveling) or feeding on: FA<3 (fallow less than 3 y old); FA>3 (fallow more than 3 y old); RESD (crop residues); ALFA (alfalfa fields); rangeland sites including GRAM (*gramadales *dominated by* Distichlis/ Muhlenbergia *spp.); PHRK (p'horkeales dominated by* Calamagrostis *sp.); CHLW (*Chilliwares *dominated by* Festuca *spp.); and YAWR (*Yawarales *dominated by* Hordeum *sp.) See text for details on various sites.*
Source: Adapted from Norton (1994)

nutritional requirements were apparently met. Results from grazing trajectories, analysis of the grazing index dynamics and flock performance all lead to the conclusion that the grazing strategies followed by agropastoralists at SJL are rational and efficient. Thus, there is probably little to be gained from modification of grazing management per se (Section 3.3.4.4: *Sustainability of the fluvio-lacustrine plains*). This study also demonstrates that labour availability may limit full utilisation of a production unit's land resources. Unused land becomes available for use by other families (Section 4.3.4: *Non-market factors in resource access*).

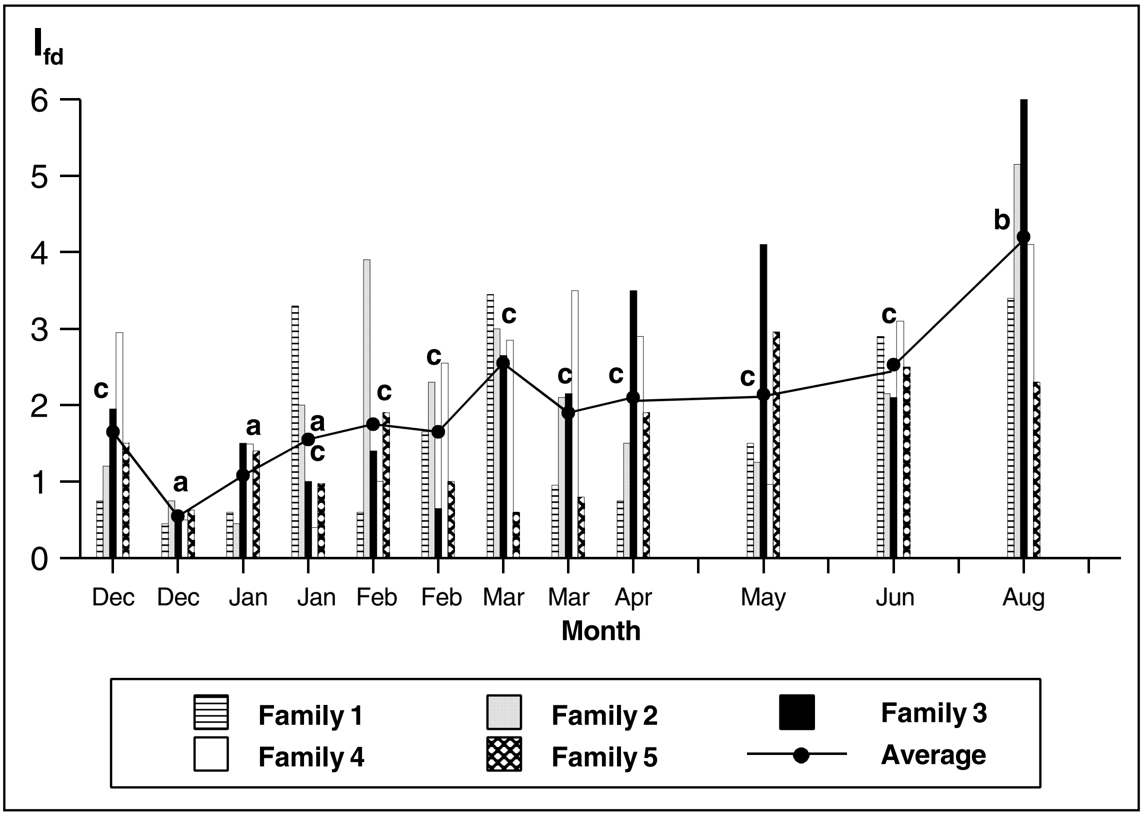


Figure 5.4. *Effects of household and month on a daily grazing index (I_{fd}) calculated for herded sheep flocks from December, 1993, through August, 1994, at San José Llanga. The grazing index is a cumulative measure of the quantity and quality of forage patches encountered by a flock of a given household throughout a grazing day.* Source: Adapted from Norton (1994)

5.3.2 Diet dynamics

5.3.2.1 Diet composition

Livestock diet composition according to forage class (i.e., forbs, grasses or shrubs) is shown in Table 5.5. These data illustrate that all three livestock species consumed large proportions of grass or forb material; shrub browse, however, was only rarely used by sheep despite its general abundance in many sites. Regardless of livestock species, consumption of forbs was associated with use of fallow fields while relatively more grass was consumed on rangeland sites. Since livestock tended to use fallow fields more during the rainy season, use of forbs was higher ($P<0.05$) in the rainy season compared to the dry season for all livestock species (Cáceres 1994, 60).

Lists of forage species consumed by livestock are provided in Cáceres (1994, 61-8); only a few summary points will be made here. As will be noted, dozens of plant species were utilised by sheep, cattle and donkeys at SJL throughout the year; however, relatively few species were dietary staples. In addition it was apparent that fallow fields, not range sites, were the major contributors in providing high levels of forage biodiversity to the system; this largely came in the form of annual forbs (consumed mostly by sheep) which colonised fields that had been fallowed for shorter periods of time.

On the fallow fields sheep, cattle and donkeys consumed 22, 13 and 14 identified forage species, respectively (Cáceres 1994). Sheep ate at least 15 forb species, five grass species and two shrub species while in contrast cattle and donkeys tended to consume relatively fewer forbs and more grasses. Forages of particular importance on fallow fields for all livestock included the forbs *Chenopodium petiolare, Erodium cicutarium, Heterosperma tenuisecta* and *Tarasa tenella.* Important grasses were *Bouteloua simplex* and *Festuca orthophylla.* The only shrub used to any

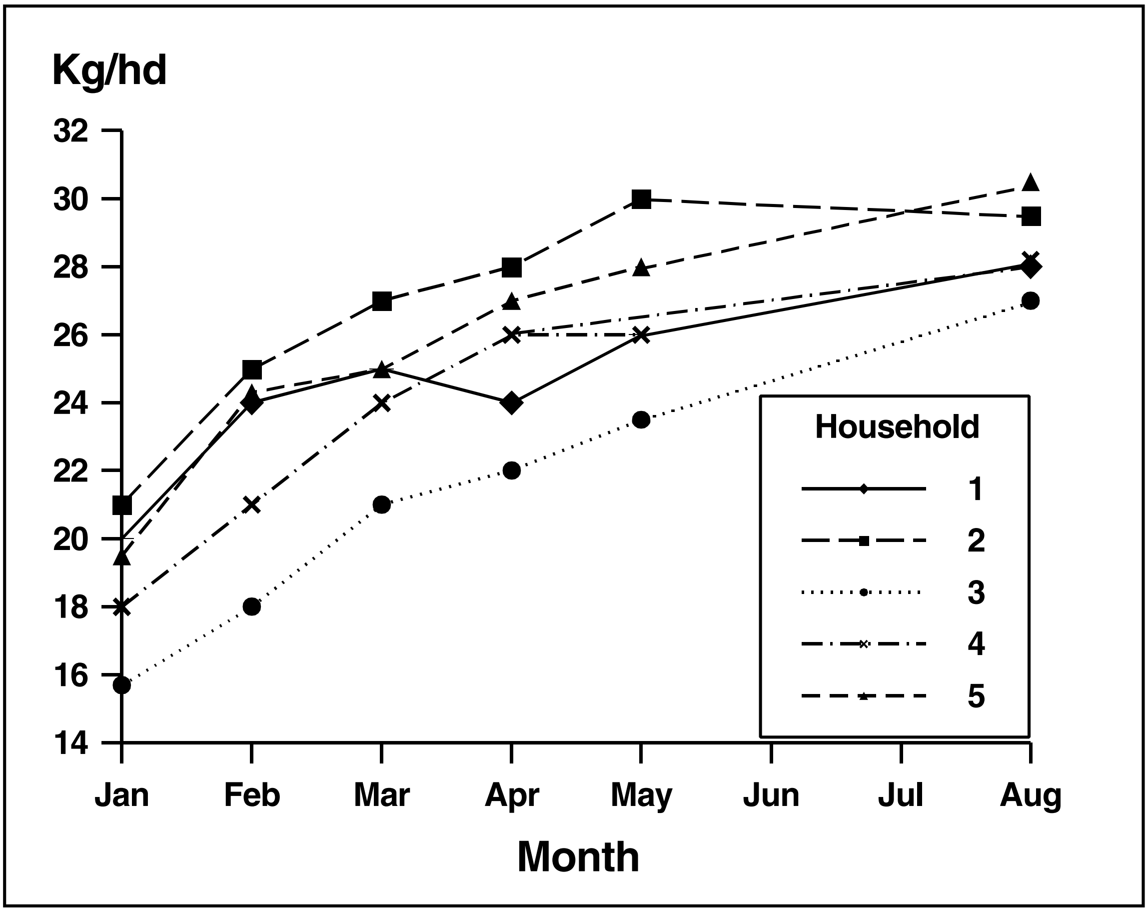


Figure 5.5. *Monthly average liveweights of lambs reared by five households from January to August, 1994, at San José Llanga. Each data point is the mean of five animals.* Source: Dr. J. de Queiroz et al (IBTA/SR-CRSP, unpublished data)

significant degree was *P. lepidophylla,* but this was only in a couple of instances during the dry season.

On rangeland sites sheep, cattle and donkeys consumed seven, four and five identified forage species, respectively. Sheep ate at least one forb species and six grass species. Cattle and donkeys consumed only grasses. Forages of particular importance on the rangelands across all livestock species included grasses such as *C. curvula, Hordeum muticum, Muhlenbergia fastigiata, Festuca dolichophylla* and *Distichlis humilis*. In addition, sheep consumed forbs of the genus *Chenopodium*.

The canonical discriminant analysis concerning dietary overlap among livestock was comprised of two major axes (Figure 5.7). On one axis there was general level of discrimination among diets obtained from agricultural fields (CADES) versus those obtained from range sites (CANAPAS), regardless of livestock species. On another axis sheep diets were distinct from those of cattle or donkeys on either CADES or CANAPAS. This analysis, in combination with work previously reported, is interpreted to indicate that while the livestock species use many range sites in common, some segregation occurs as a result of dietary preferences. Sheep are most complementary to donkeys or cattle because sheep are able to select short grasses (*Distichlis humilis*), forbs and occassional shrub browse; donkeys and cattle are somewhat restricted to feed on relatively more abundant mid- and tall-grasses. Such observations are consistent with theory (see Section 5.2.2: *Methods: Seasonal dynamics of livestock diets)* which predicts that smaller-bodied ruminants having smaller mouths and more mobile lips (i.e., sheep) will utilise short grasses and

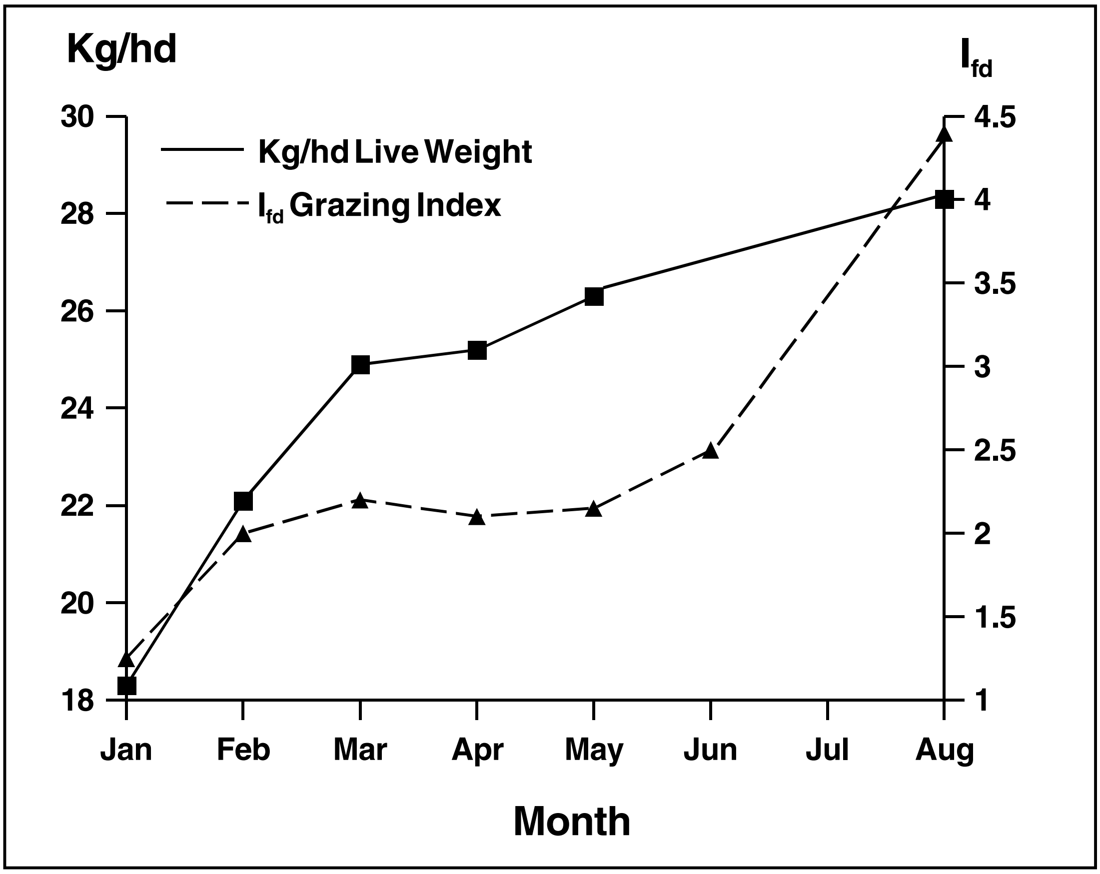


Figure 5.6. *Monthly time series of mean liveweights of lambs and the daily grazing index (I_{fd}) for sheep flocks from December, 1993, through August, 1994. Each data point for lamb weights is the mean of 25 animals. The grazing index is a cumulative measure of the quantity and quality of forage patches encountered by a flock of a given household throughout a grazing day. Each data point for the grazing index is the mean of five values.* Source: Norton (1994)

rare forbs to a higher degree than larger herbivores, given a spectrum of food choices. In other multi-species pastoral systems of sub-Saharan Africa, different types of livestock have been observed to utilise distinct habitats as well as distinct types of forage (Coppock et al 1986a). Compared to some of these African examples the spatial options for resource use at SJL are more restricted, however, and the norm is for different livestock species to use the same sites. Livestock use the same sites, but this occurs at different times in a form of a "grazing succession" where cattle get priority over sheep and donkeys (Flores 1995).

While this information can be interpreted to suggest that cattle and donkeys would tend to compete more with each other for food rather than with sheep, this can only be validated by observing what happens in a drought year when stocking rates are high and forage resources restricted. If no animal offtake occurred and livestock populations were allowed to behave according to natural ecological dynamics, the prediction would be that cattle and donkeys would inflict more negative effects on each other through inter-specific forage competition, while sheep would remain more immune from inter-specific forage competition for a longer period of time. Marketing and other influences of people greatly complicate this picture, however. When droughts occur one reaction is for households at SJL to sell sheep in high numbers to avoid wastage losses from mortality (Dr. D.L. Coppock, IBTA/SR-CRSP, personal observation); this reduces the spectre for forage competition involving sheep because animal numbers are brought in line with a reduced forage supply. In

Table 5.5. *Percentages of forbs, grasses and shrub materials in diets of grazing sheep, cattle and donkeys during two seasons (wet and dry) at San José Llanga during 1992-3*[1]. Source: Cáceres (1994, 60).

	Sheep		Cattle		Donkeys	
	Wet	Dry	Wet	Dry	Wet	Dry
Forbs	51.0b	42.1a	41.0b	19.6a	38.6b	12.4a
Grasses	46.6a	52.9b	59.0a	80.4b	59.3a	87.5b
Shrubs	2.4a	4.9b	0.0a	0.0a	2.1a	0.1a

[1]Data are based on a total of 264 000 observed bites overall. Each tabulated percentage is calculated based on observations of 50 animals (sheep), 15 animals (cattle) and 15 animals (donkeys). Entries in the same column accompanied by different letters (a, b) were significantly different at P<0.05 according to Fischer's LSD test.

contrast to sheep flock management, when drought occurs the people also react by subsidising valuable cattle with imported feed and increased management inputs (Chapter 6: *Household socioeconomic diversity and coping response to a drought year at San José Llanga*). In sum, while the issue of livestock diet overlap (and potential for inter-specific competition) has merit, the complementarity of sheep versus cattle or donkeys mostly indicates that resource use is more efficient compared to a situation where either sheep or cattle, in particular, were absent. Having both sheep and cattle allows housholds to take greater advantage of existing ecological options.

A summary of some key results from Flores (1995) concerning diets and feeding behaviour of sheep and inter-specific diet overlap is provided in Table 5.6. The first points to emphasise are the similarities in DM intake and foraging time for sheep across seasonal observation periods and grazing units. Although caution is warranted in data interpretation because bite-counts can be imprecise for estimating DM intake, the results appear to indicate that the campesinos are able to maintain a relatively constant level of DM intake for sheep through grazing management. This takes the form of active herding to promote continual encounters of the flock with palatable vegetation, and strategic use of deferred grazing (Norton 1994; Flores 1995). The second summary point relates to the likelihood of diet overlap among the three livestock species. While during the wet season the likelihood of inter-specific diet overlap was low (i.e., an index value <50), during dry periods the prospects for inter-specific competition increased on other sites and patterns became more complex. The greatest likelihood for diet overlap occurred among all three species on *C. curvula* patches in the late-dry season; sheep and donkeys had the highest degree of inter-specific dietary overlap on *H. muticum* range (Table 5.6). These results offer some qualification for results of Cáceres (above). Results of Flores (1995) are interpreted to suggest that while the broad conclusions of Cáceres (1994) may be valid when considering sites aggregated as CADES (agricultural fields) or CANAPAS (rangelands), at the level of specific plant communities patterns of diet overlap may change. For example, the conclusion that donkeys and sheep have highly complementary diets on CANAPAS may be valid overall, but this may not be true at the finer scale of *C. curvula* or *H. muticum* patches, which are two of dozens of plant communities on the rangelands (Chapter 3: *Ecology and natural resources of San José Llanga*). We feel the DM intake results of Flores (1995) shown in Table 5.6 may be some of his most important findings. In concert with other results concerning the common use of inter-specific grazing succession (Flores 1995), the general complementarity of sheep and cattle diets (Cáceres 1994), and the ability of households to maintain similar (and adequate) rates of weight

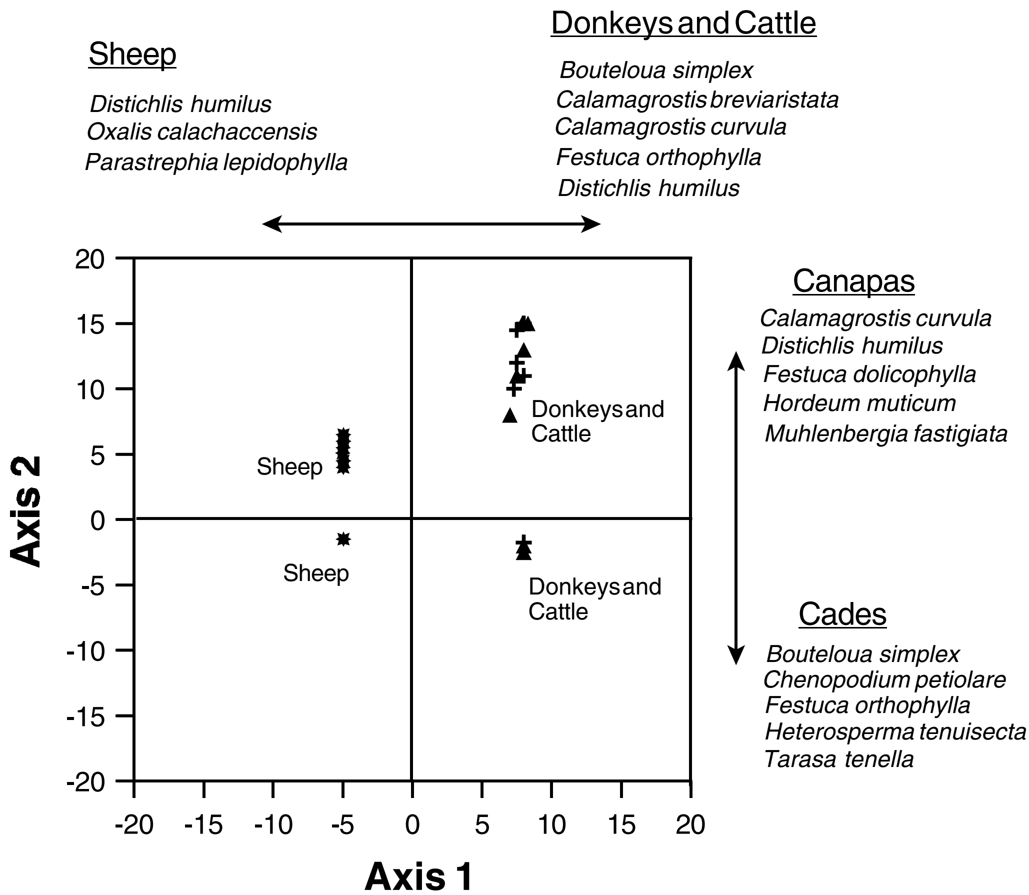


Figure 5.7. *Canonical discriminant analysis for grazed diets of sheep, cattle and donkeys in the Cantón of San José Llanga throughout the year of 1992-3. The analysis was based on 264 000 observed bites of forages.* Source: Cáceres (1994, 51)

gain for lambs despite inequities in land access and herding labour, all point to a highly efficient system for exploitation of grazing resources at SJL.

5.3.2.2 Diet quality

Nutritional features for the three forage classes are depicted in Table 5.7 . These results are typical of forages common to rangeland ecosystems (Coppock et al 1987). The entries in Table 5.7 were calculated across seasons and livestock species, but significant variability among forage classes was still evident. Forbs typically had a higher nutritional value than grasses. Compared to grasses, forbs were 40% higher in protein content and up to three-times higher in mineral content. Shrubs tended to have nutritional characteristics intermediate between those of grasses and forbs. Previously in this chapter it was noted that forbs are a relatively ephemeral grazing resource at SJL. Most forbs occur on fallow fields during the wet season. Despite this transient appearance in the production system, these data suggest that the forbs have a particularly high value for livestock nutrition.

Nutritional features of livestock diets according to the two main seasons are depicted in Table 5.8. These results also are consistent with previously observed patterns in rangeland environments (Coppock et al 1987). Results were calculated across forage classes and livestock species, but significant variability was still evident. Season had a pervasive effect on all nutritional features. Compared to forages selected in the dry season, those selected in the wet season were about 80% higher in protein content and up to three-times higher in mineral content. On a rela-

Table 5.6. *Dry-matter (DM) intake (g/hd/day)*[1]*, feeding time (hr)*[2] *and diet similarity values*[3] *for sheep using four rangeland plant communities during three seasons*[4] *in San José Llanga during 1992-3.* Source: Adapted by Dr. H. Alzérreca from Flores (1995).

Plant community	Season	Intake	Feeding time	Similarity Index		
				Sheep vs cattle	Sheep vs donkeys	Cattle vs donkeys
Calamagrostis curvula	dry	470 a[4]	4.4 a	43	45	64
	late dry	421 a	4.9 a	83	79	92
Hordeum muticum	dry	553 a	6.7 b	48	81	34
	late dry	370 a	7.1 b	28	74	16
Parastrephia lepidophylla	wet	465 a	6.9 a	20	36	49
Parastrephia lepidophylla Festuca orthophylla	wet	363 a	7.3 a	22	45	46

[1]Where intake was estimated using bite counts and estimates of bite weights.

[2]Feeding time was measured using a stopwatch.

[3]An index was used to evaluate diet similarity. The index is $IS_{jk} = 100 - \frac{\sum_{i=1}^{n} |X_{ij} - X_{ik}|}{\sum_{i=1}^{n} (X_{ij} + X_{ik})}$, where IS_{jk} is the percentage similarity in diets among herbivores j and k, and ranges from 0 to 100%, n is the number of forage species in the diet for herbivores j and k, and X_{ij} and X_{ik} are the proportions for forage species in the diets of herbivores j and k, respectively. Values >50 were interpreted to indicate potential for forage competition (Flores 1995, 8-9).

[4]Entries in the same column accompanied by different letters (a, b) were significantly different at $P<0.05$ according to Tukey's HSD criterion.

Table 5.7. *Nutritional features (DM basis) for grass, forb and shrub classes of forage selected by grazing livestock on* cades *(agricultural) sites at San José Llanga throughout 1992-3.* Source: Lopéz (1994, 59).

Forage Class	Nutritional feature[1]						
	CP	DP	ADF	TDN	P	K	Ca
Grasses	7.1 a[2]	4.5 a	39.9 a	60.0 a	0.17 a	0.85 a	0.40 a
Shrubs	8.3 ab	5.2 ab	32.6 a	66.7 b	0.20 ab	0.97 a	0.74 b
Forbs	10.0 b	6.4 b	49.6 a	58.3 a	0.23 b	2.03 b	1.2 c

[1]Where CP is crude protein, DP is digestible protein, ADF is acid detergent fibre, TDN is total digestible nutrients, P is phosphorus, K is potassium and Ca is calcium.

[2]Entries in the same column accompanied by different letters (a, b, c) were significantly different at P<0.05 according to Fischer's LSD test.

tive basis, fibre characteristics did not show such pronounced effects of season.

Figures 5.8 and 5.9 depict seasonal diet CP dynamics for the three livestock species. Results are segregated according to whether livestock used agricultural lands (CADES) or rangelands (CANAPAS) for grazing. The CP dynamics were selected as a general indicator of diet quality. Dynamics for many other dietary nutritional components are presented in Lopéz (1994) and Flores (1995) for readers interested in those details. The general picture provided by Figures 5.8 and 5.9 illustrates two patterns: (1) That sheep tended to select diets higher in CP content compared to that of the other livestock species, regardless of whether grazing occurred on the CADES or CANAPAS; and (2) that all three livestock species were below the 7% CP threshold only during the very late stages of the dry season in 1992-3; this was typically September and October. The fact that the sheep of SJL can select higher quality diets than cattle or donkeys is consistent with the theory reviewed in Section 5.2.2: *Seasonal dynamics of livestock diets*. In general, the fluctuating pattern of diet quality is also typical for livestock managed under traditional pastoral management in seasonal rangeland ecosystems (Coppock et al 1986b).

As mentioned in the methods, the CP content of livestock diets is only a very general indicator of diet quality. In the absence of intake data the dietary CP tells us little about animal productivity or nutritional status per se. Diet quality dynamics need to be augmented with data on condition score or other performance aspects to give a full picture. The CP data do, however, give some indication of possible nutritional risk for livestock. Therefore, what is striking about the data in Figures 5.8 and 5.9 is that at least in terms of diet quality, the livestock at SJL seem to be doing relatively well given the apparent harshness of the production environment. There are several possible reasons why this is the case. Elsewhere in this chapter it has been shown that active herding results in a very efficient use of the environment at SJL. Sheep condition is effectively maintained by active herding despite major declines in forage quantity and quality that occur in the dry season. It has also been shown that campesino households make strategic use of key resources like alfalfa fields to provide a periodic boost for animal nutrition; this commonly occurs in the dry season. Finally, landscape factors are probably also important in the ability of grazing livestock to maintain diet quality. This is related to the fact that many range communities on the fluvio-lacustrine plains occur on sites with high water tables (Section 3.3.2.1: *Geomorphic units*). While perennial grasses on such sites superficially appear to have become senescent early in the dry season, close inspection of large tussocks and prostrate patches often reveals small quantities of green leaves (Dr. D. L. Coppock,

Table 5.8. *Nutritional features (DM basis) from grazed diets of three livestock species (sheep, cattle and donkeys) during two seasons (wet and dry) at San José Llanga during 1992-3.* Source: Lopéz (1994, 57).

	Nutritional Features[1]:						
Season	CP	DP	ADF	TDN	P	K	Ca
Dry	5.6 a[2]	3.8 a	41.8 b	55.7 a	0.14 a	0.79 a	0.66 a
Wet	10.1 b	6.7 b	36.8 a	59.7 b	0.26 b	2.40 b	0.98 b

[1]Where CP is crude protein, DP is digestible protein, ADF is acid detergent fibre, TDN is total digestible nutrients, P is phosphorus, K is potassium and Ca is calcium.

[2]Entries in the same column accompanied by different letters (a, b) were significantly different at P<0.05 according to Fischer's LSD test.

IBTA/SR-CRSP, personal observation). The persistence of green tissues well into the dry season may be related to the ability of these plants to tap ground water. Livestock (and particularly Criollo sheep) are adept at finding such forage regardless of how bleak the surroundings appear (Dr. D. L. Coppock, IBTA/SR-CRSP, personal observation).

5.3.3 Management and productivity of sheep

Detailed descriptions of sheep management can be found in Villanueva (1995). Summaries of data analyses can also be found in Villanueva et al (1996) and Bryant (1994). Only highlights of work by Villanueva will be presented here. In general, traditional practices for managing sheep have been passed down over many generations at SJL (Plate 5.2a-c). The practices therefore have survived the "test of time" and probably are well-adapted to ecological, economic and social conditions at SJL (Villanueva 1995).

As previously mentioned, preliminary surveys indicated that the Cantón of SJL should be stratified into six zones for better depiction of livestock production systems. These zones were represented by six settlements (Table 5.3). Descriptions of the sex ratios and breed composition for sheep populations for a sample of sheep flocks across the six settlements during April, 1992, is provided in Villanueva (1995, 36). To summarise here, males overall comprised 22% of the surveyed sheep population of 397 head, although the vast majority of these males were immatures. Forty-six percent of all sheep were <12 months old, while 27% were 1 to 3 y old and another 27% were 3 to 5 y old. The native Criollo breed constituted 60% of all sheep, followed by "improved" crosses of Criollo with Targhee or Corriedale (26% of all sheep) and highly "improved" crosses (14% of all sheep). "Improved" meant a 50% cross while "highly improved" meant a >50% cross.

Descriptions of sheep flocks and land and forage resources held by the six households in the Villanueva study are given in Table 5.9. The total flock size averaged 94 head, with an average of 38 bred ewes, 3 breeding rams, 8 un-bred females (typically yearlings) and 44 lambs. The average ram:ewe ratio was thus about 1:15. There was also an average of five cattle per household. On average, the breed composition for flocks based on the 94 head was 48 Criollo, 16 of the 50% crosses and 30 of the >50% crosses. Breed composition varied markedly, however, from 95% to 5% Criollo, with corresponding shifts in the representation of improved breeds (Table 5.9). The total land resources controlled per household averaged about 38 ha, and this was dominated by annually cropped fields (5.3 ha), fallowed fields (15.0 ha), cultivated forage (alfalfa and barley, 4.9 ha) and higher-value rangeland that tended to be under *de facto* private

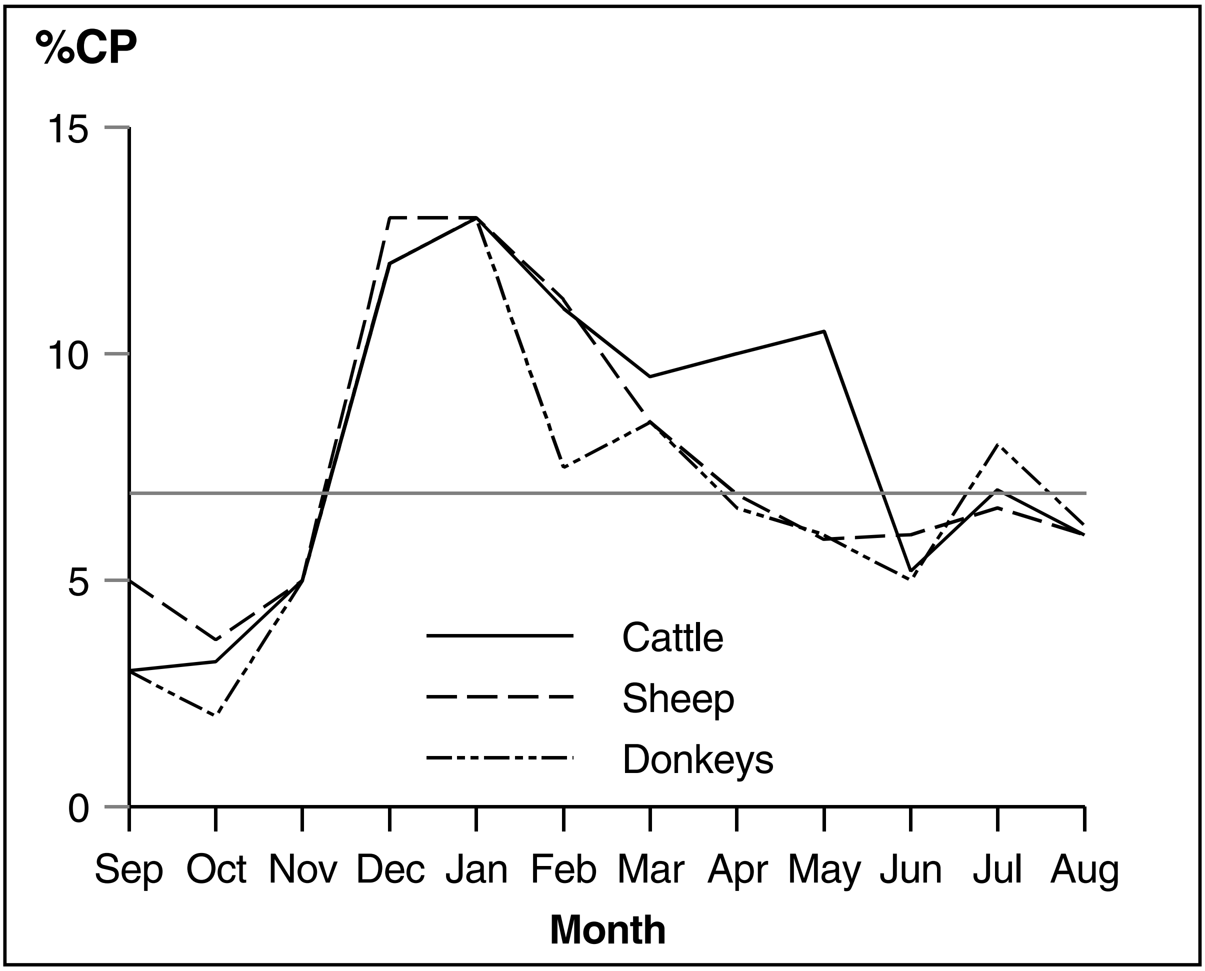


Figure 5.8. *Dietary crude protein (CP) dynamics for sheep, cattle and donkeys grazing five* cades *(agricultural) sites throughout 1992-3. Values are reported on a DM basis.* Source: Lopéz (1994, 38)

access (12.8 ha). Lower-value communal rangeland was not tabulated because it could not be easily quantified.

It is apparent from the highly variable household-level data in Table 5.9 that average flock composition or average land holdings are not very informative. Figure 5.10(a-f) depicts the distribution of land resources for the six settlements along with comparative data on sheep flock size and breed composition. This information illustrates a key hypothesis from Villanueva's work, namely that access to an improved forage resource base (especially alfalfa and barley) influences the degree to which improved sheep can be managed in household flocks. As will be shown, improved crossbred sheep are more productive than the native Criollo and consequently have higher nutritional requirements. Strategic use of grazing resources such as alfalfa fields probably provides a key nutritional boost for sheep in the later stages of the dry season. The data presented in Table 5.9 and Figure 5.10(a-f) suggested that the six households could be representative of three production subsystems (Bryant 1995). For example, while their landholdings lie at the extremes of the overall range in absolute terms, households in the settlements of *Espíritu Willq'i* and *Inkamaya* had a small percentage of improved, crossbred ewes and a relatively large percentage of landholdings in the form of native rangeland. Households in *Callunimaya* and *T'olatia*, in contrast, had a higher amount of their landholdings in crops and alfalfa, and maintained a high percentage of improved ewes. Households in *Barrio* and *Savilani* were distinguished by

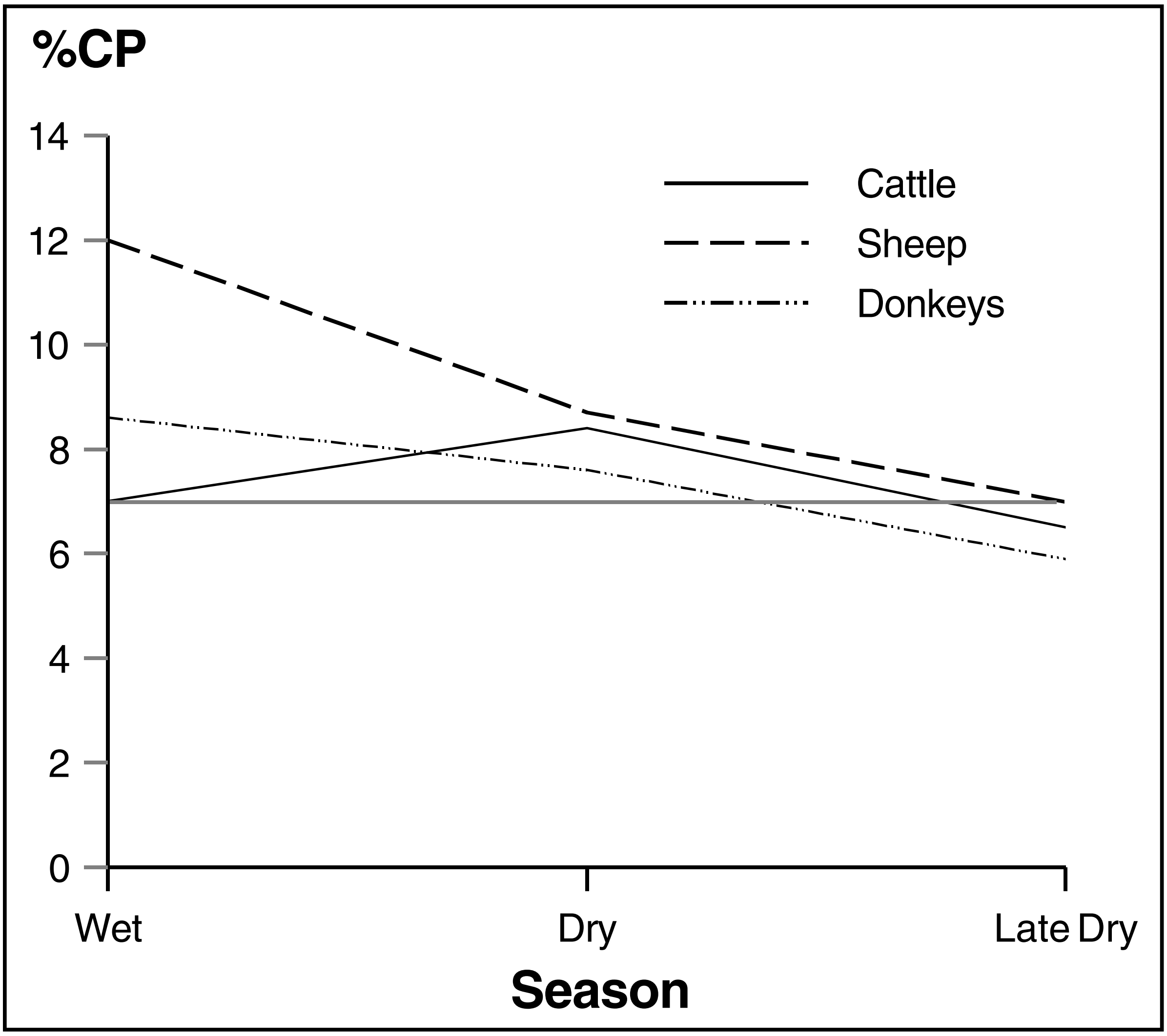


Figure 5.9. *Dietary crude protein (CP) dynamics for sheep, cattle and donkeys grazing four* canapas *(range) sites throughout 1992-3. Values are reported on a DM basis.* Source: Adapted from tabular data in Flores (1995, 114)

having the highest percentage of improved ewes and the highest percentage of their landholdings in cultivated forage. Access to forage resources was related to the proximity of households (settlements) to certain geomorphic units. Settlements such as *Callunimaya* and *Savilani* were closer to geomorphic units such as the alluvial fan, which offered the opportunity to produce high-value forages (i.e., alfalfa, barley) under irrigation with fresh water from the seasonal *Khora Jahuíra* River (see Section 3.3.2.1: *Geomorphic units*). In contrast, settlements such as *Callunimaya* were located further from the alluvial terrace. Market access may also play a role in encouraging changes in animal production systems. For example, even though the six settlements were only separated by a maximum distance of 6 km, the northernmost settlement was 6 km closer to Patacamaya town and this probably facilitated market access.

Many general aspects of sheep ownership and management were similar among the six households studied by Villanueva. For example, in addition to managing their own sheep, each of the six households typically held sheep that were actually owned by someone outside of the immediate family. These "absentee" owners varied from

a

b

c

Plate 5.2 (a-c). *Sheep management at San José Llanga: (a) Black-faced Criollo breed; (b) Criollo x Corriedale crossbred animals; and (c) milking a Criollo x Corriedale cross-bred animal. Improved crosses were more productive than Criollo animals in terms of wool and milk production, lamb growth rates, and fertility.* Photographs: Christian Jetté

resident neighbours to people who had emigrated out of SJL for varied lengths of time. Such emigrants constituted a significant portion of the total population of SJL. Households which agreed to watch over the livestock of others were typically rewarded by sharing in productive returns such as newborn young (Section 4.3.4: *Non-market factors in resource access*).

A summary of the occurrence of sheep management practices among the six households is found in Table 5.10. Some management practices, or omission of practices, were similar for all households. For example, none of the households attempted to control sheep breeding. In addition, castration was not practiced, nutritional supplementation did not occur and lambs were never forcibly weaned by flock managers. All households, however, consistently marked sheep for individual identification. While all households made use of dipping baths to help control external parasites, none engaged in routine vaccination against prevalent diseases. Household variation in management was observed in terms of the composition of sheep breeds maintained, use of tail docking and in the percentage of sheep sheared and month of sheep shearing (Table 5.10). Among the households which practiced tail-docking there was ample variation in terms of the season and lamb age at which tail docking occurred. There was also variation in terms of the weaning age of lambs; for improved and highly improved animals the range was 81 and 65 days, respectively, across the six households.

Although "modern" sheep management practices appear lacking in several respects, the campesinos of SJL devoted much time and attention to the day-to-day well-being of their sheep. High labour inputs and wise application of indigenous knowledge were probably important contributors to low rates of mortality for lambs and adult sheep at SJL in 1992-3 (Villanueva 1995, 57). Out of 266 lambs born only 14 died, which was an average of two per household and an overall death rate of 5.2%. The major cause of lamb mortality was complications from excessive diarrhea. Lambs tended to die when seasonal climate or forage conditions were more extreme-- about half of lamb deaths occurred in the wet season and the other half in the dry season. Highly improved lambs appeared the most vulnerable. Sixty-four percent (9 of 14) of lamb mortalities were highly improved animals, which was roughly twice the proportion in the local population. For a sample of 297 adult sheep, only five died during 1992-3,

Table 5.9. *Breakdown of sheep flocks according to sex, age, breed[1] and land resources[2] for one household in each of six settlements at San José Llanga during 1992-3.* Source: Adapted from Villanueva (1995, 40).

		Settlement					
		Espíritu Willq'i	*Inkamaya*	*Calluni-maya*	*Barrio*	*Savilani*	*T'olatia*
Total Sheep (no.)		58	154	102	54	87	109
Ewes (breeding)		24	66	42	20	33	46
Rams		1	1	4	3	5	3
Yearling females		8	21	1	8	1	11
Female lambs		12	36	23	11	24	23
Male lambs		13	30	32	12	24	26
Sheep Breeds							
Criollo	(no.)	55	133	5	3	8	85
	(%)	95	86	5	5	9	78
50% Cross	(no.)	3	21	17	9	20	24
	(%)	5	14	17	17	23	22
>50% Cross	(no.)	0	0	79	42	59	0
	(%)	0	0	79	78	68	0
Total Land Resources (ha)		23.0	67.7	24.5	18.4	61.8	32.9
Cropland		4.3	10.0	2.0	4.2	4.6	7.0
Faba Beans		0.2	0.0	0.0	0.0	0.0	0.0
Potatoes		1.8	5.0	1.5	2.0	3.0	2.0
Quinoa		2.3	5.0	0.0	1.2	1.6	5.0
Wheat		0.0	0.0	0.5	1.0	0.0	0.0
Fallow fields (ha)		4.0	22.2	16.5	6.8	32.7	7.4
Crop Residues		4.0	7.0	0.5	1.9	8.2	2.5
Fallowed 1-3 years		0.0	15.2	9.5	1.7	10.5	2.5
Fallowed >3 years		0.0	0.0	6.5	3.2	14.0	2.4

continued

	Settlement					
	Espíritu Willq'i	***Inkamaya***	***Calluni-maya***	***Barrio***	***Savilani***	***T'olatia***
Cultivated forage	3.7	2.0	2.5	6.0	6.1	9.0
Alfalfa	1.7	2.0	1.5	3.9	3.9	9.0
Barley	2.0	0.0	1.0	2.1	2.2	0.0
Rangeland	11.2	33.4	3.3	1.3	18.4	9.5

[1]Where breeds include indigenous Criollo, 50% crosses of Criollo with recently introduced breeds such as Targhee, Merino or Corriedale, and >50% crosses of Criollo with recently introduced breeds (i.e., more than one generation of crossing with introduced breeds).

[2]Land resources are under controlled access by the respective households, but may not all be owned. Some lands are accessed through temporary arrangements.

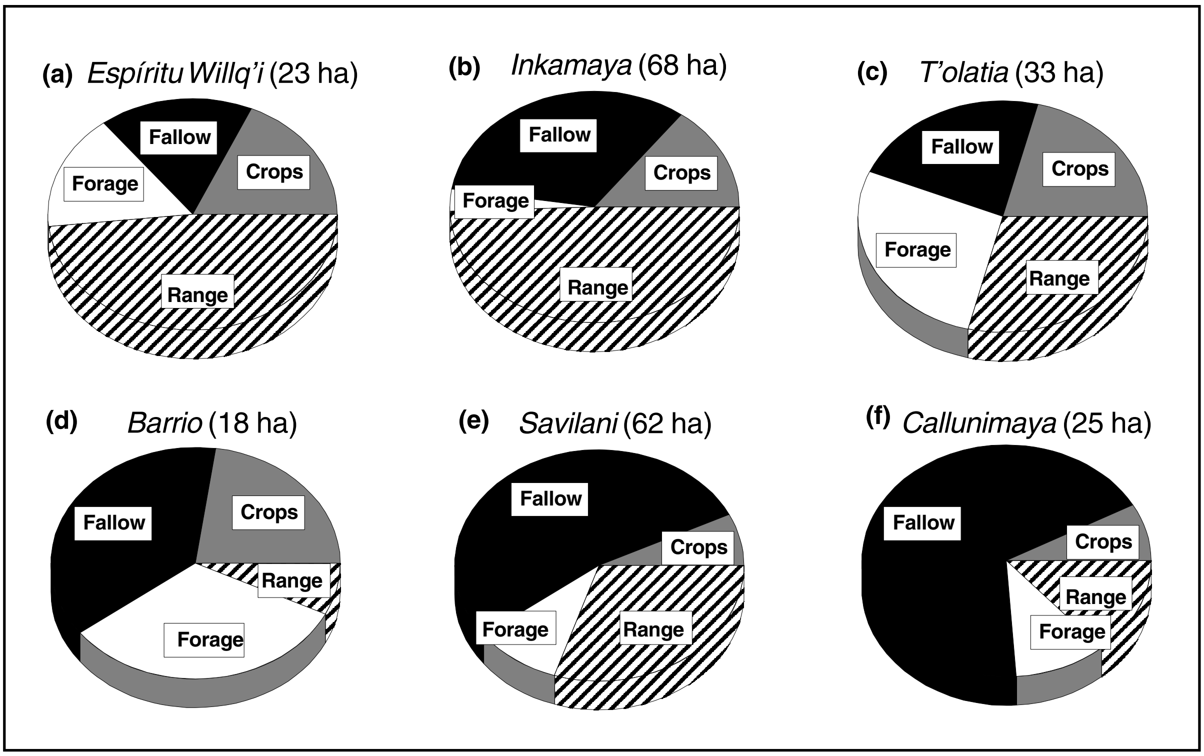


Figure 5.10 (a-f). *Variation in land resources for six settlements (or neighbourhoods) at San José Llanga. Sites markedly differed in the proportion and absolute quantities of high-value land for irrigated forage and lower-value range. This variation in turn influences breeds of sheep and cattle held by households.* Source: Adapted from data in Villanueva (1995)

Table 5.10. *Summary of sheep management practices for one household at each of six settlements at San José Llanga during 1992-3.* Source: Adapted from Villanueva (1995, 40).

Management Practices[1]	Settlement					
	Espíritu Willq'i	*Inkamaya*	*Calluni-maya*	*Barrio*	*Savilani*	*T'olatia*
Breed of ewes (%):						
Criollo	100.0	96.9	7.1	5.1	21.2	95.8
50% Cross	0.0	3.1	11.9	20.1	27.2	4.2
>50% Cross	0.0	0.0	81.0	74.8	51.6	0.0
Tail docking						
Percent of lambs	0	100	100	100	100	100
Mean age of lambs (days)	NA	15	11	15	85	15
Months occurred	NA	May	May-Nov	Mar-Sep	Jul-Jan	May-Aug
Marketing						
Mean age of lambs (mo.)	8	8	4-8	5-8	4-8	5-9
Months occurred	Feb	Feb	Feb	Feb	Feb	Feb
Weaning age (mean days):						
Criollo	190	189	--	--	--	174
50% Cross	NA	207	126	162	149	181
>50% Cross	NA	NA	214	149	182	NA
Castration	NA	NA	NA	NA	NA	NA
Shearing						
Percent of sheep	8	11	39	19	20	25
Months occurred	Jan	Sep	Sep	Sep	Sep	Jan
Health Treatments						
Dipping	yes	yes	yes	yes	yes	yes
Month occurred	Apr	Sep	Sep	Sep	Sep	Sep
Vaccination	no	no	no	no	no	no

[1]Based on breeding flocks of 24, 66, 42, 20, 33 and 46 ewes per household for *Espíritu Willq'i, Inkamaya, Callunimaya, Barrio, Savilani, and T'olatia*, respectively.

Table 5.11. *Causes and rates of morbidity for sheep held by households at six settlements at San José Llanga during 1992-3.* Source: Adapted from Villanueva (1995, 83).

Morbidity Cause and Season	Settlement												Total	
	Espíritu Willq'i		*Inkamaya*		*Callunimaya*		*Barrio*		*Savilani*		*T'olatia*			
	N	%	N	%	N	%	N	%	N	%	N	%	N	%
Diarrhea														
Wet	40	60	44	64	70	77	38	58	36	56	47	66	275	65
Transition	44	0	122	0	66	0	42	0	31	0	77	0	382	0
Dry	50	12	135	9	63	16	34	21	39	23	82	10	403	13
Nervous system disorders														
Wet	40	0	44	0	70	6	38	5	36	3	47	2	275	3
Transition	44	0	122	0	66	0	42	0	31	0	77	0	382	0
Dry	50	10	135	2	63	5	34	6	39	8	82	6	403	5
Estrus disorders														
Wet	40	5	44	0	70	0	38	0	36	0	47	0	275	1
Transition	44	0	122	0	66	0	42	0	31	0	77	0	382	0
Dry	50	0	135	0	63	0	34	0	39	0	82	0	403	0
Conjunctivitis														
Wet	40	10	44	11	70	17	38	24	36	39	47	15	275	19
Transition	44	86	122	69	66	79	42	93	31	90	77	75	382	78
Dry	50	18	135	10	63	16	34	15	39	26	82	9	403	14

continued

Morbidity Cause and Season	Settlement												Total	
	Espíritu Willq'i		*Inkamaya*		*Callunimaya*		*Barrio*		*Savilani*		*T'olatia*			
	N	%	N	%	N	%	N	%	N	%	N	%	N	%
Inflammation														
Wet	40	5	44	9	70	1	38	0	36	6	47	11	275	5
Transition	44	0	122	0	66	0	42	0	31	0	77	0	382	0
Dry	50	0	135	0	63	0	67	0	39	0	82	0	403	0
Scabies/Mange														
Wet	40	5	44	7	70	9	38	13	36	8	47	4	275	8
Transition	44	18	122	11	66	27	42	41	31	48	77	13	382	21
Dry	50	70	135	44	63	94	34	91	39	90	82	55	403	66
External Parasites														
Wet	40	0	44	0	70	0	38	11	36	0	47	0	275	2
Transition	44	0	122	0	66	0	42	0	61	0	77	0	382	0
Dry	50	2	135	2	63	0	34	0	39	0	82	0	403	1
Bloat														
Wet	40	0	44	0	70	0	38	0	36	0	47	4	275	1
Transition	44	0	122	0	66	0	42	0	31	0	77	0	382	0
Dry	50	0	135	0	63	0	34	0	39	0	82	0	403	0

yielding a mortality rate of 1.7% (Villanueva 1995, 57). Death of adult sheep was attributed to disease and accidents. Besides high levels of hands-on attention from flock managers at SJL, the fact that 1992-3 was a near-average year in terms of rainfall and forage production probably contributed to the low mortality rates at SJL (see Section 3.3.1: *Climate*). Predation is a major contributor to losses in other sheep-producing systems world-wide (Dr. D.L. Coppock, IBTA/SR-CRSP, personal observation), but this factor is notably lacking at SJL.

Morbidity rates among sheep for seven afflictions are shown in Table 5.11. Overall, diarrhea, conjunctivitis (i.e., eye inflamation) and scabies (mange of the skin) were the most common ailments. Depending on the time of year, a maximum of 65 to 78% of animals could be affected by at least one of these ailments. Diarrhea was most common in the wet season across all six households (65% of all animals), while conjunctivitis and scabies were most common in the transition and dry seasons, respectively (Table 5.11).

Considered for the fecal samples of 931 animals examined across six households and two seasons, the overall infection rate for internal parasites was 46% (Villanueva 1995, 86). The percentage of sheep infected with internal parasites ranged from 34% at *Inkamaya* to 65% at *Espíritu Willq'i* (Villanueva 1995, 86). Calculated across seasons, the infection rate in the wet season was 54% versus 38% in the dry season. Sheep <12 months of age had an infection rate of 44% versus those older sheep which had an infection rate of 50%. Sheep breeds were similar in infection rate— from 36% (improved animals) to 45% (Criollo) and 51% (highly improved). Data for occurrence of four parasite species across households, seasons, sheep breeds and age of sheep are depicted in Table 5.12. This information revealed that species typically considered as important on the Altiplano such as *Coccidia* and *Trichuris* were not prevalent at SJL. Occurrence of *Moniezia* and *Nematodirius* spp. was moderate, but occurrence of *Strongyloides* and *Tricostrongylus* spp. was regarded as high (Villanueva 1995; 94, 106).

The genetic composition, lambing statistics and fertility rates for ewes and ram:ewe ratios for flocks held by the six households are shown in Table 5.13. The proportion that twinning (or two lambs per year) made up of total births varied markedly among households and appeared to be the major contributor to variation in fertility rates. This is illustrated, for example, by the high incidence of multiple births per ewe and concomitant high fertility rates for animals held by the households at *Callunimaya* and *Savilani*. Higher rates of multiple births, in turn, tended to be associated with having improved sheep. Out of 36 cases of twinning, 21 (58%) were recorded for the highly improved sheep, seven (19%) for the improved sheep and eight (23%) were observed for the Criollo (Villanueva 1995, 53). A low ratio of rams:ewes was speculated to be an important factor influencing the low fertility rate at *Inkamaya* (Bryant 1994), but tracing a direct cause and effect in this small data base is complicated by the fact that households were confounded with differences in breed composition and other aspects of management. For example, *Barrio* and *Callunimaya* were almost identical in terms of sheep breeds and ram:ewe ratio, but varied by 52 percentage points in terms of fertility rate (Table 5.13).

Over 266 births, only 10% occurred in the wet season (i.e., November to February) , while 49% and 41% occurred in the transition (i.e., March to June) and dry (i.e., July to October) seasons, respectively (Villanueva 1995, 50). In general, seasonal distribution of lambing was similar regardless of sheep breed. Given that no effort was made by the campesinos to regulate breeding, the pattern suggests that breeding was strongly regulated by the nutritional plane for ewes and, possibly, rams. Since these sheep have a gestation period on the order of 120 days, about 90% of conceptions occurred during the wet and transition seasons (i.e., November through June). Ewes and rams probably need to recover a critical amount of body condition lost during the previous dry season before breeding activity can begin. The flush of nutritious new growth early in wet seasons may be enough to stimulate ovarian cycling and sexual behaviour in ewes and sexual behaviour in rams. Such phenomena have been commonly observed elsewhere for livestock in seasonal rangeland environments (Coppock and Sovani 1999).

Effects of breed and season of birth on liveweight dynamics, growth efficiency, average daily gain (ADG) and age at weaning for lambs are depicted in Table 5.14. Breed effects were pervasive ($P<0.05$). Compared to Criollo sheep, the highly improved sheep were 27% heavier at birth, 65% heavier at 60 and 150 days of age and had a 78% higher rate of ADG over 150 days. The highly improved sheep were also weaned 30 days earlier than Criollo sheep. Improved sheep were often intermediate between Criollo and highly

Table 5.12. *Internal parasite loads recorded from sheep fecal samples as influenced by settlement location, season, breed and age of sheep at San José Llanga during 1992-3.* Source: Adapted from Villanueva (1995, 94).

	Internal Parasite			
Factors	*Moniezia expanza*	*Nematodirius* spp.	*Strongyloides* spp.	*Tricostrongylus* spp.
Settlement				
Espritu Willq'i	1.8	1.2	2.3 a[1]	2.2
Inkamaya	1.8	1.9	3.6 bc	2.2
Callunimaya	1.4	1.9	3.0 ab	2.5
Barrio	1.2	1.2	2.5 ac	1.9
Savilani	1.0	1.0	3.2 abc	1.6
T'olatia	1.2	1.3	3.8 b	2.5
Season				
Dry	1.0 a	1.0	3.7 a	1.5
Wet	1.8 b	1.6	1.5 b	2.2
Breed[2]				
Criollo	1.6	1.6	3.5	2.2
50% Cross	1.3	2.4	2.7	2.7
>50% Cross	1.2	1.4	2.9	2.2
Age				
<12 months	1.4	1.6	3.3	2.5 a
>12 months	1.4	1.5	3.2	1.6 b

[1]Entries within each factor accompanied by different letters (a, b, c) were significantly different at P<0.05 according to Fischer's LSD test. Sets of entries with no letters had no significant differences (P<0.05).

[2]Criollo was the indigenous breed and "crosses" represent hybrids between Criollo and Targhee, Corriedale or Merino breeds. The ">50% Cross" meant that blood of Criollo animals made up less than half of the mix.

Table 5.13. ***Breed composition, ram:ewe ratios and fertility rates for sheep flocks held by one household for each of six settlements at San José Llanga during 1992-3.*** Source: Adapted from Villanueva (1995, 47).

	Settlement					
Feature	*Espíritu Willq'i*	*Inkamaya*	*Calluni-maya*	*Barrio*	*Savilani*	*T'olatia*
Breed composition of flock (%)[1]						
Criollo	95	86	5	5	9	78
50% Cross	5	14	17	17	23	22
>50% Cross	0	0	78	78	68	0
Ram:Ewe Ratio	1:24	1:87	1:11	1:9	1:7	1:20
Mature ewes (no.)	24	87	42	28	33	57
Lambs born (no.)	25	66	55	23	48	49
Ewes having twins (no.)	2	0	26	3	15	3
Fertility Rate (%)[2]	104	75	131	82	145	86

[1]Criollo was the indigenous breed and "crosses" represent hybrids between Criollo and Targhee, Corriedale or Merino breeds. The ">50% Cross" meant that blood of Criollo animals made up less than half of the mix.

[2]Fertility rate is the number of lambs born divided by the number of mature ewes in each column.

improved sheep in these productive features; there was no effect of breed, however, on productive efficiency at 150 days of age. In general, birth season had less influence on production parameters than did breed composition (Table 5.14). Lambs born in the transition season were 15% heavier than those born in the wet season. Although there were some effects of birth season on lamb weights at 60 days, this variability tended to disappear by 150 days. Lambs born in the wet and transition seasons had a markedly higher production efficiency than those born in the dry season (Table 5.14).

The numbers of sheep culled for sale or slaughter among the six households are shown in Table 5.15. An average of about 31 head, or 16% of each flock, was culled per household. Variability in culling rates was high among households. Out of a total of 189 animals culled, about 61% were culled from October to December, with 34% culled in December alone. October through December coincides with the late dry season and early stages of the wet season.

A breakdown of culling details per household is shown in Table 5.16; these data are for a subset of sheep reflected in Table 5.15 and reflect the annual increment in animal numbers between the start and end dates of the study. Out of a total of 166 head for which culling details were recorded, 76% were sold as live animals, 17% were slaughtered for home consumption, and the remainder (7%) were lost due to accidental death or disease. An average of 4.6 sheep were slaughtered for home consumption in each household; throughout the year this translated into about one sheep consumed per household every 2.5 months. No meat products of sheep were sold. Typically, lambs were culled when they were at least 12 months old. Sales of younger animals were also reported but not tabulated here (Bryant 1994).

Table 5.14. *Means (and sample sizes) for liveweight dynamics, growth efficiency, age at weaning and average daily gain (ADG) for lambs born during 1992-3 at six households in San José Llanga.* Source: Adapted from Villaneuva (1995, 58).

		Production Features					
		Live weight (kg/hd)			Growth Efficiency[1] (%)	Age at weaning (days)	ADG[2]
		Birth	60 d	150 d			
Breed[3]							
Criollo	($\bar{x}$)	2.6a[4]	7.1a	11.7a	44.9a	182.4a	59.9a
	(no.)	(96)	(93)	(63)	(63)	(54)	(63)
50% Cross	($\bar{x}$)	3.3ab	8.7ab	14.0b	50.6a	171.2b	73.3ab
	(no.)	(44)	(44)	(36)	(36)	(24)	(36)
>50% Cross	($\bar{x}$)	3.3b	11.7b	19.3b	54.3a	150.4c	106.8b
	(no.)	(99)	(98)	(75)	(75)	(47)	(75)
Season							
Wet	($\bar{x}$)	2.7a	8.3ab	17.4a	58.2a	--	96.8a
	(no.)	(25)	(24)	(5)	(5)	--	(5)
Transition	($\bar{x}$)	3.1b	10.7a	16.7a	56.7b	161.3b	89.8a
	(no.)	(118)	(117)	(87)	(87)	(94)	(87)
Dry	($\bar{x}$)	2.9ab	7.9b	14.1a	42.7c	191.8c	74.4a
	(no.)	(96)	(94)	(82)	(82)	(30)	(82)

[1]Growth efficiency was calculated as lamb liveweight at 150 days of age as a percentage of liveweight of the mother ewe at birth.

[2]ADG was calculated from birth to 150 days of age.

[3]Criollo was the indigenous breed and "crosses" represent hybrids between Criollo and Targhee, Corriedale or Merino breeds. The ">50% Cross" meant that blood of Criollo animals made up less than half of the mix.

[4]Entries within a column accompanied by different letters (a, b, c) were significantly different at $P \leq 0.05$ according to Fischer's LSD test.

Table 5.15. *Monthly pattern of sheep culling (head) among households distributed across six settlements at Sal José Llanga during 1992-3.* Adapted from Villanueva (1995, 96).

Month	Settlement						Total	Percent
	Espíritu Willq'i	*Inkamaya*	*Calluni-maya*	*Barrio*	*Savilani*	*T'olatia*		
May	4						4	2
June	3	4		1			8	4
July		1					1	<1
August	3	12	1	3	6	2	27	14
September			3	2			5	3
October	3	7	2	3	2	6	23	12
November	2	16	1	4	2	3	28	15
December	10	28	5	9	3	10	65	34
January	9	6	8	3			26	14
February		1	1				2	1
Total	34	75	21	25	13	21	189	--
Percent	18	40	11	13	7	11	--	100

Markedly older animals that were sold were largely rams (Table 5.16).

Overall, Villanueva (1995) concluded that sheep sales were largely driven by a household's acute need for money, whether this involved a need to purchase food, crop inputs or pay school fees. The acute need for cash to buy food appears to partially explain the apparent seasonal concentration of culling, as October through December would be the time when household stocks of food crop staples would be running low. There are additional reasons for a seasonal concentration of culling (Villanueva 1995; 105, 107). By October many lambs were of marketable age, and prices for sheep tended to rise by December due to increased holiday demand (see Section 4.3.3.1: *Household activities and economy*). The campesinos also strategised to reduce stocking rates by the end of the dry season in anticipation of the next year's lamb crop. The observation by Villanueva that campesinos attempt to balance forage supply with animal demand on an annual basis is important. The ready availability of market outlets probably facilitates strategic destocking and minimizes wastage losses due to starvation-- this was also true in the dry rainfall year of 1995 when sheep sales markedly increased in response to a poor crop harvest (Dr. C. Valdivia, IBTA/SR-CRSP, personal observation). In contrast, excessive wastage losses (i.e., high rates of morbidity and death) of animals due to the coincidence of drought and marketing bottlenecks is an outcome commonly seen in less developed pastoral livestock systems in sub-Saharan Africa (Coppock 1994).

Tables 5.17 and 5.18 give figures on wool and milk production. There was high variability among households in the percentage of sheep that were sheared. The percentage sheared did not exceed 27% for any one household (Table 5.17). On average, the highly improved and improved sheep

Table 5.16. *Culling statistics for sheep held by households at six settlements at San José Llanga during 1992-3*. Source: Adapted from Villaneuva (1995, 96).

	Settlement						
Category	*Espíritu Willq'i*	*Inkamaya*	*Calluni-maya*	*Barrio*	*Savilani*	*T'olatia*	Total
Total sheep managed (hd)	58	154	101	54	87	109	563
Total sheep culled (hd)	31	46	27	20	28	14	166
Live sheep sold	24	35	20	14	22	11	126
Slaughtered sheep sold	0	0	0	0	0	0	0
Slaughtered sheep consumed	5	6	6	4	6	1	28
Other sheep deaths	2	5	1	2	0	2	12
Percent sheep culled	54	29	27	37	32	13	29
Age range of culled sheep (mo.)							
Live sheep sold	12-60	12-48	12	12	12	12-48	12-60
Sheep consumed	12	12	12	12	12	12	12

yielded 5.4 kg of wool per shearing event, which was 59% higher than the mean yield from Criollo sheep. Milk yield data were not separated by sheep breed (Table 5.18), but ancillary information from Villanueva (1995) can be interpreted to indicate that households which had highly improved and improved sheep as well as access to ample cultivated forage were those households which were able to incorporate sheep milk into their economy. Villanueva (1995, 107) stated that only the highly improved and improved breeds of sheep yielded a relatively constant milk supply throughout the year. Two of the six households in Table 5.18 did not obtain sheep milk, these happened to be households which had a high proportion of Criollo sheep as well as poor access to cultivated forages (Table 5. 9). Overall, when highly improved or improved sheep were lactating they were milked about half the time. The average yield for human consumption was 158 ml per milking, with relatively little variation among households (Table 5.18). There was high variability in the percentage of lactating ewes that were milked per household.

5.4 Conclusions

First, it is clear that the grazing management system at SJL is remarkably efficient. Land and labour resources appeared to be fully utilised. Native and improved forages were effectively combined to reduce nutritional risks for livestock. Landscape features have encouraged a *de facto* deferred system of grazing that contributes to sustainable levels of resource use. We therefore see little scope to improve grazing management per se given the existing social and economic framework.

Second, in terms of ecological niches, we see sheep and cattle, the vital species in this production system, to be highly compatible. Should common forage resources be diminished during a dry season or drought, we see ample opportunity for potential competition to be mitigated through human interference, whether it be intensified management (i.e., cut-and-carry feeding, etc.) of cattle and/or dumping extra sheep in the marketplace. The observation that some households attempt to balance sheep numbers with forage resources

Table 5.17. *Wool production statistics for sheep[1] held by households at six settlements at San José Llanga during 1992-3.* Source: Adapted from Villanueva (1995, 100).

Category	Settlement					
	Espíritu Willq'i	*Inkamaya*	*Calluni-maya*	*Barrio*	*Savilani*	*T'olatia*
Total sheep managed (hd)	58	154	101	54	87	109
Sheared sheep (%)	5	8	27	13	6	19
Wool yield (kg/hd/event)						
Criollo	1.4	1.6	2.0	--	1.6	1.1
50% Cross	--	--	2.9	2.8	--	1.1
>50% Cross	--	--	2.3	2.7	3.0	--

[1]Criollo was the indigenous breed and "crosses" represent hybrids between Criollo and Targhee, Corriedale or Merino breeds. The ">50% Cross" meant that blood of Criollo animals made up less than half of the mix.

using an annual sales strategy reveals consciousness concerning carrying capacity and risk.

Third, in terms of sheep production, it was clear that introduced bloodlines have made a substantial impact at SJL over the course of the past 30 years. New breeds have been effectively mixed into the traditional system and probably offer marked boosts in terms of commodity outputs. However, one of the most important findings was that the ability of a household to use improved breeds depends on ability to grow improved forages. This, in turn, depends on location within the cantón.

Fourth and lastly, our assessment of sheep productivity resulted in a variety of insights. The exceptionally low rates of sheep mortality, perhaps the key parameter in such systems, are promoted by hands-on care from the campesinos. Despite this general attentiveness, however, morbidity of sheep due to diarrhea, conjunctivitis and scabies/mange is pervasive.

5.5 Literature cited

AOAC (Association of Official Analytical Chemists). 1990. *Official Methods of Analysis.* 15th edition. AOAC, Washington DC, USA. 1684 pp.

Arnold G. and Dudzinsky M. 1978. *Ethology of the Free Ranging Animal.* Elsevier Press, Amsterdam, the Netherlands.

Behnke R.H. and Scoones I. 1991. Rethinking range ecology: Implications for rangeland management in Africa. In: Behnke R.H., Scoones I. and Kerven C. (eds), *Range Ecology at Disequilibrium: New Models of Natural Variability and Pastoral Adaptation in African Savannas. Proceedings of a Workshop Held at Woburn, UK, November 1990.* Commonwealth Secretariat and Overseas Development Institute, London, UK. pp. 1-30.

Bell R. 1971. A grazing ecosystem in the Serengeti. *Scientific American* 224(1):86-93.

Bonham C. 1989. *Measurements for Terrestrial Vegetation.* John Wiley & Sons Inc., New York, New York, USA. 338 pp.

Briske D. 1991. Developmental morphology and physiology of grasses. In: Heitschmidt R. and Stuth J. (eds), *Grazing Management - An Ecological Perspective.* Timber Press, Portland, Oregon, USA. pp. 85-108.

Table 5.18. *Milk production statistics for sheep held by households at six settlements*[1] *at San José Llanga during 1992-3.* Source: Adapted from Villaneuva (1995, 100).

Category	Settlement					
	Espíritu Willq'i	*Inkamaya*	*Calluni-maya*	*Barrio*	*Savilani*	*T'olatia*
Total sheep managed (hd)	58	154	101	54	87	109
Milked ewes (%)	--	--	64	17	33	13
Interval between birth and first milking of ewes (days)	--	--	90	120	90	60
Period milked (days)	--	--	47	25	45	48
Average milk yield (ml/hd/day)	--	--	149	160	150	174

[1]Breed composition varies with settlement. The percentage of Criollo animals varied from 95% (*Espiritu Willq'i*), 86% (*Inkamaya*), 5% (*Callunimaya*), 5% (*Barrio*), 9% (*Savilani*) and 78% (*T'olatia*).

Bryant F. 1994. Range animal nutrition. In: Johnson S. (ed), *SR-CRSP Annual Report 1994.* Management Entity, SR-CRSP (Small Ruminant Collaborative Research Support Program), University of California, Davis, California, USA. pp. 47-67.

Cáceres M. 1994. *Comportamiento y Sobreposición Alimenticia de Tres Especies Domésticas (Ovinos, Vacunos y Equinos) en el Altiplano Central de Bolivia.* BS tesis, Universidad Autónomia Tomás Frias, Potosí, Bolivia. 111 pp.

Cloudsley-Thompson J. 1988. Desertification or sustainable yields from arid environments? *Environmental Conservation* 15:197-204.

Coppock D.L. 1994. *The Borana Plateau of Southern Ethiopia: Synthesis of Pastoral Research, Development and Change, 1980-91.* Systems Study no. 5. ILCA (International Livestock Centre for Africa), Addis Ababa, Ethiopia. 374 pp.

Coppock D.L. 1985. *Feeding Ecology, Nutrition and Energetics of Livestock in a Nomadic Pastoral Ecosystem.* PhD dissertation, Colorado State University, Fort Collins, Colorado, USA. 274 pp.

Coppock D.L. and Sovani S. 1999. Is supplementation justified to compensate pastoral calves for milk restriction? *Journal of Range Management* 52:208-217.

Coppock D.L., Ellis J.E. and Swift D.M. 1986a. Livestock feeding ecology and resource utilization in a nomadic pastoral ecosystem. *Journal of Applied Ecology* 23:573-584.

Coppock D.L., Swift D.M. and Ellis J.E. 1986b. Seasonal nutritional characteristics of livestock diets in a nomadic pastoral ecosystem. *Journal of Applied Ecology* 23:585-596.

Coppock D.L., Swift D.M. and Ellis J.E. 1987. Seasonal nutritional characteristics of livestock forage in South Turkana, Kenya. *East African Agricultural and Forestry Journal* 52:162-175.

Coppock D.L., Ellis J.E. and Swift D.M. 1988. Seasonal patterns of activity, travel and water intake for livestock in South Turkana, Kenya. *Journal of Arid Environments* 14:319-331.

Ellis J.E. and Swift D.M. 1988. Stability of African pastoral ecosystems: Alternate paradigms and implications for development. *Journal of Range Management* 41:450-459.

Flores F. 1995. *Utilización comparativa de los Campos Nativos de Pastoreo por el Ganado Doméstico en San José Llanga (Provincia Aroma Departamento de La Paz)*. BS tesis, Universidad Mayor de San Andrés, La Paz, Bolivia. 114 pp.

Heady H. 1975. *Rangeland Management*. McGraw-Hill Co., New York, New York, USA. 460 pp.

Hobbs N.T., Baker D.L., Ellis J.E. and Swift D.M. 1981. Composition and quality of elk winter diets in Colorado. *Journal of Wildlife Management* 45:156-171.

Hofmann R. 1988. Anatomy of the gastrointestinal tract. In: Church D. (ed), *The Ruminant Animal*. Prentice-Hall Co., Englewood Cliffs, New Jersey, USA. pp. 14-43.

Jahnke H. 1982. *Livestock Production Systems and Livestock Development in Tropical Africa*. Kieler Wissenschaftsverlag Vauk, Kiel, Federal Republic of Germany. 253 pp.

Janis C. 1976. The evolutionary strategy of the Equidae and the origins of rumen and cecal digestion. *Evolution* 30:757-774.

Kay, R., Engelhardt W. and White R. 1980. The digestive physiology of wild ruminants. In: Rukebusch Y. and Thivend P. (eds), *Digestive Physiology and Metabolism in Ruminants*. Avi Publishing Co., Westport, Connecticut, USA. pp. 743-761.

Lopéz C. 1994. *Contenido Nutricional de la Dieta al Pastoreo en Tres Especies: Ovinos, Bovinos y Equinos del Altiplano Central*. BS tesis, Universidad Tecnica de Oruro, Oruro, Bolivia. 136 pp.

Norton B. 1994. Range ecology. In: Johnson S. (ed), *SR-CRSP Annual Report 1994*. Management Entity, SR-CRSP (Small Ruminant Collaborative Research Support Program), University of California, Davis, California, USA. pp. 3-20.

Ortega M. 1991. *Deer and Cattle Foraging Strategies Under Different Grazing Systems and Stocking Rates.* PhD dissertation, Texas Tech University, Lubbock, Texas, USA. 152 pp.

Peña O. 1994. *Evaluación de los Recursos Hídricos del Cantón San José Llanga, Provincia Aroma, Departamento de La Paz*. BA tesis, Universidad Mayor de San Andrés, La Paz, Bolivia. 147 pp.

Pratt D. and Gwynne M. 1977. *Rangeland Management and Ecology in East Africa*. Hodder and Stoughton, London, UK. 310 pp.

Ramos A., Prieto G. y de Queiroz J. 1995. *Relaciones de Presion de Pastoreo, Productividad y disponibilidad de Forraje en Areas de Pastoreo del Cantón San José Llanga*. IBTA/SR-CRSP (Instituto Boliviano de Tecnología Agropecuria/ Small Ruminant Collaborative Research Support Program) IBTA 153/Boletín Técnico 21/SR-CRSP 19, La Paz, Bolivia. 35 pp.

Rasmusson E. 1987. Global climate change and variability: Effects on drought and desertification in Africa. In: Glantz M. (ed), *Drought and Hunger in Africa*. Cambridge University Press, Cambridge, UK. pp. 1-22.

SAS (Statistical Analysis System). 1988. *SAS/STAT™ User's Guide. Release 6.03 Edition.* SAS Institute Inc., Cary, North Carolina, USA.

Sinclair A. and Fryxell J. 1985. The Sahel of Africa: Ecology of a disaster. *Canadian Journal of Zoology* 63:987-994.

SYSTAT. 1992. *SYSTAT™ for Windows: Statistics. Version 5 Edition*. SYSTAT, Evanston, Illinois, USA. 750 pp.

Van Soest P. 1994. *Nutritional Ecology of the Ruminant*. Second edition. Cornell University Press, Ithaca, New York, USA. 476 pp.

Victoria Z. 1994. *Distribucion y Comportamiento en Pastoreo del Ganado Domestico (Ovinos, Vacunos y Equinos) en al Altiplano Central de Bolivia*. BS tesis, Universidad Autonoma Tomás Frias, Potosi, Bolivia. 126 pp.

Victoria Z., Ortega M. y Yazman J. 1995. *Distribucion Espacial y Temporal del Ganado*

Domestico en San José Llanga. IBTA/SR-CRSP (Instituto Boliviano de Tecnología Agropecuria/ Small Ruminant Collaborative Research Support Program). IBTA 149/Boletín Técnico 17/SR-CRSP 11, La Paz, Bolivia. 33 pp.

Villanueva E. 1995. *Caracterizacion del Sistema de Manejo y Produccion de Ganado Ovino en Una Comunidad del Altiplano Central*. BS tesis, Universidad Tecnica de Oruro, Oruro, Bolivia. 90 pp.

Villanueva E. y Yazman J. 1995. *Caracterization del Sistema de Produccion de Ganado Ovino del Cantón San José Llanga*. IBTA/SR-CRSP (Instituto Boliviano de Tecnología Agropecuria/ Small Ruminant Collaborative Research Support Program). IBTA 162/Boletín Técnico 30/SR-CRSP 28, La Paz, Bolivia. 44 pp.

Chapter 6

Household socioeconomic diversity and coping response to a drought year at San José Llanga

Diversidad socioeconómica familiar y respuestas de ajuste a un año de sequia en San José Llanga

by Corinne Valdivia

Summary

There were two main objectives for work described in this chapter: (1) Determine whether households at SJL pursued distinct economic strategies involving various mixes of livestock production, food crop production, wage labour and remittances; and (2) determine whether different strategies conferred different advantages in the ability of households to cope with a one-year drought. For the second objective it was expected that, compared to a near-average rainfall year, sheep sales and off-farm remittances during a drought year would be particularly important in mitigating potential declines in living standards for households. Households that were relatively more dependent on food crop production would be expected to suffer more in a drought year. All research was based on surveys conducted among 39 households in 1993 and 1995. Data were collected on various aspects of agricultural production, sources of income, expenditures and demographic profiles. In 1993 the annual precipitation was only 3% less than the long-term mean of 406 mm, while in 1995 annual precipitation was 40% lower than the long-term mean. Production of food crops reportedly declined in most instances in 1995 compared to 1993. Prices, however, rose on the order of 30 to 400% for food crops and 17 to 50% for livestock and livestock products during 1995 compared to that for 1993.

Cluster analysis was used to determine if households could be grouped according to distinct strategies. Ten variables were used as possible discriminating variables for clustering, but only three emerged as important. The cluster analysis revealed two major groups I called "active" and "passive." Active households were roughly twice as abundant as passive households in the sample. Life cycle factors such as age of household heads and size of the labour pool were important in defining active versus passive households. Active households had household heads in a "mid-career" stage of the life cycle with far more production resources, higher incomes and higher total welfare expenditures (i.e., consumption levels) compared to the passive households typically run by elderly people in a "retirement" stage of the life cycle. Passive households were further broken out into subgroups on the basis of number of adults in the household (i.e., singles versus couples). The active group was also further broken out into subgroups on the basis of those households dependent on improved livestock breeds and irrigated forages ("active/ improved") versus those dependent on indigenous livestock breeds and native, rain-fed forages ("active/Criollo"). Finally, the active/Criollo subgroup broke out further into sub-subgroups where households with a higher dependence on native range (active/Criollo/range) split off from those having access to some irrigated forage and markets to sell milk (active/Criollo/ PIL).

Two-way ANOVA was used to analyse year x subgroup interactions with the expectation that poorer subgroups, or subgroups with a higher dependence on food crops in the household portfolio, would exhibit greater relative declines in income and consumption during the drought year compared to that of other subgroups. Main effects of year revealed that the income from cultivated forage and livestock increased ($P<0.01$) in the drought year compared to the near-average year, and these components contributed to an overall 56% increase ($P<0.01$) in total income in 1995 compared to1993. Main effects of subgroup revealed large disparities in eight of 10 income categories over both years. For example, the active/ improved subgroup had a total annual income that was over seven-times more than that of passive/ singles. Year x subgroup interactions, however, were elusive in most cases; this was likely due to the modest sample size in conjunction with high inter-household variability. The general pattern was for all subgroups to increase incomes in 1995 compared to 1993, and in part this was due to the

positive price effect that drought had on commodity value. Active households invested more in irrigated forage production than passive households over the two years (P<0.01). Trends (P=0.07) suggested that compared to other subgroups, active/ Criollo households increased their total income in the drought year due to sheep sales, which was the type of pattern I expected to see.

A multiple regression approach was used to determine what factors were important in relation to change in per capita consumption between 1993 and 1995. The idea was that households should seek tactics that would minimise change in consumption during perturbations. The regression was set up with change in per capita consumption as a function of six variables. The results revealed that change in per capita consumption was positively related (P<0.02) to changes in income, remittances and sheep inventory in the drought year of 1995, and negatively related to sheep inventory in 1993. Degree of household economic diversification was not significant (P=0.07) in this case. This supported the theory that sheep assets and remittances from off-farm help mitigate fluctuations in consumption due to drought.

It was concluded that indeed households at SJL could be broken out into subgroups with distinct socioeconomic characteristics. This validated a theoretical framework used to select clustering criteria. Household strategies were primarily conditioned by stage in the life cycle and secondarily by the types of resources controlled. The last level was conditioned by access to marketing outlets. To cope with a one-year drought, households at SJL used diverse means including reliance on sheep sales and remittances. They also took advantage of a positive price effect that occurred in the drought year for most food crops and livestock products. Results illustrated the utility of sheep sales to promote food security and household stability during drought in this community. At least for the drought year of 1995, market integration had a positive effect on the community. Campesinos were able to reap the positive price effect and buy goods in markets as well.

Resumen

Los dos objetivos principales del trabajo que se presenta en este capítulo fueron: (1) determinar si las unidades económicas familiares de San José Llanga desarrollaron diferentes estrategias de reproducción social, consistentes en diversas combinaciones de actividades ganaderas, agrícolas, asalariadas y de obtención de remesas familiares; y 2) determinar si estrategias diferentes dieron ventajas para enfrentar la sequía del año 1995. Con respecto al segundo objetivo, se esperaba que la venta de ovinos y las remesas hubieran sido especialmente importantes en un año de sequía, para así mitigar los efectos negativos al bienestar familiar. Se suponía que las unidades económicas familiares más dependientes de los cultivos sufrirían más en un año de sequía. La investigación que se presenta aquí se basa en datos recolectados de 39 familias de la comunidad en 1993 y 1995. La información recogida incluyó aspectos de la producción agropecuaria, fuentes de ingreso, gastos, y las características demográficas de los miembros de cada familia. La precipitación anual en 1993 fue 3% menor que la media a largo plazo de 403mm, mientras que la de 1995 fue 40% menor. La producción de cultivos alimenticios disminuyó en casi todas las familias, si se compara con los niveles de 1993. Sin embargo, los precios crecieron entre 30 y 400% en estos cultivos, y de 17 a 50% en ganadería y sus productos, reflejando un detrimento de los términos de intercambio entre ambas actividades.

Se utilizó el análisis de conglomerados para determinar si las unidades económicas familiares podían ser agrupadas de acuerdo a diferentes estrategias. Las variables que se utilizaron en el análisis fueron 10, de las cuales tres resultaron ser las más importantes. El análisis de conglomerados reveló dos grupos, que denominamos el activo y el pasivo; el primero se caracterizó por tener aproximadamente el doble de unidades económicas familiares (UEF). Los factores que identifican el ciclo de vida, por ejemplo la edad del jefe de la UEF, y el tamaño de la oferta de mano de obra familiar, fueron factores de diferenciación. Las unidades económicas familiares activas tenían jefes de la unidad en la etapa intermedia de su fase productiva, con más recursos productivos, mayores ingresos y un mayor nivel de gastos para el consumo familiar. Esto en comparación a las unidades económicas familiares pasivas que consistían de miembros ya mayores y "retirados" de las actividades productivas. Los pasivos se subdividían en casados o parejas, y viudos sobre la base del número de miembros de la UEF. Las familias activas también se subdividieron en dos grupos, pero por el tipo de la producción ganadera: si tenían animales criollos o mejorados, con acceso a forrajes, o dependientes de áreas de pastoreo. Finalmente

el subgrupo de los criollos, dependientes de las áreas de pastoreo, se dividió en dos, uno con mayor dependencia en pastos nativos, mientras el otro tenía ganado criollo con acceso a las áreas irrigadas donde se cultivó forraje, y por lo tanto se vendía leche a la PIL.

Con el análisis de variancia se estudiaron las interacciones entre año y subgrupo. La expectativa era que los subgrupos más pobres, con mayor dependencia en los cultivos alimenticios dentro del portafolio de la UEF, serían los más afectados con la disminución del ingreso y del consumo durante la sequía, en comparación a los otros subgrupos. Los efectos de año revelaron que el ingreso por forraje y ganadería creció significativamente ($p < 0.01$) durante el año de la sequía, en comparación a 1993. Estos componentes contribuyeron 56% al incremento del ingreso total de 1995 ($p<0.01$) comparado al de 1993. Los efectos principales del subgrupo mostraron desigualdades grandes en ocho de las diez categorías del ingreso. Por ejemplo, el grupo activos/mejorado tuvo un ingreso promedio anual que fue 7 veces más grande que el de los pasivos/viudos. Las interacciones año x subgrupo, sin embargo, no fueron significativas, lo cual se debe muy probablemente al problema de tamaño de muestra, en combinación con la alta variabilidad del ingreso. En general con respecto a 1993, todos los subgrupos incrementan los ingresos en 1995. Las UEF activas invirtieron más en la producción de forraje con riego entre los dos años ($P<0.01$). Las tendencias ($P=0.07$) sugieren que el grupo de los activos/criollo incrementó el ingreso total durante la sequía con la venta de ovinos, que era la estrategia que se esperaba encontrar.

Se utilizó el modelo de regresión linear múltiple para analizar los factores que afectan el cambio del consumo per cápita entre 1993 y 1995. La idea central consistía en que las familias desarrollarían estrategias para reducir los efectos de la sequía en el consumo de la familia. La regresión incluyó el cambio en el consumo como la variable dependiente. Las variables exógenas fueron en el cambio del ingreso entre 1993 y 1995 ($P<0.02$), el nivel de las remesas en el 95, y el inventario de ovinos en 1995, los cuales se esperaba que tuvieran una relación positiva, mientras que el inventario de ovinos de 1993 tendría una correlación negativa. El nivel de diversificación del portafolio económico fue casi significativo, si elegimos como nivel crítico el 5% ($P=0.07$). Esto confirma la teoría que sostiene que el capital ovino y las remesas provenientes del empleo fuera de la UEF, ayudan a mitigar los efectos de la sequía.

Se concluyó que efectivamente las UEF en SJL pertenecen a distintos grupos socioeconómicos que tienen diferentes estrategias de reproducción familiar. Esto también sustenta el marco teórico que se utilizó para determinar los criterios de diferenciación. Las estrategias familiares se distinguen, en primer lugar, por etapa en el ciclo de vida, y en segundo lugar por el tipo y cantidad de recursos que la familia controla. El último factor de diferenciación es el tipo de mercado al que la familia tiene acceso. Para poder sobrellevar el año de la sequía, las UEF en SJL utilizaron diversos fondos, entre ellos la venta de ovinos y remesas. También se beneficiaron los que cosecharon, debido al incremento de los precios agropecuarios. En esta comunidad, los resultados obtenidos muestran que la venta de ovinos jugó un rol importante en la seguridad alimentaria y estabilidad de la UEF durante la sequía. Por lo menos para el año de sequía de 1995, la integración al mercado tuvo un efecto positivo en la comunidad. Ellos cosecharon los efectos positivos del incremento de los precios, y a la vez pudieron adquirir los bienes que necesitaban a través del mercado.

6.1 Introduction

In Chapter 4 (*Household economy and community dynamics at San José Llanga*) we described how households at SJL differed in terms of social and economic attributes. For example, households had varied access to production resources. Households differed in level of income, capital assets, degree of market participation and use of social networks to access resources.

The first objective of work presented in this chapter was to examine if households at SJL indeed pursued different economic strategies. For example, would some households rely more on crops, livestock, wage labour or various mixtures of these enterprises, and why? The second objective was to determine how different economic strategies influenced household sustainability, namely the ability to generate wealth, be opportunistic and cope with drought. In particular, I was interested in the role of livestock (especially small ruminants), off-farm employment and income transfers in mitigating fluctuations in household income (Rosenzweig and Wolpin 1985; Kusterer 1989; Fafchamps 1992; Reardon et al 1992; Webb

1992; Fafchamps et al 1998). Households that rely on food crop production could be expected to suffer marked declines in income due to drought since crop yields would be reduced. Having livestock, wage labour, and/or options for income transfers would be important to maintain income and hence enhance food security in a drought year. A mix of enterprises, also referred to as a diversified portfolio, has been found important elsewhere in promoting food security and sustainability among peasant households in variable environments (Cotlear 1989; Kusterer 1989; von Braun et al 1989; Reardon et al 1992). Some researchers have found that as income increases the level of diversification decreases, especially with well-developed markets (von Braun et al 1989). Others have found diversification and income growth go hand-in-hand to fully utilize resources (Ellis 1993) and/or because markets are unreliable (Fafchamps 1992). In the southern Andean region of Peru diversification grew with commercialisation (Cotlear 1989).

6.2 Methods

To understand the rationale for production, land use and income generation in SJL it was necessary to identify driving forces influencing decisions, the social relations that govern decisions, and economic forms of production that interact with markets. With this perspective in mind we developed a typological framework guided by theory from household economics and political economy. While the unit of analysis was the household, it is important to realise that households integrate a variety of intra- as well as inter-household variables. Such variables include interactions among individuals and households within the community in terms of market and non-market relations. We essentially analyzed “snapshots” of households over time that depict production strategies. Production strategies are defined here in terms of the portfolio of enterprises that each household was engaged in. A portfolio is an outcome of a multitude of inter-linked decisions involving production, consumption and marketing (Fafchamps 1992; Ellis 1993). To give an example of inter-linked decisions, we know that if food markets are unreliable, households will produce food for themselves. We know that if access to resources in the community is difficult or uncertain, families will incorporate other income-generating activities. In the case of access and control of land, social relations are often more important than markets (Alberti and Mayer 1974).

A review of more than 200 studies of rural households showed that households exhibit a hierarchical goal-seeking behaviour (Kusterer 1989). The life cycle of households shapes the basic process of seeking day-to-day economic security (Kusterer 1989; Norman 1992). Progression occurs through various stages. There is an initial survival stage followed by stages where households grow and accumulate more resources over time. Ultimately, if successful, households will accumulate enough to bequeath substantive resources to descendants, thus ensuring the reproduction of households from one generation to the next. During the life cycle a threshold is reached whereby households begin to diversify their economic portfolios as long as their current welfare situation is not threatened. It is within this framework that coping strategies were studied here.

6.2.1 Data collection

Data used for this chapter came from several sources. One prominent source was a formal socioeconomic survey of 45 households in 1993 by Drs. E. Dunn and C. Valdivia (IBTA/SR-CRSP, unpublished data); other results from this 1993 survey are reported in Section 4.3.3: *Household production system*. The same survey instrument was implemented among 39 of the same households at the end of the annual production cycle in May, 1995, by Dr. C. Valdivia and Mr. C. Jetté (IBTA/SR-CRSP, unpublished data). The survey recorded estimates of commodities produced, land area cultivated, agricultural production, cash income, expenditures and demographic features of households. Interviews were conducted in Spanish and *Aymara* to foster joint participation by male and female heads of household (Valdivia et al 1995).

The two survey years markedly differed in terms of precipitation. In 1992-3 the annual rainfall was 389 mm, only 3% below the long-term mean of 406 mm (see Section 3.3.1: *Climate*). In 1994-5 the annual rainfall was 242 mm, or about 40% below the long-term mean and the third-lowest annual total in the past 36 years. We therefore regarded 1994-5 as a “drought year.” Crop production for 1994-5 was hindered in general by a delay in the onset of the rainy season as well as by pervasive frost damage (Valdivia and Jetté 1998). As previously reviewed in Section 3.3.1.2: *Air temperature and frost*, drought and risk of frost appear linked. Interviews with campesinos (i.e., peasants) confirmed that 1994-5 was indeed a below-average year for crop production in general, but not all crops were negatively affected. For example, farmers considered 1994-5 to be a better year for potato production compared to 1992-3, while the reverse was true for *quinoa* [N=20 households interviewed by Céspedes and Rodríguez (1996)]. In addition, while production probably declined for most crops in 1992-3, prices tended to rise, giving an economic advantage to those households which had enough land to produce a marketable surplus. Relative prices for commodities such as *kara grano* (e.g., a wheat-like grain) and potatoes increased between 30 to 50% in 1994-5 compared to 1992-3, decreasing the purchasing power of those families that were unsuccessful in producing their own crops.

Other price changes for crops coincided with change in crop yields. The 1994-5 prices for *quinoa*, faba beans, barley grain, forage barley, *cañawa* and alfalfa increased by 400, 300, 200, 100, 70 and 60%, respectively, relative to prices in 1992-3 (Dr. C. Valdivia, IBTA/SR-CRSP, unpublished data). In contrast, the 1994-5 prices for improved sheep were 46% higher, Criollo sheep were 18% higher, milk was 50% higher per litre, and live cattle were 17% higher. The rate of growth was greater for crops due to the drought and frost, the terms of trade being negative towards livestock as an enterprise. The exchange rate of Bolivianos per USD rose 10% from 4.05 to 4.50 between 1993 and 1995 (Dr. C. Valdivia, IBTA/SR-CRSP, unpublished data).

6.2.2 Data analysis

6.2.2.1 Identification of socioeconomic groups

Cluster analysis (Aldenderfer and Blashfield 1984; Romesburg 1990) was used to determine if households could be broken out into socioeconomic groups with distinct strategies (i.e., distinct economic portfolios). Ten variables were used for the cluster analysis. Selection of variables was primarily guided by the previously mentioned framework dealing with the life cycle. Variables are listed below:

(1) Stage of the life cycle for each household. Stage of the life cycle plays a vital role in defining producer social and economic behaviour (Deere and de Janvry 1981; Kusterer 1989). Age of the male head of household (MHH) was one of the proxy variables used for stage of life cycle. Age of the female head of household (FHH) was used if a MHH was absent;

(2) Labour pool for each household. Labour is a critical component that underlies resource exploitation tactics and also changes through the life cycle, so it is another indicator of life stage (Deere and de Janvry 1981; Cotlear 1989; Ellis 1993). A cumulative index for labour pool was used for each household based on age of household members (Deere and de Janvry 1981; Paredes 1995). People >15 years old (i.e., "adults") were given a rank of 1.0, while persons nine to fourteen, six to eight, and four to five years of age had weighted ranks of 0.6, 0.3 and 0.1, respectively (Valdivia and Jetté 1996);

(3) Amount of higher-quality land accessed per household. Land quality in terms of the soil fertility and quantity and quality of soil water resources has a large role in promoting productivity and stability for food and forage crops (Hopkins and Barrantes 1987; Montes de Oca 1989). At SJL the highest quality land was typically used under irrigation for forage production (i.e., alfalfa, forage barley, etc.). Land quality was therefore quantified using total area of cultivated forage accessed per household as a proxy variable;

(4) Household reliance on novel animal production technology for income generation and food production. The number of improved sheep (i.e., improved crosses) owned by each household was used as an indicator of reliance on novel animal production technology. Improved sheep also reflect access to cultivated forage. See Section 4.3.1 (*Human population and resource base*) and Section 5.3.3 (*Management and productivity of sheep*) for information on improved sheep at SJL;

(5) Household reliance on indigenous animal production technology for income generation and food production. The converse of (4) above was estimated by the number of Criollo sheep owned per household. Criollo sheep reflect access to unimproved, rain-fed grazing resources;

(6) Household reliance on novel animal production technology for income generation, market integration and capital asset accumulation. The number of improved dairy cattle owned by each household was used as an indicator for this component. Improved dairy cattle reflect access to cultivated forages. See Section 4.3.3. (*Household production system*) for reviews of the role of smallholder dairying in stimulating income generation and market integration;

(7) Household reliance on indigenous animal production technology for capital asset accumulation. The number of Criollo cattle owned by each household was used as an indicator for this component. Criollo cattle reflect access to unimproved, rain-fed grazing resources;

(8) Off-farm income for households. Off-farm income can help smooth the income stream and be a risk-mitigating component for households (Low 1986; Norman 1992; Reardon et al 1992). Off-farm income can also reflect demand for cash and thus market integration. Annual wages derived from off-farm employment were used for each household as an indicator of reliance on off-farm income;

(9) Level of consumption by households. Level of household consumption of goods and services can reflect wealth (Morduch 1995). Total per capita sum of in-kind and cash income per household was used as an indicator for consumption and household wealth. See Section 4.3.3.2: *Household income synopsis* for a review of income sources for households at SJL; and

(10) Ability of households to capitalize and reinvest. The ability of households to capitalize and reinvest is important (Kusterer 1989). Households at SJL accumulate capital mostly in the form of cattle. Reinvestment can occur when households buy land to build homes in local towns (Dr. C. Valdivia, IBTA/SR-CRSP, unpubl. data). Net income from sales of live cattle was used as a proxy for this characteristic.

Cluster analysis was carried out using the Pearson correlation method in SYSTAT (1992). This matrix-based procedure organised households into groups based on common characteristics. The analysis routine attempts to minimise variation within groups and maximise variation among groups.

Cluster analysis was performed on data for 39 households collected in 1993 and 1995. It was expected that there would be high repeatability between years in that clusters and household membership within clusters would not change.

6.2.2.2 Effects of socioeconomic group and rainfall years on household economy

The Inverse Simpson Diversity Index (Hill 1973) was used to measure the degree of household income diversification (Valdivia et al 1996). The index incorporates the number of distinct, income-generating activities (i.e., cash and in-kind) as well as the relative contribution of each activity to total household income. The index becomes larger when the number of income-generating activities increases and when the relative contributions from each activity become more equitable. The formula for the index is as follows:

$$D = 1/\ p_i^{2}$$

where D is the diversity index value and p is the proportion of the i^{th} income-generating activity. The value for D has a lower limit of 1.0 for a household engaged in only one income-generating activity and an infinite upper limit.

Variation in resources across socioeconomic groups was assessed using t-tests for paired comparisons or with a one-way Analysis of Variance (ANOVA) for multiple comparisons. For the ANOVA, means separation was provided using the Least Significant Difference (LSD) test.

Effect of rainfall year and socioeconomic group on household income sources, total value of production (TVP) and per capita change in consumption were analysed using a split-plot, repeated measures, two-way ANOVA where households were the experimental unit for group and repeated measures were the experimental unit for years. The LSD test was used for means separation. Raw data were log-transformed prior to conducting the ANOVA so they would conform to assumptions of normality and homogeneous variability (SPSS 1998). The main reason for selecting the two-way ANOVA was to examine possible year x group interactions. The basic hypotheses are based on such interactions. One key hypothesis, for example, was that groups more dependent on income from livestock and/or off-farm employment would have income less affected by a drought year compared to that for households with more reliance on income from food crops. Such results would illustrate the effects of group on consumption smoothing across years. Response variables included cash plus in-kind income derived from off-farm wages, food crops, sheep production, cattle production, handicrafts and remittances. These collectively added to total income. The response variable TVP was defined as total income plus the value of cultivated forage production. Cultivated forage production was estimated using figures for forage yield per household along with market prices per unit air-dried weight. Forage yield considered acreage devoted to cultivated forage as well as production per unit area. The rationale for using TVP and thus including forage value was to look at the effect of production capacity from agriculture. Per capita consumption was defined as cash and in-kind income derived from sheep, food crops, wages, handicrafts and remittances. These sources of income provided for important welfare expenditures such as food, clothing, health care and entertainment; consumption expenditures are thus synonymous with household welfare expenditures (see Section 4.3.3*: Household produc-*

tion system). Income from cattle, in contrast, was used for investing in cattle or property and was not a component of household welfare expenditures (Valdivia et al 1995). "Per capita" here refers to an adult equivalent unit (above) and not per head.

Effects of socioeconomic group and key household enterprises on change in annual per capita consumption by households between 1993 and 1995 were also analysed using a multiple regression model to complement the two-way ANOVA approach. In contrast to the ANOVA, where socioeconomic group could obscure effects of individual enterprises, the multiple regression allowed for an analysis whereby effects of specific enterprises could be evaluated. For example, another multiple regression conducted on data collected from 45 households during the near-average rainfall year of 1993 indicated that per capita consumption in SJL households was positively influenced ($P<0.01$, $R^2 = 0.38$, df = 41) by total sheep held, diversity of the economic portfolio (i.e., Inverse Simpson Index) and income transfers or remittances (Valdivia and Jetté 1998). The dependent variable of change in per capita consumption was calculated as 1995 values minus 1993 values for the same 39 households. These were the households that remained in the sample of 1995, as the other families (13%) migrated to other regions such as Villazón, Cochabamba and Argentina. Consumption was constructed from the in-kind and cash income of food crops, the products from livestock consumed by the family, the income from wages which are used for welfare expenditures, and the income from the sales of sheep and milk, which are also reported as being used for consumption. Change in per capita consumption was postulated to be a function of up to six key, independent household variables. These variables included: (1) Change in total income between 1993 and 1995; (2) value of total sheep assets in 1993; (3) value of improved sheep assets in 1995; (4) income transfers in 1995; (5) diversity of the economic portfolio in 1993; and (6) change in the area planted to irrigated forages between 1993 and 1995. The rationale was that consumption change should be positively related to income change (Deaton 1996), sheep assets in 1995, income transfers (Rosensweig and Wolpin 1985; Morduch 1995) and economic diversity (Reardon et al 1992), but negatively related to sheep assets in 1993 and change in forage area. Sheep assets in 1993 were used as an indicator of savings behaviour—anticipation of using sheep sales to cope with future shocks [see the "permanent income hypothesis" in Deaton (1996)]. Households having a smaller change in consumption over the period 1993-5 would have larger sheep flocks, hence the proposed negative relationship. Sheep assets in 1995 would reflect contemporary household emphasis on expendable income in a stressful production year. The reason that value of "total sheep" assets was used in 1993 and "improved" sheep assets in 1995 was to reduce problems of co-linearity among independent variables in the multiple regression. The thought behind the forage component was as follows: If irrigated forage area was increased, risk from drought should be reduced and a smaller change in per capita consumption should result. The model that was constructed was an ordinary, least-squares regression (Deaton 1996). In addition to variables representing enterprises or diversity, dummy variables were also included to incorporate socioeconomic groups.

6.3 Results and discussion

6.3.1 Socioeconomic groups

6.3.1.1 Primary categories

Cluster analysis revealed two primary categories of households, largely defined by the age of household heads and access to labour (Valdivia and Jetté 1996; Valdivia et al 1996). For this presentation we have labeled these groups as: (1) Activos or active (i.e., productive households at a "mid-career" stage in terms of the life cycle); and (2) Pasivos or passive (i.e., less-productive households with elderly household heads in a "retirement" stage of the life cycle). Active households were twice as abundant in the sample of 45 households as passive households were. Statistics contrasting the two groups in terms of livestock holdings, access to irrigated forage, income and economic diversity are displayed in Table 6.1.

Differences between the two groups were marked. Active households held more productive resources and were considerably wealthier than passive households in nearly every category shown in Table 6.1. Compared to passive households, active households had: (1) Heads of household who averaged 20 years younger; (2) more than twice the labour pool; (3) four-times more Criollo sheep; (4) 17-times more improved sheep; (5) 15-times more improved cattle; (6) over 30-times more net income from cattle; (7) over five-times more acreage devoted to irrigated forages; (8) around five-times the cash and total (i.e., cash plus in-kind)

Table 6.1. *Distinguishing features between active ("mid-career") and passive ("elderly") groups of households at San José Llanga in 1993 as identified using cluster analysis.* Source: Adapted from Valdivia and Jetté (1996).[1]

	Household Group	
Variable	Active (n=29)	Passive (n=16)
Age of household head (years)	44 a[2]	65 b
Size of household labour pool (index)[3]	3.4 a	1.5 b
Criollo sheep (no.)	12 a	3 b
Improved sheep (no.)	17 a	1 b
Criollo cattle (no.)	1.3 a	0.7 a
Improved cattle (no.)	3.0 a	0.2 b
Irrigated forage (ha)[4]	3.3 a	0.6 b
Annual total household income (Bolivianos)[5]	8193 a	1720 b
Annual total cash household income (Bolivianos)	662 a	120 a
Annual per capita consumption (Bolivianos)[6]	1167 a	1145 a
Annual cattle net income (Bolivianos)[7]	1474 a	48 b
Inverse Simpson Diversity Index[8]	3.40 a	2.26 b

[1]See text for a description of the cluster methodology and details for socioeconomic groups. USD 1.0 = 4.05 Bolivianos.

[2]Entries within the same row accompanied by the same letter (a,b) were not significantly different according to a *t*-test at $P \leq 0.05$.

[3]Labour index was based on age and gender of family members as in Deere and de Janvry (1981).

[4]Typically alfalfa and barley.

[5]Includes cash and in-kind income.

[6]Considers cash and in-kind income from sheep, food crops, wages, handicrafts and remittances. This income typically represented welfare expenditures and was spent on clothing, food, health and entertainment.

[7]Proxy for capitalisation and investment potential. Net income from cattle was typically reinvested in cattle or property.

[8]Diversity index as in Hill (1973).

level of income; (9) about twice the level of consumption per capita; and (10) half again the level of economic diversity. That age of household heads, and thus stage of the life cycle, was a key discriminatory variable was not surprising. As reviewed in Section 4.3.4: *Non-market factors in resource access*, as household heads age they gradually redistribute their controlled land and livestock resources to their maturing off-spring, through a process of inheritance that starts when the children marry (see Section 4.3.1.2: *Living standards, household structure and human population dynamics*).

Several passive households reported very low as well as high total annual incomes, ranging from 150 to 6232 Bolivianos per year (USD 37 to 1537 per year). Remittances and other transfers from relatives typically appeared to be low, though in the case of the pasivos it was important (60% of them received remittances), especially when food crop income was low, as in 1995. Transfers represented from 6 to 61% of total income, enough to play a smoothing role in consumption (Dr. C. Valdivia, IBTA/SR-CRSP, personal observation). While it is possible that we underestimated income from social reciprocity relationships, the general impression was that a number of passive households were indeed extremely poor (Valdivia and Jetté 1996).

6.3.1.2 Secondary categories

Active households. A major clustering variable which discriminated among households within the active category was whether or not households relied on improved or Criollo livestock breeds. Active households were thus divided into two additional subgroups: (1) Active/improved; and (2) active/Criollo. Household statistics contrasting these two subgroups are displayed in Table 6.2. Compared to active/Criollo, the active/improved households had: (1) Nearly four-times more improved sheep; (2) nearly four-times more improved cattle; (3) about three-times more acreage devoted to irrigated forage; (4) about three-times the cash income, although highly variable; (5) about twice the level of household consumption per capita; and (6) half again the level of net income from cattle. The degree of diversification of economic portfolios was similar between the two subgroups; however, net returns from portfolios differed (Table 6.2). This illustrates that diversification was common regardless of income level.

The active/Criollo subgroup was further divided into two more sub-subgroups based on the quality of land accessed for animal production. One of these sub-subgroups I called active/Criollo/range while the other I called active/Criollo/PIL. In general, these two sub-subgroups were distinguished by location of residence, which in turn influenced quality of forage resources that were accessed, and the distance to the PIL collection centre. Households in the active/Criollo/range category were located nearer to the settlement of *Espíritu Willq'i* where unimproved, native rangeland dominated forage resources (see Figure 3.5 and Section 3.3.2.4: *Land cover*). These households were consequently less able to adopt improved livestock breeds unless they gained access to improved forages through rentals or non-market means. This constraint and the distance to the milk collection building may have undermined the ability of these households to maintain themselves at SJL, as three were in the process of emigrating by 1995 (Dr. C. Valdivia, IBTA/SR-CRSP, unpublished data).

Households of the sub-subgroup called active/Criollo/PIL resided closer to the main *Barrio* and had more routine access to improved pastures, cultivated fodder and a milk market. While this differential access to higher-quality forage did not markedly affect livestock breed composition or numbers for either cattle or sheep between sub-subgroups, it appeared to influence the ability of the active/Criollo/PIL households to sell milk to the local dairy cooperative called PIL [Programa de Industrialización Lechera (Valdivia and Jetté 1996); see Section 2.4.2: *Local society*]. Households in the active/Criollo/PIL sub-subgroup also had slightly younger household heads (i.e., with a mean age of 36 years versus a mean age of 47 years for active/Criollo/range; $P<0.05$) and a slightly larger labour pool (i.e., with an average of 4 labour units versus an average of 2.6 units for active/Criollo/range; $P<0.05$). The level of economic diversity was 2.8 for the active/Criollo/range and 3.6 for the active/Criollo/PIL. Households in the active/Criollo/PIL appeared to be in a transition of increasing their volume of dairy sales by intensifying milk production (Valdivia and Jetté 1996).

Passive households. The passive group was also divided into two subgroups-- these were distinguished ($P<0.05$) according to number of adult labourers per household. We called these either: (1) Passive/couples; or (2) passive/singles. The passive/couples were households where both the MHH and FHH were present. The average labour

Table 6.2. *Distinguishing features between active/improved and active/criollo subgroups of households at San José Llanga in 1993 as identified using cluster analysis.* Source: Adapted from Nolan and Valdivia (1995, 138)[1].

Variable[1]	Active Subgroup: Improved (n=15)	Active Subgroup: Criollo (n=14)
Age of household head (years)	46 a[2]	42 a
Size of household labour pool (index)[3]	3.4 a	3.3 a
Criollo sheep (no.)	4 a	20 b
Improved sheep (no.)	27 a	7 b
Criollo cattle (no.)	0.3 a	2.5 b
Improved cattle (no.)	4.8 a	1.3 b
Irrigated forage (ha)[4]	4.9 a	1.6 b
Annual total household income (Bolivianos)[5]	2561 a	1226 b
Annual total cash household income (Bolivianos)	1000 a	299 a
Annual per capita consumption (Bolivianos)[6]	1561 a	616 b
Annual cattle net income (Bolivianos)[7]	1784 a	1143 a
Inverse Simpson Diversity Index[8]	3.57 a	3.24 a

[1]See text for a description of the cluster methodology and details for socioeconomic groups. USD 1.0 = 4.05 Bolivianos.

[2]Entries within the same row accompanied by the same letter (a,b) were not significantly different according to a *t*-test at $P \leq 0.05$.

[3]Labour index was based on age and gender of family members as in Deere and de Janvry (1981).

[4]Typically alfalfa and barley.

[5]Includes cash and in-kind income.

[6]Considers cash and in-kind income from sheep, food crops, wages, handicrafts and remittances. This income typically represented welfare expenditures and was spent on clothing, food, health and entertainment.

[7]Proxy for capitalisation and investment potential. Net income from cattle was typically reinvested in cattle or property.

[8]Diversity index as in Hill (1973).

pool for passive/couples was two. The passive/singles were households where typically the MHH had died and the FHH was widowed and alone. The average labour pool for passive/singles was one. The dominant types of sheep or cattle held by both subgroups was Criollo which reflected their uniform access to marginal forage resources.

In summary, the cluster analysis for 1992-3 revealed two primary household groups and each of these was broken out into two subgroups. One of the active subgroups was then broken out into two more sub-subgroups. This classification was highly repeatable in 1994-5, indicating robustness (Dr. C. Valdivia, IBTA/SR-CRSP, unpublished data; Aldenderfer and Blashfield 1984). The discriminatory variables also appear very meaningful in relation to factors affecting household productivity, welfare and sustainability. Figure 6.1 depicts the summarised cluster results. Table 6.3 displays variability in other land resources for subgroups. Active subgroups typically had larger land holdings than passive subgroups—particularly in the case of comparisons between active/improved versus passive/singles, which is the result of the latter group bequeathing land to descendants. Compared to passive/singles, the active/improved households had three-times more land devoted to food crops, 11-times more land devoted to alfalfa, and almost twice the area of privately accessed rangeland (Table 6.3).

Overall, we believe that the cluster approach revealed meaningful socioeconomic groups, and this validated the conceptual framework proposed for prioritising variables. Clustering has been used elsewhere to segregate groups within target populations and identify recommendation domains for development interventions (Jamtgaard 1989; Coppock and Birkenfeld 1999). The primary organising factor that discriminated among different groups of households was age of household heads or stage of the life cycle. This supports contentions of Deere and de Janvry (1981) that life cycle is a crucial variable. Our secondary organising factor, namely reliance on improved or traditional breeds of livestock, really was a proxy for resource base. The importance of this factor supports perspectives of Hopkins and Barrantes (1987) and Montes de Oca (1989) that resource base fundamentally conditions and shapes the configuration of the household economic portfolio.

6.3.2. Coping with a drought year

Previously we introduced some general hypotheses regarding variation among socioeconomic groups in term of their ability to mitigate drought. Now that the cantón community has been stratified in terms of socioeconomic features of groups and subgroups, detail can be added to the hypotheses.

Our analysis proceeded at the level of the four subgroups (i.e., active/improved, active/Criollo, passive/singles, and passive/couples). The number of observations per subgroup averaged about 10 with a range of eight to 15. We were interested in the variability among these subgroups in terms of how they mitigated negative effects of a drought year. We were unable to conduct any analyses at a higher level of resolution (i.e., sub-subgroups) because of problems concerning small sample sizes for the two-way ANOVA.

One hypothesis was that all subgroups would exhibit a similar relative decline in the contribution of food-crop income in a drought year compared to an average rainfall year. We expected that contributions of income related to livestock production, off-farm employment, and remittances would increase in a drought year compared to an average year, and that this would mitigate loss of food-crop income to a different degree depending on subgroup. The active subgroups having more livestock, forages and labour were therefore expected to show less of an overall decline in TVP in a drought year compared to passive subgroups. Households at a higher stage in the accumulation process would have less need to deplete their livestock assets (Kusterer 1989). Households in a lower stage of accumulation (Criollo group) would have to increase their sales of livestock products, hence income from this enterprise would increase. Sheep should thus have the most important mitigating role for those households with intermediate to low levels of crop production—in other words, those who would likely have a food deficit. The wealthiest households could conceivably sustain themselves in a drought year by being able to subsist on home-grown crops production and not need to increase sheep sales to buy food.

6.3.2.1 Year effect on income sources for socioeconomic groups

Overall—and somewhat of a surprise—average TVP per household and average total income per household significantly increased on the order of

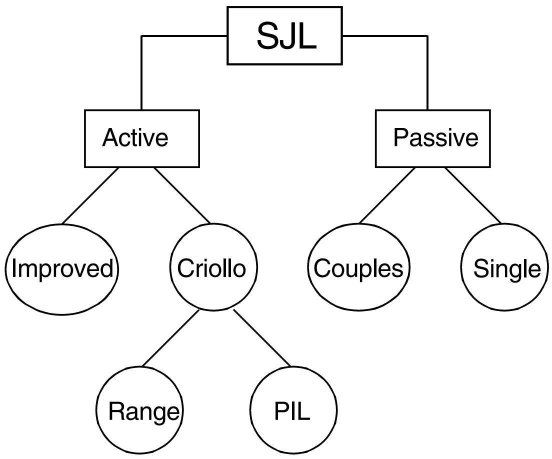


Figure 6.1. *Depiction of socioeconomic groups and subgroups revealed from a cluster analysis of 45 households at San José Llanga for 1993 and 1995.* Source: Dr. C. Valdivia (IBTA/SR-CRSP, unpublished analysis)

60% in the drought year of 1995 compared to the average rainfall year of 1993. The major contributors to this pattern were significant increases in the value of cultivated forage and cattle production in the drought year (Table 6.4) as well as the positive price effect for most crops (see Section 6.2.1: *Data collection*). In contrast, there was no significant effect of year (P>0.05) on the mean household value of off-farm wages, sheep production, food crops, or "other" sources such as handicraft production and remittances. High variability among households, in concert with relatively modest sample sizes, contributed to a lack of significant year effects in wages and sheep income despite apparent marked increases in their mean values between years. High price changes in crops were compensated with low yields which probably was the main factor explaining no effect of year. In aggregate, however, income from sheep plus cattle significantly increased in 1995 compared to 1993 (Table 6.4).

On a relative scale only, the most notable increases in the drought-year household economy compared to the average-year were observed for off-farm wages when all socioeconomic groups were combined (Figure 6.2a,b). The most notable relative decrease between 1993 and 1995 was observed for food crops. Some added descriptive detail on a relative basis was provided by breaking out households into active versus passive subgroups (Figure 6.3a-d). These pie charts illustrate the decrease in the proportion of income generated from food crops. The cause is two fold, first because households had less actual quantity of food produced that they could consume, and second because they had to sell more livestock products, or labour, in order to purchase the food at higher prices.

Main effects of subgroup on income features are shown in Table 6.5. There was statistically significant variation between active and passive subgroups in terms of value of forage, food crops, sheep production, cattle production, total livestock production, total income and TVP.

Year x subgroup interactions were significant (P<0.05) for TVP and forage value. Inspection of patterns indicated that, relative to the average year, active households in the drought year had a greater relative increase in TVP than passive households, the source was forage value (Figure 6.4 a,b). Overall, the average area devoted to irrigated forage production per household increased by 48% from 2.5 to 3.7 ha in 1993 to 1995, respectively (Valdivia and Jetté 1997). The substitution of income from wages and livestock and shift on the crops side to forages are strategies that reduce the vulnerability of the household to climate risks.

Year x subgroup interactions approached significance (0.05<P>0.10) for value of total livestock production, total income and sheep production. These are shown in Figure 6.5 (a-c) for illustrative purposes—patterns suggested that, compared to other subgroups, the active/Criollo subgroup increased total income relatively more in the drought year largely due to increased livestock income derived from sheep, which indicated a strategy to use sheep sales as an income-smoothing mechanism. Year x subgroup interactions were clearly not significant (P>0.230) for all other response variables.

An ANOVA on per capita changes in consumption between 1993 and 1995 showed no significant differences due to socioeconomic group or year, hence patterns are not illustrated. Per capita consumption ranged from a mean of 2295 Bolivianos per year for the active/improved group to 1186 Bolivianos per year for passive groups. While the apparent statistical similarity among groups may be indicative of opportunistic behaviour and a common ability to smooth consumption regardless of wealth or agricultural enterprises, sample sizes may have been inadequate to detect differences given high variability among households.

Table 6.3. ***Land resources accessed by various socioeconomic subgroups of households at San José Llanga in 1993.*** Source: Valdivia and Jetté (1997).[1]

	Active Subgroup		Passive Subgroup	
Land Resource	Improved (n=15)	Criollo (n=14)	Couples (n=8)	Singles (n=8)
Potato cultivation (ha)	1.1 a[2]	0.7 b	0.6 b	0.6 b
Quinoa cultivation (ha)	0.9 a	0.8 ab	0.4 ab	0.3 b
Barley cultivation (ha)	1.0 a	0.7 ab	0.6 ab	0.1 b
Wheat cultivation (ha)	0.1 ab	0.3 a	0.0 b	<0.1 b
Total food crop cultivation (ha)	3.3 a	2.6 ab	1.5 b	1.1 b
Total food crop plots (no.)	6.3 a	5.2 a	4.5 b	2.8 b
Alfalfa cultivation (ha)	3.4 a	1.0 b	0.6 b	0.3 b
Forage barley cultivation (ha)	1.6 a	1.0 ab	0.1 b	0.2 b
Total forage cultivation (ha)	5.0 a	1.9 b	0.7 b	0.5 b
Total irrigated crop production (ha)	1.4 a	0.3 b	0.4 ab	0.9 ab
Total land rentals for food/forage crops (ha)	1.4 a	1.9 a	0.5 a	0.6 a
Private access range (ha)	4.2 ab	7.7 a	0.8 b	3.1 ab
Fallowed cropland (ha)	9.6 a	5.9 ab	1.3 b	5.9 ab
Total grazing access (ha)	13.9 a	13.6 a	2.0 a	9.0 ab

[1]See text for a description of the cluster methodology and details for socioeconomic groups. Households from various subgroups were unevenly distributed within the Cantón of SJL. Six of 15 active/improved were located in *T'olatia*, five of 14 active/Criollo were located in *Espiritu Will'qi*, and seven of passive/couples and passive/singles combined lived in *Savilani*. This affected access to land resources.

[2]Entries in the same row accompanied by the same letter (a,b) were not significantly different according to an LSD test at $P \leq 0.05$.

6.3.2.2 Factors affecting consumption smoothing during a drought

Table 6.6 illustrates results from the multiple regression analysis on determinants of change in per capita consumption between 1993 and 1995. The overall model was significant ($P<0.01$, adjusted $R^2 = 0.71$, df = 32). Hypotheses were supported regarding effects of income, sheep assets and income transfers in reducing variation in consumption (all at $P<0.05$). Economic diversity approached significance, while change in area planted to irrigated forage was not significant.

The multiple regression was more illuminating than the ANOVA in revealing sources of change

Table 6.4. *Main effects of rainfall year on various household income components (in Bolivianos) for 39 campesino households at San José Llanga during 1993 and 1995*[1].

	Rainfall Year		
Income Category[2]	1993 (Average)	1995 (Drought)	P
Off-farm wages	509	1598	0.21
Cultivated forage	1699	3163	<0.01
Cultivated food crops	1402	1313	0.98
Sheep production	763	1315	0.29
Cattle production	1282	2073	<0.01
Total livestock production[3]	2045	3388	<0.01
Other[4]	233	234	0.22
Total income[5]	4189	6533	<0.01
TVP[6]	5889	9696	<0.01
Per capita consumption[7]	1159	2396	0.95

[1]Where USD 1.0 = 4.05 Bolivianos. Tabulated P values are based on ANOVA using log-transformed data.

[2]Categories include cash and in-kind components.

[3]Sheep production plus cattle production.

[4]Value of handicrafts plus remittances.

[5]Includes all categories except cultivated forage (i.e., wages, crops, sheep, cattle and other).

[6]Includes all categories (i.e., wages, forage, crops, sheep, cattle and other).

[7]Includes income from sheep, food crops, wages and other. This income was typically used for welfare expenditures (i.e., clothing, food, health, etc.)

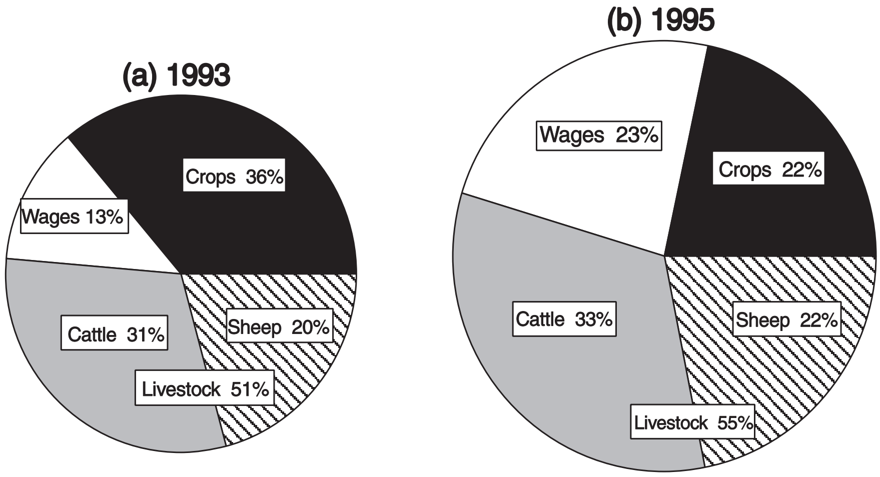


Figure 6.2 (a,b). *Distribution of total income from crops, livestock, wages and other sources for 39 campesino households at San José Llanga in: (a) 1993, a year of near-average precipitation; and (b) 1995, a drought year. Total income increased overall in the drought year by 64% compared to near-average 1993.* Source: Dr. C. Valdivia (IBTA/SR-CRSP, unpublished data)

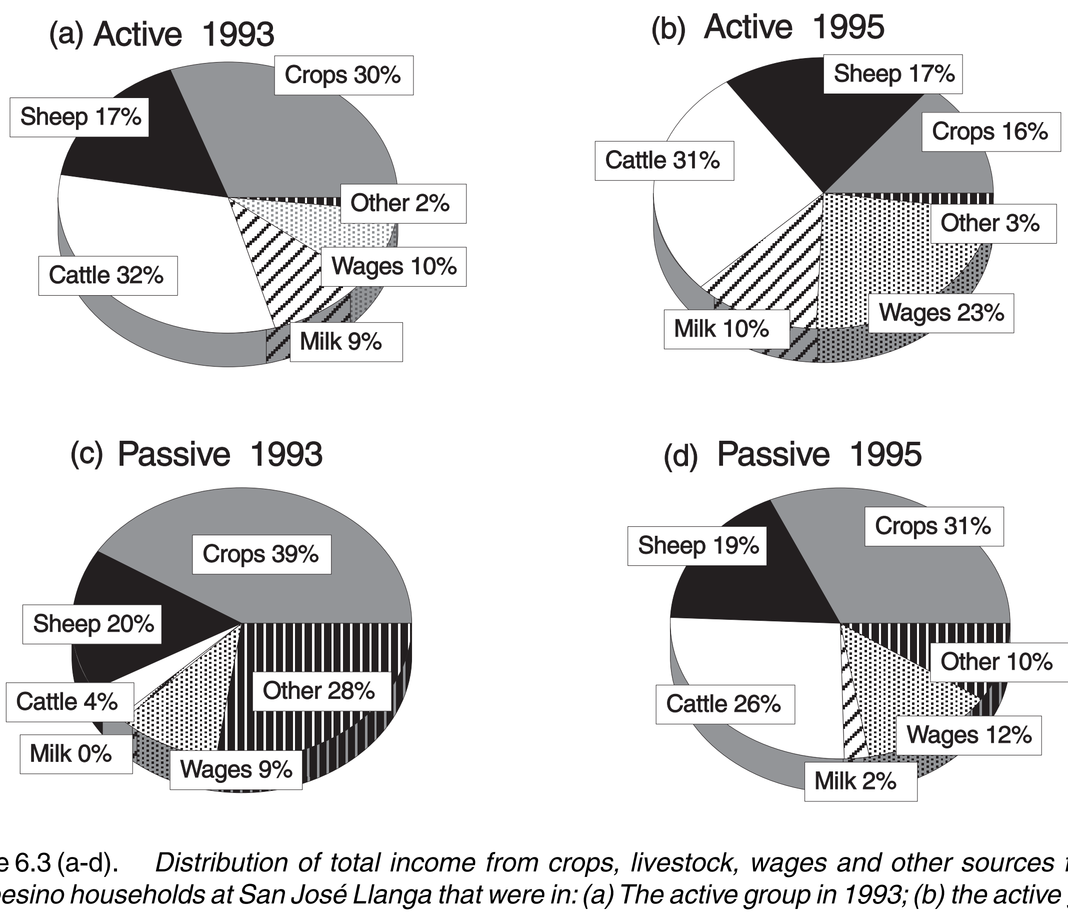


Figure 6.3 (a-d). *Distribution of total income from crops, livestock, wages and other sources for 39 campesino households at San José Llanga that were in: (a) The active group in 1993; (b) the active group in 1995; (c) the passive group in 1993; and (d) the passive group in 1995.* Source: Dr. C. Valdivia (IBTA/SR-CRSP, unpublished data)

Table 6.5. *Main effects of socioeconomic subgroup on various household income components (in Bolivianos) for 39 campesino households at San José Langa during 1993 and 1995.*[1]

	Subgroup				
	Active		Passive		
Income Category[2]	Improved	Criollo	Couples	Singles	P
Off-farm wages	2262a[3]	584a	302a	167a	0.57
Cultivated forage	4843a	1819ab	331c	881bc	<0.01
Cultivated food crops	2265a	1223ab	692b	495b	<0.01
Sheep production	1438a	1505a	345b	367b	<0.01
Cattle production	3042a	1740a	506b	194b	<0.01
Total livestock production	4481a	3247a	851b	561b	<0.01
Other[5]	224a	198a	446a	60a	0.77
Total income[6]	9232a	5252a	2292b	1282b	<0.01
TVP[7]	14 076a	7072a	2623b	2163b	<0.01
Per capita consumption[8]	2829	1102	1756	666	

[1]Where USD 1.0 = 4.05 Bolivianos. Tabulated P values are based on ANOVA using log-transformed data.

[2]Categories include cash and in-kind components.

[3]Entries in the same row followed by the same letter (a,b,c) were not significantly different (P<0.05) according to overlap of 95% confidence limits on log-transformed means.

[4]Sheep production plus cattle production.

[5]Value of handicrafts plus remittances.

[6]Includes all categories except cultivated forage (i.e., wages, crops, sheep, cattle and other).

[7]Total value of production includes all categories (i.e., wages, forage, crops, sheep, cattle and other).

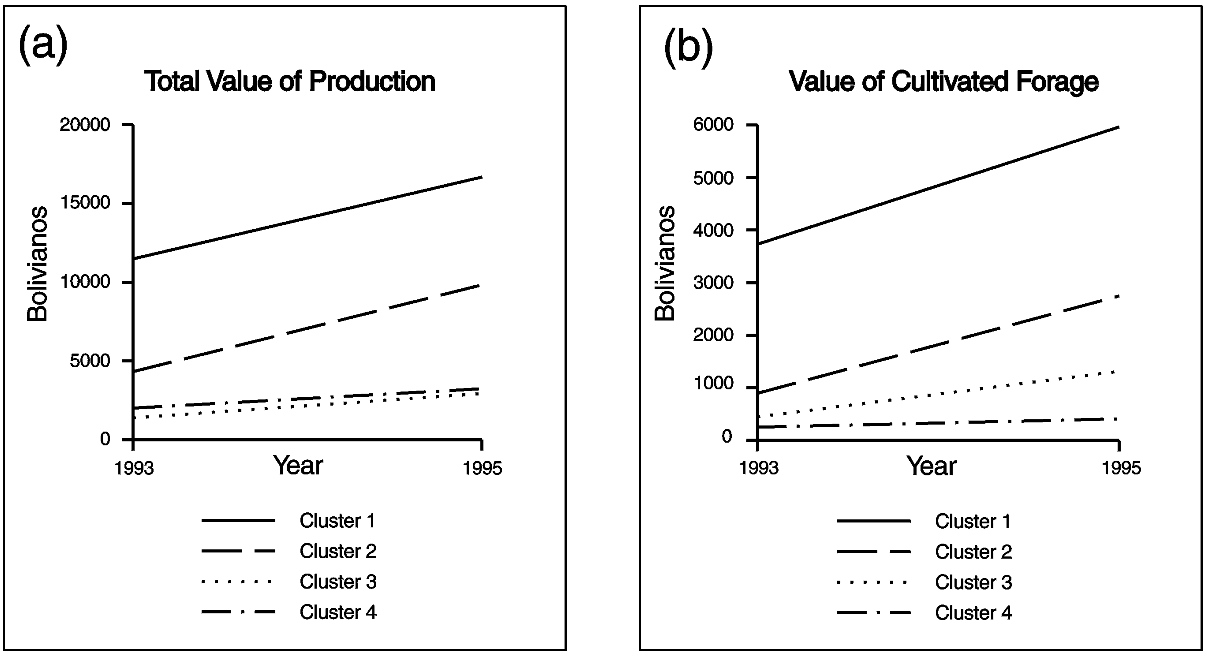


Figure 6.4 (a,b). *Significant year x subgroup ANOVA interactions for: (a) Total value of production (TVP; P=0.017); and (b) value of cultivated forage (P=0.05). Data were based on 39 campesino households from four socioeconomic subgroups. The two active groups tended to have "mid-career" households with larger, more-diverse enterprises, while the two passive groups tended to have "retired" household heads. The year 1993 was near-average in terms of rainfall, while 1995 was a drought year. See text for details including definitions of response variables. Cluster 1 was the active/improved, cluster 2 was the active/Criollo, cluster 3 was the passive/couples and cluster 4 was the passive/singles.* Source: Dr. C. Valdivia (IBTA/SR-CRSP, unpublished analysis)

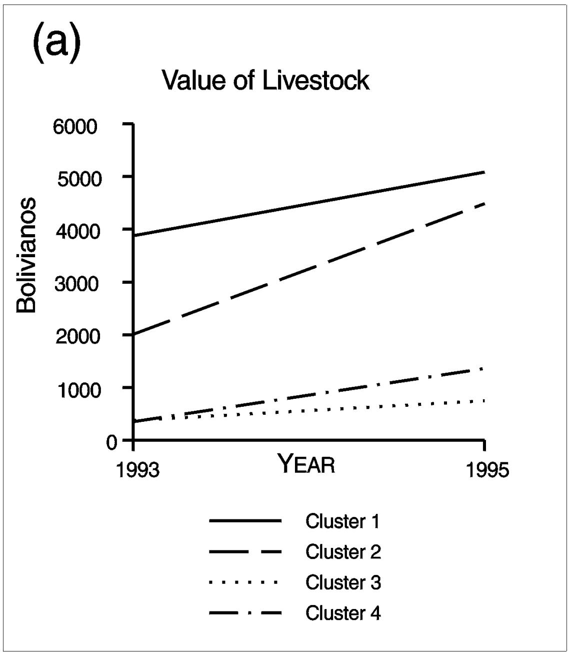
in per capita consumption. The role of income, sheep assets and income transfers in dampening variation in consumption during a perturbation confirms other findings in the literature (Kusterer 1989; Morduch 1995). Our results highlight the role of small ruminants as a source of cash for household purchases and as a buffer when food shocks take place (Fafchamps et al 1998). The role of diversification was two-fold; maximizing use of resources (Ellis 1993) and as an *ex-ante* strategy to smooth income and consumption (Morduch 1995; Valdivia et al 1996). Unlike von Braun et al (1989) and Bromley and Chavas (1989), we have found diversification to occur at all levels of income, decreasing only at older stages in the life cycle, as in Kusterer (1989).

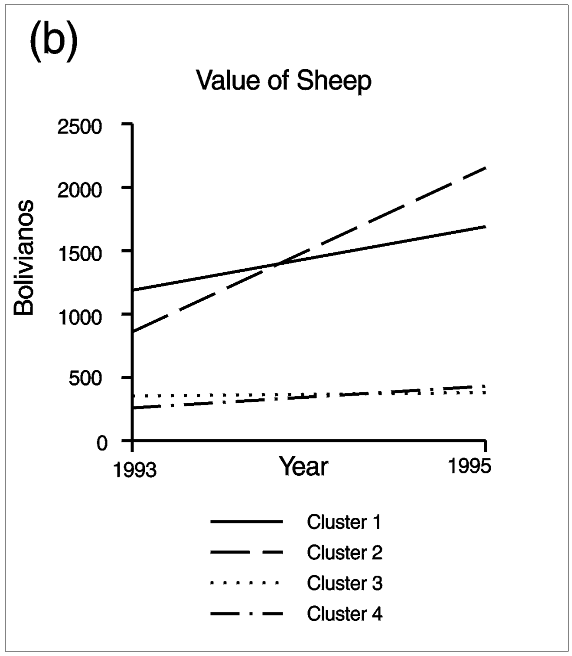
During our relatively brief period of research from 1991-5, it appeared as though the community of SJL was shifting towards more livestock production, which may be part of a coping response to a drier climatic phase (see Section 3.3.1: *Climate*). There was no collective mechanism to respond to the increased inequality caused by the climatic shock. There were mechanisms to reduce the impact of drought, such as the projects to develop irrigation and access to water. These efforts did not differentially affect active and passive members. Instead, they differentially affected people residing in various locations.

The shifts observed illustrated that household economic portfolios were dynamic and opportunistic, and strategies appeared to maintain a dual nature with regards to production for market as well as for home consumption. Food crop production is not abandoned here with the advent of improved markets (Valdivia and Jetté 1997, 1998). Producers assimilated new technology when appropriate as well as retained indigenous methods (see Chapter 7: *Patterns of technology adoption at San José Llanga*).

6.4 Conclusions

The framework proposed by investigators such as Norman (1992) and Valdivia and Jetté (1996) was validated through use of cluster analysis. We iden-





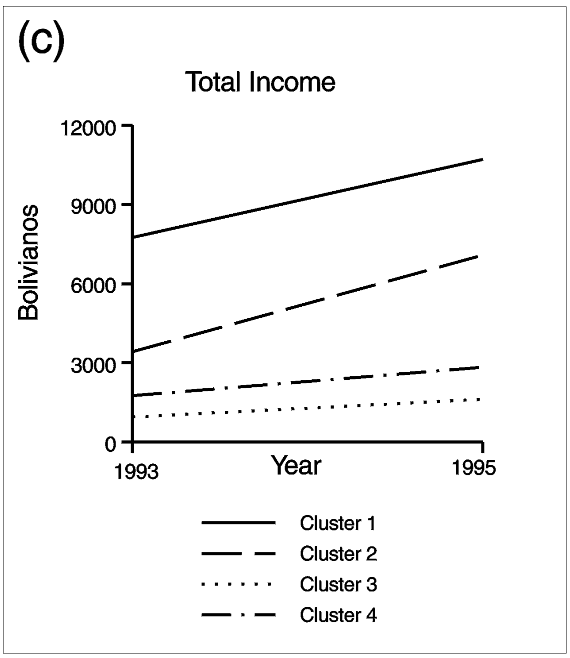


Figure 6.5 (a-c). *Year x subgroup ANOVA interactions that approached significance (0.08< P<0.10) for: (a) Value of livestock that includes sheep and cattle; (b) value of sheep; and (c) total income. Data were based on 39 campesino households from four socioeconomic subgroups. The two active groups tended to have "mid-career" households with larger, more diverse enterprises, while the two passive groups tended to have "retired" household heads. The year 1993 was near-average in terms of rainfall, while 1995 was a drought year. See text for details including definitions of response variables. Cluster 1 was the active/improved, cluster 2 was the active/Criollo, cluster 3 was the passive couples and cluster 4 was the passive singles.* Source: Dr. C. Valdivia (IBTA/SR-CRSP, unpublished analysis)

Table 6.6. *Statistics pertaining to a multiple regression where change in per capita consumption was analysed as a function of income, sheep assets, income transfers, economic diversity, and change in area planted to irrigated forages. Change was measured using the difference between variables in 1993, a near-average year for rainfall, and 1995, a drought year. The overall regression model was significant ($P<0.01$; adjusted $R^2 = 0.71$; $df = 32$).* Source: Dr. C. Valdivia (IBTA/SR-CRSP, unpublished data).

	Statistics			
Variable	Coefficient[1]	SE	*t*	P
Constant	-629.07	436.33	-1.44	0.159
Per Capita Income Change[2]	0.17	0.03	6.54	0.001
Sheep Assets 1993[3]	-23.27	0.61	-2.42	0.021
Improved Sheep Assets 1995[4]	17.37	7.07	2.51	0.017
Transfer of Income 1995[5]	1.32	0.37	3.53	0.001
Diversity Index[6]	259.19	140.96	1.83	0.075
Forage Area Change[7]	-81.04	94.96	-0.85	0.400

[1]Potential bias in coefficients was reduced by using two proxy measures for sheep assets that were not correlated (see below).

[2]Per capita income in 1995 minus per capita income in 1993 for each household.

[3]Indicative of savings behaviour in anticipation of future calamity.

[4]Indicative of current disposable assets in a drought year.

[5]Remittances, etc., from off-farm employment accruing to the household in a drought year.

[6]Inverse diversity index (Hill 1973). See text for details.

[7]Area planted to irrigated forages per household in 1995 minus the same for 1993.

tified various groupings of households that had varied income-generation strategies. These strategies were primarily conditioned by stage in the life cycle (i.e., age of household heads and size of labour pools), secondarily by the type of resources controlled by households, and lastly by access to marketing outlets.

In an economic sense, households at SJL coped with a one-year drought using diverse means including sheep sales, remittances and increased income from food crops that increased in value. This supported the literature on consumption smoothing, and illustrated that sheep, off-farm employment options and viable markets play key roles in promoting food security. Other implications are reviewed in Chapter 8: *Conclusions and recommendations*.

6.5 Literature cited

Aldenderfer M. and Blashfield R. 1984. *Cluster Analysis*. Sage University Paper 44. Sage Paper Series. Quantitative Applications in Social Sciences, Newbury Park, California, USA. 87 pp.

Alberti G. y Mayer E. 1974. *Reciprocidad e Intercambio en los Andes Peruanos*. IEP (Instituto de Estudies Peruanos), Lima, Perú. 308 pp.

Bromley D. and Chavas J. 1989. On risk, transactions, and economic development in the semiarid tropics. *Economic Development and Cultural Change* 3:719-736.

Céspedes J. y Rodríguez L. 1996. E*valuación y Pronóstico de la Producción El Punto de Vista del Productor Campesino*. Imprenta papiro. La Paz, Bolivia. 24 pp.

Coppock D.L. and Birkenfeld A. 1999. Use of livestock and range management practices in Utah. *Journal of Range Management* 52:7-18.

Cotlear D.1989. *Desarrollo Campesino en los Andes. Cambio Tecnológico y Transformación Social en las Comunidades de la Sierra del Perú*. IEP (Instituto de Estudies Peruanos), Lima, Peru. 325 pp.

Deaton A. 1996. *The Analysis of Household Surveys.* Johns Hopkins University Press, Baltimore, Maryland, USA. 479 pp.

Deere C. and de Janvry A. 1981. Demographic and social differentiation among northern Peruvian peasants. *The Journal of Peasant Studies* 8(3):335-366.

Ellis F. 1993. *Peasant Economics and Agrarian Development*. Second edition. Cambridge University Press, Cambridge, UK. 309 pp.

Fafchamps M. 1992. Cash crop production, food price volatility, and rural market integration in the third world. *American Journal of Agricultural Economics* 74:90-99.

Fafchamps M., Udry C. and Czukas K. 1998. Drought and saving in West Africa: Are livestock a buffer stock? *Journal of Development Economics* 55(2):273-305.

Hill M. 1973. Diversity and evenness: A unifying notation and its consequences. *Ecology* 54:427-432.

Hopkins R. y Barrantes R. 1987. El desafío de la diversidad: Hacia una tipología de la agricultura campesina. En: Gonzales de Olarte E. (ed), *La Lenta Modernización de la Economía Campesina. Diversidad, Cambio Técnico y Crédito en la Agricultura Andina.* IEP (Instituto de Estudies Peruanos), Lima, Peru. 231 pp.

Jamtgaard K.1989. Targeting production systems in the Small Ruminant CRSP: A typology using cluster analysis. In: McCorkle C.M. (ed), *The Social Sciences in International Agricultural Research Lessons from the CRSPs.* Lynne Rienner Publishers, Boulder, Colorado, USA. 266 pp.

Kusterer K. 1989. Small-Farmer attitudes and aspirations. *AID Programme Evaluation Discussion Paper* No. 26, June. Washington DC. 36 pp.

Low A. 1986. *Agricultural Development in Southern Africa: Farm Household-Economics and the Food Crisis.* James Currey Co., London, UK. 217 pp.

Montes de Oca I. 1989. *Geografía y Recursos Naturales de Bolivia*. Editorial Educación del Ministerio de Educación y Cultura. La Paz, Bolivia. 574 pp.

Morduch J. 1995. Income smoothing and consumption smoothing. *Journal of Economic Perspectives* 9:103-114.

Norman D. 1992. Household economics and community dynamics. In: Valdivia C. (ed), *Sustainable Crop-Livestock Systems for the Bolivian Highlands. Proceedings of an SR-CRSP (Small Ruminant Collaborative Research Support Program) Workshop, held at Lubbock, Texas, USA, 14-17 May 1991.* pp. 39-70.

Paredes V. 1995. Género y participación de la mujer dentro de un sistema agropastoril. BA draft tesis, Universidad Mayor de San Andrés, La Paz, Bolivia. 170 pp.

Reardon T., Delgado C. and Matlon P. 1992. Determinants and effects of income diversification amongst farm households in Burkina Faso. *The Journal of Development Studies* 28:264-296.

Romesburg C. 1990. *Cluster Analysis for Researchers*. Robert E. Krieger Publishing Co., Malabar, Florida, USA.

Rosenzweig M. and Wolpin K. 1985. Specific experience, household structure, and intergenerational transfers: Farm family land and labor arrangements in developing countries. *Quarterly Journal of Economics* 100(supplement):961-987

SPSS (Statistical Package for the Social Sciences). 1998. *SPSS™ for Windows Professional Statistical Release 8*. SPSS Inc., Chicago, Illinois, USA.

SYSTAT. 1992. *SYSTAT for Windows: Statistics Version 5.* SYSTAT, Evanston Illinois, USA. 750 pp.

Valdivia C., Dunn E. and Jetté C. 1996. Diversification as a risk management strategy in an Andean agropastoral community. *American Journal of Agricultural Economics* 78(December):1329-1334.

Valdivia C., Dunn E. and Sherbourne J. 1995. *Gender, Livestock and Household Peasant Production: Dairy and Diversification in Crop-Livestock Systems of an Andean Community*. IBTA/SR-CRSP (Instituto Boliviano de Tecnología Agropecuria/Small Ruminant Collaborative Research Support Program). IBTA 165/Boletín Técnico 33/SR-CRSP 31, La Paz, Bolivia.

Valdivia C. and Jetté C. 1996. *Peasant Households in Semi Arid San José: Confronting Risk Through Diversification Strategies*. IBTA/SR-CRSP (Instituto Boliviano de Tecnología Agropecuria/Small Ruminant Collaborative Research Support Program). IBTA 181/Boletín Técnico 49/SR-CRSP 47, La Paz, Bolivia. 24 pp.

Valdivia C. and Jetté C. 1997. *Peasant Household Strategies, Technologies and Diversification in Andean Fragile Lands.* Agricultural Economics Working Paper AEWP-1997-6. University of Missouri, Columbia, Missouri, USA. 16 pp.

Valdivia C. and Jetté C. 1998. *La Diversificacion en los Andes: Estrategia de Riesgo o Crecimiento Económico en el Altiplano Central Boliviano.* Tercer Simposio Latinoamericano Sobre Investigación y Extensión en Sistemas Agropecuarios. Nuevos Enfoques Para la Superación de la Pobreza Rural y Para el Desarrollo de las Capacidades Locales. Lima, Peru.

von Braun J., Hotchkiss D. and Immink M. 1989. *Nontraditional Export Crops in Guatemala: Effects on Production, Income, and Nutrition*. IFPRI (International Food Policy Research Institute). Research Report 73. Washington, DC, USA. 99 pp.

Chapter 7

Patterns of technology adoption at San José Llanga: Lessons in agricultural change

Patrones de adopción tecnológica en San José Llanga: Lecciones sobre el cambio agrícola

by Lisa Markowitz and Corinne Valdivia

Summary

Technological development programs on the Altiplano were introduced with the hopes of increasing productivity and supply of commodities for domestic and international markets. The development paradigm has been based on the promotion of "modernisation," which pervades aid efforts throughout the world. This paradigm is founded on the belief that technologies developed elsewhere could be diffused in developing countries. This chapter presents the economic and social events that influenced the fate of key technological innovations at San José Llanga (SJL), including characteristics of households and resources that influenced technology adoption. Attention is also given to how technologies have influenced the sustainability (e.g., household reproduction) of the system.

Three spheres of technological change were analysed that spanned 30 years: Sheep, potatoes and dairy. Interdisciplinary approaches in social sciences were used to study technical change. These have a greater emphasis on anthropology, sociology and economics to understand paradigm shifts in technology diffusion. Methods used to collect data included informal and formal interviews of sampled households. Analyses for sheep involved SJL and other neighbouring communities while analyses for dairy and potatoes focused solely on SJL.

Several development programs were introduced on the central Altiplano starting in the mid-1950's. One of the first efforts was creation of the Patacamaya Experiment Station with support of the Institute for Inter-American Affairs, a US technical assistance program. This station focused on improvement and management of sheep. International cooperation in the 1950s and 1960s promoted production of improved sheep with an extension emphasis on distribution of Corriedale rams and supporting technologies. Between 1965 and 1975 a sheep production and marketing program was introduced to improve wool exports—Utah State University was an important collaborator. Our study of the long-term outcome of this effort, involving 80 households in seven communities, revealed that improved sheep have been an important component of production systems even though wool markets are no longer attractive. Adoption patterns for improved sheep indicated that community location (in the plains) and training through extension programs were positive factors increasing the likelihood that improved sheep would be adopted.

An effort to improve food supply was introduction of new potato varieties suitable for urban consumption during the mid-1960s. Traditionally only "bitter" varieties adapted to the Altiplano environment were grown by peasant households. Traditional growing methods included use of sheep manure as fertiliser and tillage with human labour or animal draft power. The new technological package included use of chemical fertiliser and tractors for tillage. A cooperative was formed at SJL and a tractor was purchased on credit by the community. The cooperative eventually disintegrated, but producers continued to plant these new potato varieties—they remained common through 1995. Emphasis on introduced potato varieties was diminished with the drought of 1982-3. Despite a decline in emphasis on production of improved potatoes, the ancillary technologies of chemical fertilisers and tractor tillage remained widespread at SJL in the 1990s.

Dairy is the latest technological change, and this has boomed on the central Altiplano. A secure market with infrastructure, price supports, extension programs and credit were factors explaining how two-thirds of households at SJL became involved in this activity between 1989 and 1995. A drought also motivated producers to seek income via smallholder dairying. A study of fac-

tors that explain the probability of adoption of dairy husbandry using a logistic regression analysis revealed that increased access to alfalfa fields and level of wealth (e.g., income) had significant and positive effects.

The blending of new and traditional technologies has led to diversification and opportunism rather than specialisation predicted in the "Modernisation Paradigm." By incorporating new technologies in varying proportions, producers guaranteed their household consumption requirements and gained advantage from markets when possible. Rather than specialisation, diversification seemed to be the strategy for persistence and growth in this region characterised by erratic economic and climatic features.

We found that the impacts of technological changes were not merely neutral or positive. Increase in the use of tractors has resulted in an increased labour demand for weeding and herding sheep, both female activities. The probability of adopting dairy was affected by income and quality of resources available to households; therefore, wealthier producers have been able to initially capture most of the benefits of this technology. For improved potato production, chemical fertilisers and herbicides were required to obtain profitable yields. Therefore wealthier households with cash were also able to invest in this technology and reap initial benefits. Chemical fertilisers, by replacing manure, may have led to soil management problems. Benefits of technology adoption, overall, have accrued more to wealthier groups. More labour burdens have been placed on females.

The community of SJL has provided a useful case study of technology transfer. The community has successfully integrated improved sheep and potatoes into the traditional production system, although emphasis on innovations waxes and wanes with market opportunities. Overall, technology adoption has been a dynamic and somewhat episodic process. The trend towards modernisation may be gradually undermining the ability of the community to grow their own food, possibly due, in part, to unintended consequences of technology packages and increasing monetisation.

A critical lesson is that change is the rule, not the exception. The current dairy boom will also end some day and other opportunities may come forward. Technical, outreach and policy measures should therefore promote a dynamic market awareness and an opportunistic capacity to respond to change in communities like SJL.

Resumen

En el Altiplano, se han llevado a cabo muchos proyectos de cambio tecnológico con el objeto de incrementar la producción y la oferta para los mercados doméstico e internacional. El paradigma de desarrollo tecnológico ha estado basado en la "modernización" —concepto prevaleciente en las agencias de desarrollo en el mundo—que fomenta el incremento de la especialización como base de la eficiencia económica y por lo tanto del crecimiento. Este capítulo presenta los eventos históricos, económicos, y sociales que fueron claves en la introducción de tecnologías en San José Llanga. Se estudian las características de las unidades económicas familiares y sus recursos con relación a la adopción de nuevas tecnologías. El papel de género también es discutido, al mismo tiempo que la influencia de todos estos cambios tecnológicos en la sustentabilidad del sistema de producción.

En este capítulo se estudian tres esferas de cambio tecnológico que abarcan 30 años de la historia de San José. Los cambios en las esferas de producción de papa, del ganado ovino, y del vacuno. Los métodos utilizados para la recolección de información de los estudios que sustenta este capítulo incluyen encuestas formales, entrevistas formales e informales, y la revisión de material histórico relacionado a los eventos que motivaron estos cambios. En el caso del estudio de las tecnologías de ovino introducidas en los sesenta, se hizo una encuesta de 80 productores en 7 comunidades de la zona del altiplano. En el estudio de la ganadería lechera el análisis se informa de dos encuestas, una de 45 productores jóvenes de la comunidad, y una segunda encuesta para el estudio de género y ganadería con selección de 45 familias al azar que representan toda la población de la comunidad. Para el estudio de la papa se contó con los estudios de tesis sobre cambio tecnológico en la producción de la papa, y sobre los costos de las tecnologías de papa. El análisis de cambio tecnológico se hace a partir de un enfoque interdisciplinario en ciencias sociales, que incluye la antropología, la economía, la historia y la sociología. Este enfoque nos permite comprender mejor el paradigma de desarrollo y las acciones de las familias de San José.

A partir de mediados de los cincuenta, se introdujeron muchos cambios tecnológicos en SJL, comenzando por el establecimiento de la Estación Experimental de Patacamaya con el apoyo del Instituto de Asuntos Interamericanos de los Estados Unidos. Esta estación tenía como una de sus misiones la investigación para el mejoramiento de la producción ganadera, en esos tiempos con énfasis en el mejoramiento ovino. Con este programa de apoyo se distribuyeron carneros Corriedale, al igual que otras tecnologías para su manejo. Entre 1965 y 1975 el programa para la producción y comercialización de ovinos se difundió con la colaboración de la Universidad del Estado de Utah, con la esperanza de mejorar la exportación de lana. Un estudio del efecto de este programa, en 1993 con 80 productores de la zona en 7 comunidades campesinas del altiplano, muestra que los ovinos mejorados persisten como una tecnología, aún cuando ya no se exporta lana. El estudio de adopción muestra que el factor agroecológico, comunidades situadas en la pampa, influyen positivamente en las posibilidades de adopción. La propiedad del ganado ovino criollo también influencia positivamente las probabilidades de adopción del ganado mejorado. Una sorpresa del estudio es que la variable género no es significativa, a pesar de que esta actividad es del dominio de las mujeres. Problemas de autoselección pueden explicar este resultado, pues la muestra sólo tenía un 25% de mujeres encuestadas. Un segundo esfuerzo para incrementar la oferta al mercado se hizo con los cambios tecnológicos en la producción de nuevas variedades de papa con mayor demanda en zonas urbanas, la papa blanca. Esto sucedió a mediados de los sesenta. En esta zona las variedades de papa amarga eran cultivadas con el principal objetivo de satisfacer las necesidades del hogar. El cambio tecnológico comprendió nuevas variedades, el uso de fertilizantes químicos y el uso del tractor. Para acceder al crédito se creó una cooperativa, la que luego se disolvió. Sin embargo los productores continuaron con la producción de las nuevas variedades. El auge de esta actividad terminó con la sequía del 1982-1983. Los productores en las entrevistas realizadas reportaron que la producción desde ese entonces no ha sido la misma. Sin embargo los estudios muestran que se continúa con estas variedades de papa dulce, en combinación con las amargas, al igual que se continúa con el uso del tractor en la preparación del terreno. La ganadería lechera es la última actividad introducida en esta comunidad, y está en auge en todo el altiplano. Un mercado seguro, precios fijos, programas de extensión y crédito, son algunos de los factores que han hecho posible este auge. En este capítulo se muestran las características que influyen en su adopción. Los productores de San José han optado por mantener una diversidad de actividades, lo cual se refleja en el portafolio económico. En vez de optar por la especialización, se ha optado por un comportamiento oportunista, que les permite aprovechar las tecnologías que los ayuden a persistir en la región, y acumular, en vez de incrementar su vulnerabilidad frente al ambiente o al mercado. Encontramos que el cambio tecnológico no es neutral. Los cambios en las variedades de papa y la ganadería lechera han beneficiado más a las familias de más recursos. Todas las tecnologías han aumentado la demanda del trabajo femenino, pues son ellas las que ordeñan, deshierban, y pastorean el ganado. Por eso señalamos que las tecnologías no han tenido un impacto neutral. Tampoco lo han sido en su impacto en el medio ambiente, pero más estudios son necesarios para determinar las causas de la degradación en los campos de cultivo y los problemas de salinidad en los de regadío.

La comunidad de SJL nos ha proporcionado un estudio de caso muy útil para entender la transferencia de tecnología. La comunidad ha logrado integrar exitosamente el ganado mejorado y la producción de nuevas variedades de papa a su sistema de producción, aun cuando el énfasis en las innovaciones decrece cuando las oportunidades del mercado desaparecen. Sobre todo, la adopción de tecnología ha sido dinámica y más o menos un proceso episódico. Las tendencias hacia la modernidad pueden socavar la habilidad que tienen las comunidades de producir sus propios alimentos, en parte debido a las consecuencias no esperadas de los paquetes tecnológicos, y al incremento en la monetización de su economía.

Una lección crítica de este capítulo es que el cambio es la regla y no la excepción. El auge actual en la lechería también terminará un día, y puede ser que entonces se presenten otras oportunidades. Las medidas de carácter técnico, de extensión y de política deben por lo tanto promover un conocimiento constante de las dinámicas del mercado y una capacidad para responder oportunistamente al cambio en comunidades como SJL.

7.1 Introduction

As previously noted in Chapter 4: *Household economy and community dynamics at San José Llanga*, the production system incorporated a mix of introduced and indigenous technologies. This reflected the community's history as recipient of imported technologies and use of time-tested local practices to meet the challenges of food production on the central Altiplano. The ability of local residents to opportunistically and effectively integrate innovations into their productive regime in response to changing economic conditions has played a large part in helping maintain a diversity of crop and livestock enterprises that facilitates coping with perturbations (Jetté 1993; Murillo and Markowitz 1995; Chapter 6: *Household socioeconomic diversity and coping response to a drought year at San José Llanga*). This reliance on diversity contrasts with predictions of classical modernisation theory which holds that economic growth and specialisation go hand-in-hand, the latter being a condition for the former to take place (Bromley and Chavas 1989). In San José Llanga we have found an alternative path, namely one of opportunistic behaviour that maintains flexibility and diversification that ensures cash and in-kind income in the face of climatic and market vicissitudes (Chapter 6: *Household socioeconomic diversity and coping response to a drought year at San José Llanga*).

The objectives for this chapter include determination of: (1) How social and economic events have influenced key phases of technology transfer at San José Llanga (SJL); (2) how household-level factors have influenced adoption of new technology; (3) whether males and females, as well as various wealth classes, have similarly benefited from adoption of new technology; and (4) whether technology adoption has influenced sustainability of the production system. Answering these questions helps us understand what factors facilitate or constrain technology transfer to rural producers. Technology transfer is a vital, culminating and problematic process for research.

To achieve these objectives, this chapter takes a chronological approach to tracing the course of technological intervention and uptake at SJL to understand development and configuration of the current production system. The account integrates material from a number of independent investigations to examine technological change in three critical spheres of household production: Sheep, potatoes and dairy. The history and policy antecedents of each episode of intervention are described both to better contextualize SJL within broader political-economic systems and to identify critical points of macro-micro articulation (Berdegué and Escobar 1995; Valdivia 1995).

7.2 Methods

7.2.1 Review of technology paradigms

Placing technological interventions at SJL within a broader framework recognises that technologies are not neutral in either their genesis, dissemination or local impacts; nor can these processes be fully assessed without consideration of the overarching political economy (Biggs and Clay 1988; Smillie 1991; Pfaffenberger 1992). This perspective departs from the relatively non-problematic treatment of technology within the Modernisation Paradigm which informed the creation and operation of most of the programs that have influenced the contemporary system of SJL. Modernisation theory posits the presence of modern and traditional sectors and assumes the goal of development is transformation of the traditional into the modern. Transfer of technology is key in that it offers a means to accelerate this transformation (Biggs and Clay 1988: 22-3). In this vision of development, technology itself becomes a positive, modernising force (Escobar 1995, 36). Accordingly, the ability to specialise is a reflection of economic development (Bromley and Chavas 1989).

Challenges to this understanding of technology transfer have arisen from many theoretical quarters, but three in particular inform our approach. Recent work in a post-structuralist vein examines the political and ideological underpinnings of this notion of transformation and contends that the language, assumptions and institutions that constitute the development enterprise have served to perpetuate global inequalities (Sachs 1992; Escobar 1995). This provocative critique, although difficult for many involved in agricultural development to embrace, compels attention to the political and historical contexts of technical assistance programs.

At a more operational level, systems-oriented researchers have documented the important interactions between technology uptake and policy, support systems and macro-conditions (Valdivia 1995), matters too often excluded from consideration by their definition as "external parameters." A recent review of the systems approach in Latin America calls for greater attention to non-farm variables in general and "intermediate agrarian institutions" in particular (Berdegué and Escobar 1995; Valdivia 1995). This expanded focus has characterised social science research in the IBTA/SR-CRSP project and here we emphasise the nature of extension work in the region and community.

A third challenge arises from scholars and development practitioners who have combined concepts from agroecology with an interest in the revalorisation of Andean technologies. In the face of the diffusion of imported technologies and the denigration of Andean cultures, there is burgeoning recognition that recuperation of technologies specifically developed to cope with the Altiplano and Cordillera environments has much to offer contemporary producers (Rengifo and Kohler 1992; Healy 1996). Revalorisation encompasses appreciation of Andean cosmologies in the many ways religious belief orders peoples' relation with the natural world. From an *Aymara* perspective, religious practice is inextricably linked with productive activities (van den Berg 1992), leading van Kessel (1992, 198) to term such practices the "symbolic dimension" of Andean technology.

7.2.2 Specific methodologies

Overall methods used to collect data for this chapter involved formal and informal interviews of sampled populations of the community, focus group sessions, household-level case studies, participant observation and reviews of archival data sources. Highlights of key contributions are noted below.

The history of technology transfer and extension programs in the central Altiplano since the 1950s was reconstructed through archival research and open-ended interviews with current and former extension agents in the SJL area (Markowitz and Valdivia 1995). To assess research undertaken at the Patacamaya Experiment Station, Quino (1994) reviewed technical reports from station archives from 1960 to the early 1990s.

The adoption and contemporary role of improved sheep breeds for SJL households was addressed by Espejo (1994) while other economic issues pertaining to improved sheep were studied by Valdivia and Jetté (1996).

Spatial diffusion of improved sheep breeds over the past three decades was examined by using a census of flocks held by 80 households at SJL and seven other nearby communities in the plains and hills of the Province of Aroma (Markowitz 1995). The communities, selected on the basis of past involvement with technology transfer programs, varied with respect to local climate, ecology and degree to which irrigation was used in livestock and crop production. Sheep were categorised as either Criollo or 50% cross-breeds of Criollo x Corriedale according to phenotypic characteristics. Probability of adoption of improved sheep by households was assessed as a function of seven variables by Sheikh and Valdivia (IBTA/SR-CRSP, unpublished) using a logit model (Kmeta 1986). Independent variables were selected to characterise features of the resource base, gender and age of household heads, years of formal education, and access to training or extension activities. For example, producers having a resource base oriented more toward plains agriculture rather than a mix of plains and hillside agriculture were expected to be more likely to adopt improved sheep because plains resources were more conducive to intensification of sheep husbandry through methods involving crop residues and improved forages. Female household heads who were also younger and had received special extension training in sheep husbandry were also thought to be more likely to adopt improved sheep. Since other studies had shown that sheep husbandry is a female dominated activity (Section 4.3.3: *Household production system*), gender was expected to influence adoption. One-quarter of the households in the analysis were headed by women. Life cycle, with an arbitrary demarcation between household heads older or younger than 50 years, was expected to influence adoption because younger, "mid-career" household heads had a greater abundance of labour and a proclivity to invest in improved technology (see Section 6.3.1: *Socioeconomic groups*). As will be noted later in this chapter, special training in husbandry of improved sheep had been provided for several decades in the region, although only about one-quarter of survey respondents had actually participated in a training opportunity (Markowitz 1995). There was some degree of self-selection of participants in the survey, simply because some potential respondents elected not to participate. Unlike residents of SJL, residents of nearby communities were less familiar with the IBTA/SR-CRSP project and more wary of participating in surveys. Self-selection in surveys can result in bias of regression coefficients (Maddala 1983). We felt, however, that a reasonable cross-section of participants was achieved.

Probability of adoption (z) by the ith household was assessed as a function of seven variables using the following model:

$Z_i = a + b_1(\text{COMMTY}) + b_2(\text{AGE}) + b_3(\text{GENDER}) + b_4(\text{TRAIN}) + b_5(\text{CROPAREA}) + b_6(\text{TOTALCRI}) + b_7(\text{ALFAREA}) + e$

The variables are proxies for hypotheses noted above. The statistical analysis was conducted using the LOGISTIC procedure in SAS (SAS 1990). Interviews for the 80 households were also used to assess how revenue from sheep sales was spent and various aspects of sheep management (Markowitz 1995).

Huanca (1995) conducted a study of potato cultivation. She examined producer attitudes towards change in potato production and events which led to introduction of mechanised tillage and adoption of other novel inputs at SJL using archival records and participant observation, oral history, and structured interviews for 30 households (Huanca 1995; Huanca et al 1995). Lizárraga (1994) assessed the economic costs and benefits of new technologies by using structured interviews of 36 households and collecting production data from 55 parcels of their crop land (Lizárraga1994; Lizárraga et al 1995). Victoria et al (1994) interviewed 25 community members in their study focused on relative merits of sheep manure versus introduced chemical fertilisers.

Adoption of dairy technology and promotion of dairy cooperatives were topics studied by by Illanes (1994) and Illanes et al (1995). They conducted informal and structured interviews and focus group meetings with 46 randomly selected producers to identify behavioural and economic variables influencing participation in small-scale commercial dairying. Dairy adopters and non-adopters were contrasted in terms of various household and resource features using *t*-tests. In addition, Dr. L. Markowitz (IBTA/SR-CRSP, unpublished data) interviewed 32 of the most active milk producers at SJL to determine their patterns of technology adoption.

Statistical analysis of dairy producers at SJL involved a logistic regression (Valdivia 1998) that looked at the variables affecting adoption of this enterprise among 45 households. Procedures were similar to the analysis for sheep. The statistical package used was SPSS (1998). The model attempted to explain dairy adoption as a function of alfalfa area, total income and household economic diversity.

7.3 Results and discussion

7.3.1 History of technical assistance at San José Llanga

The scope and tenor for international assistance programs of the US Government was set in the Inaugural Address of US president Harry S. Truman on January 20, 1949. A key excerpt follows of "The Point IV Speech" (Baldwin 1966, 61):

> "Fourth. We must embark on a bold new program for making the benefits of our scientific advances and industrial progress available for the improvement and growth of underdeveloped areas. ...The United States is pre-eminent among nations in the development of industrial and scientific techniques. The material resources which we can afford to use for the assistance of other peoples are limited. But our imponderable resources in technical knowledge are constantly growing and inexhaustible."

The Cantón of SJL has been subject to a series of technology assistance projects supported by foreign donors since the early 1960s. This was part of a broad US involvement in Altiplano agriculture starting in the 1950s (see Section 1.4.1: *Research setting*). Implementation rested on the direct transfer of technologies developed in Europe and North America. The assumption of northern technological beneficence appears in the diffusion processes described below. As noted by Healy (1996, 14) in the models of Altiplano agricultural development that followed over the following decades, "the Bolivian extension agent was the key actor and peasant farmers remained backward and passive."

By 1954 the US technical assistance program to Bolivia, financed through the Institute of Inter-American Affairs, was the second largest in the hemisphere. The vehicle for much of this effort was the Inter-American Agricultural Service (or SAI—Servicios Agrícolas Interamericanos), a descendant of the servicios established in 1942 as means to acquire strategic defense materials from Latin America (Iverson 1951, 223). A servicio was conceived as a flexible administrative entity that could undertake whatever technical cooperation was agreed upon (Mosher 1957, 323). Through the early 1960s the SAI supplied much of the direction and budget for the Bolivian Ministry of Agriculture [see Rice (1971) for discussion and evaluation of the SAI's structure and programs]. Although

SAI activities focused mostly on tropical eastern Bolivia, their priority in the Altiplano was creation of agricultural research and demonstration centres. As an example, the Patacamaya Experiment Station was constructed in 1958 on lands of the former hacienda Culta Arajllanga (PES 1962-3, 5).

The initial mission of the Patacamaya Experiment Station was to improve the quality of Altiplano sheep. Researchers thus carried out experiments dealing with sheep genetics, management, health and nutrition. To this end a variety of breeds including Romney Marsh, Corriedale, Rambouillet, Hampshire Down and Targhee were imported from Chile, Peru, Uruguay and the US. A review of station research (Quino 1994) revealed several important accomplishments by station staff. Most notable was the development of a crossbred sheep (i.e., Corriedale x Criollo) that was well-adapted to the elevation and climatic extremes and able to be more productive than other pure-breds or crosses (see Section 5.3.3: *Management and productivity of sheep*). Quino (1994) noted a tendency, however, for researchers to rely on on-station tests and not consider on-farm conditions. Similarly, nutrition research tended to focus on feed resources that were too expensive for most local producers to acquire. Finally, basic health problems received little attention compared to research on uncommon, but more interesting, ailments (Quino 1994).

In the late 1950s and 1960s the Patacamaya Experiment Station also served as a base for international cooperation programs and as an extension centre. According to informants, SAI extension teams worked with community leaders focusing on establishing cooperatives meant as vehicles for training, extension of credit, parasite control (i.e., construction of at least 2000 sheep dips) and improved breeding (i.e., distribution of up to 3000 Corriedale rams). Although the SAI teams operated independently of the Patacamaya Experiment Station, feedback concerning success of research applications was maintained. In 1962 the Patacamaya Experiment Station designated its own extension personnel who began to organise formal outreach meetings and short-courses. These facilitated formation of a regional ranchers association (AREGA–Asociación Regional de Agricultores; PES 1962-3) a grouping of cooperatives from over 20 communities from the central Altiplano, including SJL.

More technical assistance from the US was directed to the Altiplano by 1965. During the same period political fears over left-wing insurgencies led to higher levels of overall aid to Bolivia (Wilkie 1982, 84). A major effort on the Altiplano from 1965-75 was the Utah State University/USAID Sheep Production and Marketing Program (abbreviated as USU/USAID/SPMP) which, like SAI, operated within the Bolivian Ministry of Agriculture. This program aimed to improve rural conditions through development of agricultural research and extension and to improve the country's balance of payments through development of exports and import substitutes (Wennergren 1975, 6).

Program participants included Bolivian technicians and university faculty from Utah, where "cold desert" conditions parallel those of the Altiplano. Like their predecessors, these people were primarily concerned with sheep production, especially breeding, wool marketing and forage improvement. They arranged to import some 2000 pure-bred sheep (i.e., Targhee and Corriedale) and distributed rams among Altiplano communities, often building on previous work of SAI teams. Extension teams conducted shearing demonstrations in support of a revitalised national wool market. On-farm forage trials contributed to the testing and widespread dissemination of new varieties of alfalfa and other cultivated forages (Haws 1975).

Another form of technical assistance in the region was extension of credit for purchase of farm inputs (Huanca 1995). By the mid-1960s funds for communities in Aroma Province were available from the Inter-American Development Bank and USAID via the Agrarian Bank of Bolivia. Little credit, however, was directly given to smallholders (Heilman 1982). Agencies considered rural cooperatives better risks, a view consonant with the goals of community development. Within Aroma new cooperatives proliferated, often established on the basis of the rancher groups (e.g., AREGA) created a few years earlier.

Residents of SJL organised a cooperative in 1966 to receive loans under rural development and commodity support programs aimed at increasing food production for urban markets through intensified cultivation (Huanca 1995). With the credit arrived a "technology package" consisting of seeds for "improved" potatoes (e.g., *Papa dulce*) developed for urban tastes along with mechanised tillage, chemical fertiliser and herbicide.

The most recent technological change at SJL has been development of smallholder commercial dairying that began in the late 1980s (see Section 4.3.3: *Household production system*), but its institutional antecedents actually dated back to the mid-1950s. The UNICEF (United Nations

Children's Fund) had identified increasing milk production as a goal for Bolivian economic and agricultural development and subsequently financed construction of milk processing plants in Cochabamba, Tarija, Chuquisaca, Santa Cruz and La Paz. To coordinate milk promotion programs, the FAO (Food and Agriculture Organization of the United Nations) worked with the Bolivian government in 1970 to design a framework for increasing dairy production and consumption. The following objectives emerged: (1) Increasing on-farm milk production and rural incomes; (2) creation of a milk industry infrastructure; (3) encouraging milk consumption as a response to endemic malnutrition; and (4) supplying an import substitute (Catacora 1993). Since this time most multi-lateral assistance to the dairy sector has fallen within the contours of this master-plan. See Illanes et al (1995) for further details.

For milk producers on the central Altiplano, the most visible support for dairying was a parastatal organization called PROFOLE (Programa de Fomento Lechero, or Milk Promotion Program). Starting in 1978 PROFOLE extension agents provided technical assistance to smallholders in scores of Altiplano communities. Their primary financial backing has come from the WFP (World Food Program of the United Nations) which began in 1984 to coordinate contributions of milk solids and butterfat to Bolivia by international donors. The La Paz milk plant reconstituted dried solids into liquid milk, which was then sold to generate revenues for PROFOLE extension activities. Between 1980 and 1990 donations accounted for about 40% of the total national milk supply (Materson et al 1991).

In more recent times producers on the central Altiplano have sold milk to PIL (Programa de Industrialización Lechera) through community-based collection centres (centros de acopio) or through more elaborate producers' associations called módulos. These organisations have a dual role; on one hand they were meant to facilitate transmission of information from extensionist to farmer, perpetuating a one-way model of technology transfer, while on another they were conceived as organisational vehicles to engender community activism and autonomy (Catacora 1993).

While some residents of SJL had previously raised a few cows for draft power and household milk production, the severe drought of 1982-3 spurred widespread interest in dairying (and animal husbandry in general) as a potentially more secure livelihood option compared to cultivation (Markowitz 1993). This interest coincided with construction of a 23-km irrigation canal by local residents from the Rio Desaguadero to SJL and three surrounding communities (Section 3.3.2: *Description of natural resources*). Irrigation permitted more intensive use of what had been grazing or more marginal rain-fed crop land. Alfalfa thrived in this area, as well as along the *Khora Jahuíra* River. Also, in the mid-1980s the Programa de Ayuda Campesina (Peasant Self-Development Program) sponsored by the EEC (European Economic Community) started to distribute forage seeds, and in 1989 improved the dirt track leading into the main *Barrio* at SJL in part to facilitate milk commercialisation. The PROFOLE extensionists began work at SJL that same year and a módulo was established in 1990.

Participation in the módulo at SJL has facilitated access of members to various dairy technologies. Improved calves, usually Friesian (i.e., Holstein) or Brown Swiss crossed with Criollo, are given to members via a lottery with the understanding that in three years time a calf will be returned to PROFOLE to pass to other producers in need. The practice for SJL, however, has been for calves to go to the most active members. The PROFOLE advances credit to producers, and this is to be repaid out of future milk revenues for purchase of forage seed (i.e., oats, alfalfa, and barley). The PROFOLE also delivered feed supplements on 30-day credit. Larger loans have been available for such infrastructural improvements as sinking pumps and animal holding facilities. Tractor rentals, artificial insemination and weekly veterinary visits have been other perquisites of membership.

7.3.2 Diffusion and use of new technologies

As introduced above, major changes in sheep, potato and milk production enterprises have occurred over the past 30 years at SJL. The key role of new technology in community development and change is outlined below.

7.3.2.1 Improved sheep breeds

A look at the contemporary use of disseminated technologies has helped us evaluate the success of extension efforts involving improved sheep in the 1960s. Impact was evident in the composition of local flocks in the early 1990s. A census of all households at SJL in May, 1994, revealed that out of a total of 4635 sheep, 2779 (60%) were at least a 50% cross of Corriedale x Criollo (henceforth referred to here as "improved"). The remaining 1856 (40%) were less than a 50% cross with the phenotype dominated by Criollo features (Drs. L. Markowitz and C. Valdivia, IBTA/SR-CRSP, unpublished data). The proportion of improved animals at SJL was two to twelve-times higher than proportions of improved animals observed in seven neighbouring communities (Table 7.1). Considered overall across eight communities (including SJL) and a grand total of 9724 sheep, about 5338 (or 55%) were improved crosses.

The analysis of what influenced adoption of improved sheep revealed three associated factors, namely, community location, training and Criollo sheep held. Statistics are shown in Table 7.2. As predicted, operations dominated by plains resources were positively associated with having improved sheep but, paradoxically, the finer-scaled variables of total cropped area or area planted to alfalfa were not significant ($P>0.37$). Exposure to extension training was also a positive factor. Ownership of Criollo sheep was negatively associated with adoption of improved sheep, presumably a substitution effect (Table 7.2).

As previously indicated, the non-random process of sample selection may have lead to biased coefficients; therefore, these results should be interpreted with care. A relatively low representation of female household heads and difficulty for women to attend extension meetings may help explain why gender was not significant in the final model. The result was surprising because sheep management is in the domain of women on the Altiplano.

In Section 4.3.3.4: *Gender, livestock and household welfare*, it was noted that income from sales of live sheep and sheep products was used for welfare expenses at SJL. The survey of 80 neighbouring households in seven other communities gave similar results (Markowitz 1995). Most of the 80 households (i.e., 72%) listed food as the top priority purchase item from sheep sales while 11% listed school supplies and 6% listed clothing as top priorities.

7.3.2.2 Improved potato production

Introduction of new potato technology in the 1960s fundamentally altered potato production at SJL, as revealed by Huanca's (1995) interviews with elderly residents. Before the intervention, people mostly raised indigenous potatoes such as the "bitter" varieties (i.e., *amarga—k'ullu* and *luk'i*) and "sweet" varieties (i.e., *dulce—ajawiri*, *sultana* and *saqampaya*). Producers used ox-drawn wooden plows for tillage, coats of ashes on top soil to help control pests, and partially decomposed and fermented sheep manure (*wanu*) as fertiliser. Producers would either apply decomposed manure at the moment of planting or spread the fields with fresh manure about five months before planting to allow its gradual disintegration. Typically between 40 and 60 quintals of *wanu* was used per hectare. Potato fields were fallowed for six to 10 years in a rotational scheme. In response to the aforementioned potato technical package, some 30 campesinos formed a cooperative in 1966. By 1967 they secured credit to purchase a tractor, truck, seeds and other inputs for collective potato cropping. Initially production boomed. Elderly informants recall that trucks laden with potatoes would roll out of the community on a weekly basis during the harvest season (Jetté 1993).

Informants who had been former members of the cooperative pointed out that while profits from increased potato production were high enough to eventually pay off debt incurred by the cooperative, participation brought the majority of members no long-term economic benefits (Huanca 1995). The cooperative eventually disintegrated as farmers began to apply technology packages to their own private parcels. Residents of SJL have reported that potato production has subsequently declined. Drops in soil fertility and shifts in other management practices have been implicated in the decline of potato production at SJL, but the most pervasive explanation may be cyclic declines in precipitation (see Section 3.3.4: *Integration of ecological findings*). The drought of 1982-3 was thought by campesinos to be the termination point of the "potato boom," which persisted for nearly 15 years (Huanca et al 1995).

Despite a perceived decline in levels of potato production, producers in SJL during the early 1990s still employed a combination of indigenous and introduced methods for potato production. In other words, the innovations of the 1960s have been retained. The campesinos also expressed a range of opinions and rationales concerning the relative merits of indigenous and introduced modes of potato production. Table 7.3 summarises some aspects discussed more fully below.

First, cultivation of introduced potato varieties (i.e., *Papa alpha* and *Papa sani imilla*) remained

Table 7.1. *Apparent breed composition of sheep flocks in seven rural communities in the Province of* Aroma *in 1994.*[1] Source: Dr. L. Markowitz and J. Valdivia (IBTA/SR-CRSP, unpublished data).

		Breed Composition[2]		
			Corriedale x Criollo	
Community	Total Sheep[1]	Criollo	50%	>50%
Ayamaya	1256	1009 (80%)	244 (19%)	3 (<1%)
Culli Culli	381	237 (62%)	144 (38%)	0 (0%)
Chiarumani	638	430 (67%)	208 (33%)	0 (0%)
Huari Belen	1217	450 (37%)	671 (65%)	96 (8%)
Inacamaya	981	204 (21%)	455 (46%)	322 (33%)
Patarani	243	163 (67%)	79 (33%)	1 (<1%)
Pomani	373	37 (10%)	186 (50%)	150 (40%)
All	5089	2530 (50%)	1987 (39%)	572 (11%)

[1]Based on census of community flocks.

[2]Where breed composition was discerned on the basis of phenotypic characters (see text for details). The 50% column refers to animals which appeared to be a 50:50 cross of Corriedale x Criollo. The >50% column refers to animals which were dominated by the Corriedale phenotype.

widespread at SJL in 1992-3. Lizárraga (1994) found that during the 1992-3 agricultural cycle these were planted in 91% of the plots controlled by sampled households. Farmers cultivated a mix of seeds from indigenous and introduced varieties in 78% of these fields, while just 9% of parcels contained only indigenous seeds. The different cultivars were either planted in separate rows or intermingled within furrows.

Diversification of potato production reflects varied household needs for consumption, exchange and production (Lizárraga 1994). Indigenous varieties are better suited for making freeze-dried *chuño* (see Section 4.3.3.1: *Household ac-*

Table 7.2. ***Logit model coefficients, and respective P values, for seven variables postulated to be important factors in the process of adopting improved breeds of sheep among residents of the Province of*** Aroma ***in 1994***[1]. Source: Adapted from Sheikh and Valdivia (IBTA/SR-CRSP, unpublished).

		Statistics	
Variable[2]	Definition	b[2]	Pr[3]
Intercept	y-intercept	2.38	0.21
COMMTY	Location	-1.49	0.05*
AGE	Age of household head	0.01	0.74
GENDER	Gender of household head	-0.15	0.84
TRAIN	Exposure to extension	2.63	0.06*
CROPAREA	Total area cultivated	<0.01	0.99
TOTALCRI	Criollo sheep owned	-0.03	<0.01*
ALFAREA	Alfalfa area cultivated	0.21	0.37

[1]Based on a survey of seven communities (N=80 households). See text for a description of the logit model.

[2]The equation was thus: $Z_i = 2.38 + -1.49(\text{COMMTY}) + 2.63(\text{TRAIN}) - 0.03\ (\text{TOTALCRI})$

[3]Probability (Pr) values ≤ 0.10 are regarded as statistically significant and labeled with an asterisk(*).

tivities and economy) and for certain types of food preparation. In contrast to the indigenous varieties, however, the higher yielding introduced varieties received better market prices during bumper years when sales were more likely. Introduced varieties, although less frost-resistant than indigenous varieties, had shorter growing periods which reduced their vulnerability to drought in the early spring and frost in late summer (Lizáragga et al 1995). Farmers attempted to avert risk by staggering sowing over three distinct periods within the spring planting season (i.e., August through November) and by adjusting planting schedules to presence or absence of early rains and forecasts they drew from star patterns in the night sky and observing behaviour of wild animals (Huanca 1995). The aforementioned spatial dispersion of varieties also served as another means to lessen the risk of frost damage (see Section 4.3.3.1: *Household activities and economy*).

The use of tractor tillage has become widespread at SJL largely because it has offered a great savings of labour and time. Huanca (1995) found that all households in her sample of 30 households used tractor tillage for at least the initial stages of field preparation such as clearing debris and furrowing. To plow one hectare with animals takes one person four days. In contrast, a tractor could cover the same field in about three hours, with the cost equivalent to about USD 28 in 1993. Animal power still predominated, however, for the more delicate tasks of planting and soil mounding (*el aporque*) for potato production.

Table 7.3. *Use (frequency, %) of various options[1] for potato production practices among a sample of 30 households in San José Llanga in 1992-3.* Source: Adapted from Huanca (1995).

Practice	Options			
Tillage	Animal-drawn plough only	Tractor only	Plough and tractor	Manual only
	17 (57%)	11 (37%)	2 (6%)	0 (0%)
Soil mounding[2]	Animal-drawn plough only	Tractor only	Plough and tractor	Manual only
	22 (77%)	3 (10%)	2 (7%)	3 (10%)
Fertiliser use	Manure only	Chemical only	Manure and chemical	None
	3 (10%)	11 (37%)	16 (53%)	0 (0%)

[1]Where tractors and chemical fertilisers were introduced in the 1960s. Huanca (1995) also reported ubiquitous use of tractors for clearing of field debris in the initial steps of field preparation.

[2]Soil mounding is the process of creating small mounds around young potato plants.

A second factor mitigating against heavy reliance on animal traction has been the rise of smallholder dairying, which has led to reductions in numbers of Criollo bulls and oxen in household herds (Huanca 1995, 163). Presumably this trend resulted from attempts to reduce competition between high-value dairy cows and lower-value oxen for limited forage resources. The campesinos also preferred to avoid using cattle for furrowing and other activities which imposed high degrees of stress (Huanca 1995, 163). It is possible that increased reliance on tractor tillage has undermined some aspects of the sustainability of the cropping matrix at SJL (see Section 3.3.4: *Integration of ecological findings*).

The application of chemical fertilisers in place of, or in combination with, *wanu* was also common at SJL (Table 7.3). The motivations for increased reliance on chemical fertilisers varied, but most involved the relative ease of applying chemical fertilisers compared to manure application. Other aspects include perceived boosts for potato production, at least over the short term. Victoria et al (1994) found that nearly half of 25 households in her survey at SJL reported that labour was a key reason for greater reliance on chemical fertilisers. Today fresh manure—not decomposed—is applied to fields by hand at the moment of planting. Donkeys with wooden packs or pulling sleds haul *wanu* from livestock corrals near homesteads to the widely dispersed parcels. Contemporary farmers use, on average, 18.5 quintals (833 kg) of manure per hectare (Lizárraga et al 1995). Even though this amount is less than half that used by producers in the early 1960s (Huanca 1995), applying *wanu* to a hectare of land takes much more labour than does applying a 45-kg sack of chemical fertiliser typically used for the same-sized plot (Lizárraga 1994). It should be noted that this quantity of chemical fertiliser is much less than the 225 kg per hectare recommended by local agronomists (Lizárraga 1994). About half of surveyed households perceived that chemical fertilisers boost crop production more than manure does (Victoria et al 1994). Lizárraga (1994) measured potato fresh-weight yields from plots treated with chemical fertilisers or manure during the 1992-3 production year. The 14 plots fertilised with manure produced an average of 45 kg fresh weight of potatoes per hectare, while 48 plots fertilised with urea produced an average of 88 kg fresh weight. A third important reason producers use chemical fertilisers is their perception that the chemical fertilisers can still be effective even if rainfall is deficient. Higher levels of rainfall were seen as necessary for effective decomposition of manure and recycling of nutrients (Huanca 1995). Similarly, Victoria et al (1994, 14) found that 40% of interviewed households noted that use of manure appears to exacerbate dry soil conditions in drought years, a perception that may have to do with water-retention properties of organic material in manure (see Section 3.3.4: *Integration of ecological findings*). Finally, producers explained to Huanca (1995) that two other benefits of chemical fertilisers were a reduced presence of worms and weed seeds.

Advantages of using manure have also been noted by Victoria et al (1994) and Huanca et al (1995). These include the fact that manure use does not require a cash outlay—a 45-kg sack of chemical fertiliser cost around USD 26 during the time of our study—and that potatoes grown with manure reportedly have a better flavour. Victoria et al (1994, 14) found that half of her informants thought that manure improved "the physical properties of soil," in contrast to use of chemical fertilisers. A common local opinion used to explain a perceived, gradual decline in crop production at SJL was that "the land seems tired" (Huanca 1995, 147). We speculate that there could be a causal link between this perception and a long-term decline in manure use. Our IBTA/SR-CRSP project, however, was unable to conduct a detailed investigation of soil management on crop lands. Priorities for future research are found in Section 8.3: *Recommendations*.

7.3.2.3 Dairy production

By 1995, over one-third of households at SJL participated in the PIL dairy cooperative activity. By early 1994 the producers at SJL were selling more milk compared to those in any of 24 other communities in the Aroma sector (Markowitz and Valdivia 1995). This program has spurred investment in improved cattle at SJL and fostered a reallocation of some land from food crop production to cultivated forage production. Of 33 core módulo members surveyed, nearly half (i.e., 17) had taken advantage of the PROFOLE rotating credit scheme to purchase forage seed and two thirds (i.e., 22) had acquired improved cattle (Dr. L. Markowitz, IBTA/SR-CRSP, unpublished data). Some 65 individuals were currently associates of the program, and about half of the members regularly delivered milk to the PIL main office. Milk sales seasonally varied and this reflected calving patterns, rainfall and forage conditions. Rain-fed forage conditions were particularly important for poorer or more marginalised dairy producers who were less able to gain access to irrigated forage plots (Espejo 1994, 178).

Despite fears that the PIL could be privatised (Drs. L. Markowitz and C. Valdivia, IBTA/SR-CRSP, personal observations), milk sales in SJL and other communities in Aroma Province rapidly increased, doubling between 1990 and 1992 (Illanes et al 1995). In 1992 producers in SJL delivered about 85 000 l of milk. A major stimulus of further involvement in milk commercialisation at SJL was a drought in 1991. Many campesinos lost their entire potato crop that year, rendering milk sales a crucial source of cash income. The prospect that dairying, at least when based on irrigated forage cultivation, could become a relatively stable source of income in the face of wide swings in annual rainfall, became increasingly attractive (Jetté 1993).

The potential for a higher and more stable income appears to strongly motivate households at SJL to invest in dairy cattle, along with support technologies such as irrigated alfalfa plots (Illanes et al 1995). Households begin to rely on the higher plane of income derived from dairying, and they want to protect their large investment in improved cows. While a Criollo cow may cost USD 250 to 300, the improved crosses can easily cost twice as much (see Section 4.3.3.1: *Household activities and economy*). It was only through improved animals that households could realise substantial increase in earnings: a Criollo cow gave at best 3 to 4 l of milk per day, while an improved animal yielded 10 to 12 l per day (Illanes 1994).

Out of 46 households sampled at SJL, Illanes et al (1995) found 28 to be involved in dairying while 18 were not. Household attributes are contrasted in Table 7.4. Particularly notable differences occurred in terms of total crop land, cultivated forage and improved cattle.

Results from the logistic regression on dairy adoption are shown in Table 7.5. The model correctly predicted the non-adopters and 94% of adopters. Access to cultivated feed resources and wealth largely explained adoption. Wealth was important because it conferred risk tolerance. We expected that more diversified producers would also adopt dairying, but other studies have shown that involvement in dairying reduced the need for off-farm employment (Céspedes et al 1995).

Synergisms between dairying and production of improved sheep have been observed. Dairying has been shown to be positively correlated with having improved sheep. It has also been noted that the stimulus to adopt dairy cattle has spurred the spread of cultivated forage which, in turn, has further affected production of improved sheep as a secondary effect (Yazman et al 1995; Valdivia and Jetté 1996).

7.4 Conclusions

The residents of San José Llanga have experienced an exceptional degree of exposure to extension initiatives and market incentives to alter their time-tested traditions. It indeed has been an ideal "living laboratory" for study of development processes.

Our review of technology transfer indicates that interventions involving improved sheep and improved potatoes have been sustained for about 30 years, and there was no sign that their basic utility would wane in the near future. As described in previous chapters, these interventions have been successful in terms of economic impact, at least over the short- to medium-term.

Because interventions have involved production of more marketable commodities, it was not surprising that the relative emphasis on various commodities appeared to wax and wane with market signals. In the case of smallholder dairying, drought provided additional incentive for

Table 7.4. *Various contrasts (means) for households that had adopted dairying (n = 28) and those that had not adopted dairying (n = 18) at San José Llanga in 1993.* Source: Adapted from Illanes et al (1995).

Variable	Dairy Producers	Non-Dairy Producers	*P*[1]
Children living in SJL (number)	3.5	2.9	≤0.10
Children living away from home (number)	1.3	0.3	≤0.10
Education of household head (years)	6.8	5.3	≤0.10
Total crop land[2] (hectares)	34.0	14.0	≤0.10
Forage[2] (hectares)	5.3	2.6	≤0.10
Fallow (hectares)	11.3	3.9	≤0.10
Number of cattle (head)	6.4	4.9	≤0.10
Improved cattle (head)	4.8	1.9	≤0.10

[1]Significant difference among means in each row established using *t*-tests.

[2]Controlled access including cultivated forage.

Table 7.5. *Logistic regression statistics for adoption of dairying among 45 households at San José Llanga in 1993.* Source: Adapted from Dr. C. Valdivia (IBTA/SR-CRSP, unpublished data).

	Statistics		
Variable	Coefficient	Wald	*P*
Alfalfa Hectares	2.8	3.8	0.05
Diversity Index	1.4	2.02	NS
Total Income	0.001	3.02	0.08
Constant	-10	3.8	0.01

adoption. Macro-events thus seem to set the stage for technology adoption, rather than merely micro-level (e.g., household-level) events. The political economy therefore influences these dynamics because it influences windows of economic opportunity.

As reviewed in previous chapters, introduced technologies have been effectively mixed with traditional options at SJL. Consequences of introduced technologies have not all been positive or neutral, however. Many consequences have been unintended or unforeseen. Technology packages for improved potato may have ultimately compromised soils in the crop land matrix. Benefits of dairying may be biased towards males and the wealthier strata of society, contributing further to wealth polarisation. Because of their traditional socioeconomic role, improved sheep have a gender bias in favour of female managers. An increasingly parcelised and diverse cropping matrix may yield more work for females, both in terms of attentive shepherding and field maintenance.

The ability of households to adopt dairying or improved sheep was inextricably linked to their access to cultivated forages. The ability to cultivate forages was linked to landscape location. It is likely that synergisms occur among technologies that affect their prevalence over time. Although adoption and relative emphasis on any particular innovation appear to have a dynamic or episodic character, the overall push towards modernisation may be compromising the ability of the people to grow their own food.

Recently we have entered the "dairy boom." One lesson from our historical analysis is that change is constant. The dairy boom will end, and something else will take its place. It would be wise, therefore, to emphasise technical, outreach and policy measures that promote a dynamic market awareness and an opportunistic capacity to respond to change in communities like SJL (see Section 8.3: *Recommendations*). Rampant ecological and economic shocks dictate that the most economically diverse households will be the least vulnerable over the long haul.

7.5 Literature cited

Baldwin D. 1966. *Foreign Aid and American Foreign Policy: A Documentary Analysis.* Praeger, New York, New York, USA. 257 pp.

Berdegué J. and Escobar G. 1995. New directions of the systems approach for the modernization of Latin American peasant agriculture. *Journal for Farming Systems Research-Extension* 5:1-30.

Biggs S. and Clay E. 1988. Generation and diffusion of agricultural technology: Theories and experiences. In: Ahmed I. and Ruttan V. (eds), *Generation and Diffusion of Agricultural Innovation: The Role of Institutional Factors.* Gower, Brookfield, USA. pp. 19-67.

Bromley D. and Chavas J.P. 1989. On risk, transactions, and economic development in the semi-arid tropics. *Economic Development and Cultural Change* 3:719-736.

Catacora A. 1993. La cooperación del programa mundial de alimentos al desarrollo lechero nacional. *Procampo* August/September, pp. 2-16.

Céspedes J., Dunn E. y Valdivia C. 1995. *Impactos de la Introduccion de Leche en el Ingreso Familiar.* IBTA/SR-CRSP (Instituto Boliviano de Tecnología Agropecuria/ Small Ruminant Collaborative Research Support Program). IBTA 144/Boletín Técnico 12/SR-CRSP 14, La Paz, Bolivia. 43 pp.

Dunn E. and Valdivia C. 1993. *Gender and Livestock: Dairy Expansion and Traditional Agropastoral Systems in the Bolivian Highlands Data Base.* Unpublished SR-CRSP (Small Ruminant Collaborative Research Support Program) report. University of Missiouri, Columbia.

Dunn E., Valdivia C. and Nolan M. 1992. *The Dynamics of Livestock and Community Change and Their Impact on Gender Roles.* Special Needs Funds Pool, unpublished SR-CRSP (Small Ruminant Collaborative Research Support Program) report. University of Missouri, Columbia. 4 pp.

Escobar A. 1995. *Encountering Development: The Making and Unmaking of the Third World.* Princeton University Press, Princeton, New Jersey, USA. 290 pp.

Espejo R. 1994. *Practicas Socieconomicas de Tenencia y Adquisición de Ganado, Estudio de Caso: Comunidad San José Llanga.* BA Tesis, Universidad Mayor de San Andrés, La Paz, Bolivia. 147 pp.

Fender K. 1997. *Empowerment Within the Household: A Study of Income Allocation in Bolivia.* MS thesis, University of Missouri, Columbia, Missouri, USA. 187 pp.

Haws G. 1975. Bolivia and Utah State University: A decade of contracts. Summary report 1965-75. *Utah State University Bulletin* 75(12). Logan, Utah, USA. 200 pp.

Healy K. 1996. Ethno-development of indigenous Bolivian communities: Emerging paradigms. In: Kolata A (ed), *Tiwanaku and its Hiterland: Archaeology and Paleoecology of an Andean Civilization, Volume 1: Agro-Ecology.* Smithsonian Press, Washington, DC, USA. pp. 243-263.

Heilman L. 1982. *U.S. Development Assistance to Rural Bolivia, 1941-1974: the Search for a Development Strategy.* PhD dissertation, American University, Washington, DC, USA. 303 pp.

Huanca J. 1995. *El Sistema Tecnico en el Cultivo de la Papa, Estudio de Caso: Comunidad San José Llanga, Provincia Aroma (Dept. La Paz).* BA tesis, Universidad Mayor de San Andrés, La Paz, Bolivia. 186 pp.

Huanca J., Markowitz L. and Jetté C. 1995. *El Proceso de Cambio Tecnologico: Perspectiva de los Productores de una Comunidad Agropastoril.* IBTA/SR-CRSP (Instituto Boliviano de Tecnología Agropecuria/Small Ruminant Collaborative Research Support Program). IBTA 158/Boletín Técnico 26/SR-CRSP 24. 25 pp.

Illanes P. 1994. *Adopción de Tecnologia en la Producción Lechera Estudio de Caso de los Cantones San José Llanga y Chijmuni.* BA Tesis. Universidad Mayor de San Andrés, La Paz, Bolivia. 159 pp.

Illanes P., Cuesta M. and Céspedes J. 1995. *Adopcion de Tecnologia en la Produccion Lechera: Estudio de la Communidad San José Llanga.* IBTA/SR-CRSP (Instituto Boliviano de Tecnología Agropecuria/Small Ruminant Collaborative Research Support Program). IBTA 147/Boletín Técnico 15/SR-CRSP 17. 35 pp.

Iverson K. 1951. The "servicio" in theory and practice. *Public Administration Review* 11:223-228.

Jetté C. 1993. *A diachronic analysis of changing resource use patterns on the central Bolivian highlands.* Small Ruminant Workshop, San Juan, Puerto Rico. 11 pp.

Kmenta J. 1986. *Elements of Econometrics.* Macmillan Publishing Company, New York, New York, USA. 796 pp.

Lizárraga M.R. 1994. *Cambio Tecnologico en el Cultivo de la Papa en la Comunidad de San José Llanga.* BA tesis, Universidad Mayor de San Andrés, La Paz, Bolivia.

Lizárraga M.R., Cuesta M. and Céspedes J. 1995. *Cambio Tecnologico en el Cultivo de la Papa en la Comunidad de San José Llanga.* IBTA/SR-CRSP (Instituto Boliviano de Tecnología Agropecuria/Small Ruminant Collaborative Research Support Program). IBTA 163/Boletín Técnico 31/SR-CRSP 29. La Paz, Bolivia. 38 pp.

Maddala G.S. 1983. *Limited-Dependent and Qualitative Variables in Econometrics.* Cambridge University Press, Cambridge, UK. 401 pp.

Markowitz 1993. *Till the Cows Come Home: Small Scale Dairying on the Central Bolivian Altiplano.* Paper presented at the 94th Annual Meeting of the American Anthropological Association. Washington, DC, USA. 12 pp.

Markowitz L. 1995. *The Impact of Improved Sheep Technologies in the Province of Aroma: Preliminary Findings.* Unpublished SR-CRSP (Small Ruminant Collaborative Research Support Program) report. University of Missouri, Columbia. 5 pp.

Markowitz L. and Valdivia C. 1995. *Technologies Through Time: Contradictions in an Andean System of Production*. Paper presented at the 94th Annual Meetings of the American Anthropological Association. Washington, DC, USA. 11 pp.

Materson D., Wyeth J., Stobberup J., and Anderson E. 1991. *Bolivia Dairy Sector Study*. Draft Report. DANIDA (Danish International Development Agency). Copenhagen, Denmark. 163 pp.

Mosher A. 1957. *Technical Cooperation in Latin American Agriculture*. University of Chicago Press, Chicago, Illinois, USA. 449 pp.

Murillo C. and Markowitz L. 1995. *Food and Nutrition in San José Llanga, an Agropastoral Community in the Central Altiplano of Bolivia*. IBTA/SR-CRSP (Instituto Boliviano de Tecnología Agropecuria/Small Ruminant Collaborative Research Support Program). IBTA 171/ Boletín Técnico 41/SR-CRSP 39. 37 pp.

PES (Patacamaya Experiment Station). 1962-3. *Informe Anuales.* Patacamaya Experiment Station, Patacamaya, Bolivia.

Pfaffenberger B. 1992. Social anthropology of technology. *Annual Review of Anthropology* 21:491-516.

Quino E. 1994. *Evaluación de Investigaciones de la Estación Experimental de Patacamaya*. RISPAL (Red de Investigacion en Sistemas de Produción Animal). American Latina.

Rengifo G. and Kohler A. (eds). 1989. *Revalorización de Tecnologías Campesinas Andinas*. HISBOL (Institute of Historia Boliviana), La Paz, Bolivia.

Rice E.B. 1971. *Extension in the Andes: An Evaluation of Official U.S. Assistance to Agricultural Extension Services in Central and South America*. MIT Press, Cambridge, Massachusetts, USA. 552 pp.

Sachs W. (ed). 1992. *The Development Dictionary: A Guide to Knowledge as Power.* Zed Books, London, UK. 305 pp.

SAS (Statistical Analysis System). 1990. *SAS/STAT™ User's Guide. Volume 2, GLM-VARCOMP. Version 6.* Fourth Edition. SAS Institute Inc., Cary, North Carolina.

Sherbourne J., Dunn E., Valdivia C. and Nolan M. 1995. *Agropastoral Production Systems, Intra-household Resource Allocation and Household Members Domains: Five Case Studies from the Community of San José Llanga.* IBTA/SR-CRSP (Instituto Boliviano de Tecnología Agropecuria/Small Ruminant Collaborative Research Support Program). IBTA 171/Boletín Técnico 171/SR-CRSP 39. La Paz, Bolivia. 34 pp.

Shucksmith M. 1993. Farm household behaviour and the transition to post-productionism. *Journal of Agricultural Economics* 44(3):466-478.

Smillie I. 1991. *Mastering the Machine.* Westview Press, Boulder, Colorado, USA. 268 pp.

SPSS 1999. *The SPSS Base 10.0 Applications Guide*. 537 pp.

Valdivia C. 1995. Policy impact assessment in small-ruminant production systems: The Peruvian case. In: Ruiz M., Seré C., Li Pun H. (eds), *Animal Production Systems Global Workshop*. IDRC/ IICA/RISPAL (Inter-American Institute for cooperation on Agriculture/Latin American Research Network for Animal Production Systems). San Jose, Costa Rica. pp. 385-415.

Valdivia C. and C. Jetté. 1996. *Peasant Households in Semi-Arid San José: Confronting Risk Through Diversification Strategies*. IBTA/SR-CRSP (Instituto Boliviano de Tecnología Agropecuria/ Small Ruminant Collaborative Research Support Program). IBTA 181/ Boletín Técnico 181/SR-CRSP 47. La Paz, Bolivia. 24 pp.

Valdivia C., Dunn E., and Sherbourne J. 1996. *Gender, Livestock and Household Peasant Production: Dairy and Diversification in Crop-Livestock Systems of an Andean Community.* IBTA/ SR-CRSP (Instituto Boliviano de Tecnología Agropecuria/Small Ruminant Collaborative Research Support Program). IBTA 165/ Boletín Técnico 33/SR-CRSP 31. La Paz, Bolivia. 42 pp.

van den Berg H. 1992. Religión Aymara. In: van den Berg H. and Schiffers N. (eds), *La Cosmovisión* Aymara. UCB/HISBOL. La Paz, Bolivia, pp. 291-308.

van Kessel J. 1992. Technologia Aymara: Un enfoque cultural. En: van den Berg H. and Schiffers N. (eds), *La Cosmovisión* Aymara. UCB/HISBOL. La Paz, Bolivia. pp. 187-219.

Victoria Z., de Queiroz, J., and Norton B. 1994. Production and utilization of manure in an agropastoral community in the central Altiplano of Bolivia. *ReRumen Newsletter* 3:13-15.

Wennergren E.B. 1975. *An Evaluation of the Utah State University/USAID Sheep Production and Marketing Program in Bolivia*. Utah State University Series 7/75. La Paz, Bolivia (also USU archives). 79 pp.

Wilkie J.W. 1982. U.S. foreign policy and economic assistance in Bolivia: 1948-1979. In: Landman J. (ed), *Modern-day Bolivia*: *Legacy of the Revolution and Prospects for the Future*. Centre for Latin American Studies, Arizona State University, Tempe, Arizona, USA. pp. 38-121.

Yazman J., Jetté C., and Cáceres M. 1995. *Producción de Ovinos en Sistemas Agropastoriles en el Altiplano Central de Bolivia*. IBTA/SR-CRSP (Instituto Boliviano de Tecnología Agropecuria/Small Ruminant Collaborative Research Support Program). IBTA 148/ Boletín Técnico 16/ SR-CRSP 10. La Paz, Bolivia. 27 pp.

Chapter 8

Conclusions and recommendations

Conclusiones y recomendaciones

by D. Layne Coppock, Corinne Valdivia, Jim Yazman, Christian Jetté, João S. de Queiroz, Lisa Markowitz and Isaac M. Ortega

Summary

The purpose of this chapter is to provide comprehensive briefs of the main points of preceding chapters, offer answers to basic questions posed at the start of the project, and give some ideas for future research, outreach and policy consideration. We close with an epilogue describing recent events in Bolivia between 1996-9.

Because the joint IBTA/SR-CRSP project was only in the field for four years, virtually any conclusion must be viewed with caution. We were unable to conduct research on agronomy, soil management, commodity marketing or management of dairy cattle, and all of these loomed as critical topics where important questions emerged. The uniqueness of some aspects of San José Llanga (SJL) precludes extrapolation of findings elsewhere, but it is argued that there is utility in knowing one place very well. It is hoped our results will inform development dialogue in the Andean zone and beyond.

One prominent question was the degree to which humans, livestock or abiotic forces were responsible for environmental degradation at SJL. If humans and livestock were culpable then some remedial measures could be recommended. We repeat a conclusion reached earlier, that environmental degradation must first be qualified with respect to geomorphic units. Possible sources of mis-management could be identified with regards to crop lands, but for rangelands abiotic processes of salinisation, flooding and drought appeared to dictate system dynamics.

The "major question" posed at the start of the project was: "What is the role of small ruminants in sustaining agropastoralism on the Altiplano, and can this role be strengthened or improved through better use of technology or policy?" Considering inputs from sheep to land, labour and capital, it is offered that the critical roles for sheep are in providing: (1) Manure for crop lands; (2) income, cheap meat and wool to help sustain the labour component; and (3) a source of liquid assets for capital generation. Of these inputs, the most unique is the manure function. The alleged decline in crop productivity on the alluvial terrace may be traced, in part, to effects of modernisation on reducing manure soil amendments, but this remains to be proven. If we are conservative, however, and must make decisions in the absence of new information, one course of action could be to encourage dialogue among producers, researchers and outreach personnel regarding problems of crop land management, and consider technical and policy options that could shift more manure back onto farmer's fields. This could involve interventions as basic as labour-saving technology (i.e., wheelbarrows or manure spreaders) and/or incentives to discourage manure sales through outreach education and policy instruments. The solutions would probably not be easy to achieve given system constraints, but the alleged problem is important enough for food security that it cannot be ignored. In contrast to manure, other functions of sheep in providing income and capital have been recently complicated by the advent of smallholder dairying and people seeking off-farm employment. These income-generating activities provide alternatives to sheep production, and for some households they offer highly competitive options for investment. For households with choices we speculate that investing in dairy and pasture, or investing in the education of one's children, are superior options compared to lower returns and higher risks of investing in sheep and rangeland improvements. This is not to say that sheep are not vital, just that the marginal returns from making improvements in the sheep subsystem are probably less attractive over the short term than other options in today's economy. Such insights could have been missed if the joint IBTA/SR-CRSP project had not embraced a systems approach when studying SJL. It is also instructive, however, to recall the high variability among households in terms of wealth, production strate-

gies and resource access. Indeed, there are some households for which investment in sheep production will be the most effective development option. It is therefore important not to embrace a "one size fits all" mentality when considering the utility of development interventions.

Finally, our work also revealed that "sustaining agropastoralism on the Altiplano" goes far beyond the question of whether or not to invest in livestock to better maintain soils, incomes and assets. It is clear that there must also be substantive investment in people and communities to promote improved standards of living. If people do not have potable water supplies, electricity, transportation and basic educational opportunities they will be tempted to go elsewhere. While investment in basic public services may never stem the recent high rates of emigration, which appeared to largely be due to "pull" factors of altered expectations among youth rather than "push" factors, they would make places like SJL more desirable to live in. If SJL is a more desirable place to live, the likelihood is greater that emigrants would periodically return and invest in their home areas. This would help strengthen rural social institutions and livelihoods and keep options open for people. In the future the urban economy may become less attractive relative to the rural economy, and people may be compelled to return home to grow food.

Recommendations for future research include attention towards study of : (1) Alleged climate cycles; (2) crop land management; (3) risk management for households and communities including review of relevant policies; (4) human nutrition and health; (5) mitigation of salinisation and frost challenges for important food crops; (6) livestock morbidity causes and cost-effective solutions; and (7) range improvements.

Recommendations for research management include attention towards: (1) Moving the research focus more off-station to better understand rural problems; (2) incorporating more social science (especially household economics and marketing) along with traditional agricultural and biological research; (3) adopting more interdisciplinary thinking, even simply within the biological arena; (4) increase investment in staff and key facilities; and (5) along with shifting the research focus off-station, reduce emphasis on studies of crop and livestock production under optimal conditions.

Recommendations for outreach include engaging local people to discuss: (1) How to improve profitability in sheep marketing; (2) how to improve management of crop lands, with an emphasis on soil fertility management; (3) how to improve sustainability and effectiveness of irrigation systems; and (4) how to improve human health, nutrition and access to family planning information.

Recent information has been gathered regarding events at IBTA and SJL between 1996-9. Decentralisation of the Bolivian government led to the demise of IBTA by the late 1990s. It is envisioned that IBTA will be replaced by private research centres that will solicit and fund proposals dealing with priority problems in various ecological zones; this plan may be enacted during the year 2000. Many interesting changes have occurred at SJL. The number of households has reportedly risen to 130, a dramatic deviation from our prediction that household number would continue to decline to 80 in the near future. Dairying remains important, but there is a renewed effort to produce improved potatoes for market and home consumption. Land clearing for potato planting has increased due to mechanisation and high potato prices; it is still reported that the land is "tired" and producing below capacity. Efforts to rehabilitate some saline rangelands have occurred with funds from the Popular Participation Act. Smallholder dairying continues to be supported by external donors at least through 2003. Considering local society, it is notable that the first young women to graduate from the secondary school did so in 1999. An incipient potato "boom" and dramatic increase in residents at SJL are critical observations. We hypothesise that the ability to obtain higher incomes drives people in and out of SJL. This validates the idea that investing in rural communities is important to allow people to take advantage of dynamic opportunities in rural and urban sectors. This benefits local society and the nation.

Resumen

El propósito de este capítulo es proveer un informe comprensible de los puntos principales de los capítulos anteriores, entregar respuestas a preguntas básicas postuladas al comienzo del proyecto, y dar algunas ideas para futuras investigaciones, y consideraciones en las políticas y extensión. Cerramos con un epílogo describiendo los recientes eventos en Bolivia entre 1996-9.

Debido a que la unión del proyecto IBTA/SR-CRSP fue solo en el terreno por cuatro años, virtualmente cualquier conclusión debe ser tomada con precaución. No nos fue posible realizar una investigación en temas críticos como agronomía, manejo del suelo, mercadeo de los productos, o el manejo de los productos lácteos, y todos esos que aparecieron como temas críticos de los cuales emergieron preguntas importantes. Lo excepcional de algunos aspectos de San José Llanga (SJL) previene la extrapolación de los resultados a otro lugar, sin embargo se ha discutido la importancia de tener conocimientos avanzados de un lugar determinado. Esperamos que nuestros resultados informen y ayuden al comienzo de dialogos desarrollados en la zona andina y zonas aledañas.

Una pregunta importante fue el grado en que los humanos, el ganado y las fuerzas abioticas han sido responsables por la degradación del medio ambiente en SJL. Si los humanos y el ganado fueron los culpables, entonces algunas medidas para remediar ésto podrían ser recomendadas. Repetimos una conclusión alcanzada antes, que la degradación del medio ambiente debe ser calificada primero con respecto a unidades geomórficas. Las posibles fuentes de un mal manejo podrían ser identificadas con respecto a las tierras cultivadas, pero para las tierras con ganado el proceso abíotico de salinización, inundaciones y sequías parecieran dictar la dinámica del sistema.

La "principal pregunta" formulada al comienzo del projecto fue: "¿Cúal es el rol de los pequeños rumiantes en mantener un agropastoralismo en el Altiplano? y ¿Puede este rol ser reforzado o mejorado a través de un mejor uso de tecnología o de políticas?" Considerando la información dada desde la oveja a la tierra, mano de obra y capital, es evidente que los roles críticos de las ovejas son de proveer: (1) Estiécol como abono para las tierras cultivadas; (2) ingreso, carne y lana barata para mantener la mano de obra; y (3) una fuente ingresos liquida por fondos de grupo. De estos datos, el de mayor excepción es la función de abono. La discutida baja de la productividad de la siembras en las terrazas aluviales podria deberse, en parte, a los efectos de modernización al reducir las reformas de abono en el suelo, pero esto queda por probarse. Sin embargo, si somos conservadores y debemos tomar una decisión por falta de nueva información, una linea de acción podría ser el fortalecer un dialógo entre los productores, investigadores y personal designado respecto a los problemas de manejo de las tierras sembradas y considerar técnicas y opciones políticas que pudiera transportar más estíercol de vuelta a los terrenos de los campesinos. Esto podría involucrar intervenciones tan básicas como tecnología para reducir la mano de obra (ej., carretillas o diseminador de abono) y /o incentivos para disuadirles de la venta de estíercol a traves de educación y políticas. Las soluciones probablemente no serían fáciles de lograr dado a las restricciones del sistema, pero dicho problema es suficientemente importante para asegurar que el alimento que no puede ser ignorado. En contraste al estíercol, otras funciones de la oveja al proveer un sueldo y capital se ha complicado por la llegada de pequeñas lecherias y gente buscando empleos fuera de las granjas. Estas actividades generadas por ingresos proveen alternativas a la crianza de ovejas y para algunas familias éstas ofrecen opciones altamente competitivas de inversión. Para familias con alternativas, nosotros especulamos que la inversión en productos lácteos y pastizales, o la inversión en la educación de los niños, son opciones superiores comparadas con los bajas ganancias y los altos riesgos de inversión en ovejas y mejoramiento de los terrenos de agricultura. Esto no quiere decir que la oveja no sea vital, sólo que las ganancias marginales al hacer mejoras en el subsistema de las ovejas son probablemente menos atractivas a travéz de un período corto que otras opciones en la economía de hoy. Tales conocimientos pudieron no haber sido observados si la unión de los projectos IBTA/SR-CRSP no hubieran adoptado un sistema de acercamiento cuando estudiaron SJL. Sin embargo, es importante recordar la alta variabilidad entre las familias en términos de bienes, estrategias de producción y acceso a recursos. En verdad, hay algunas familias para las cuales la inversión en la crianza de ovejas será la opción más efectiva de desarrollo. Es por lo tanto importante no adoptar la mentalidad de que "un tamaño le queda a todos" cuando se considere la utilidad de las intervenciones en el desarrollo.

Finalmente, nuestro trabajo también reveló que "el agropastoralismo sostenido en el Altiplano" va más allá de la pregunta de si invertir o no en ganado para mantener mejores suelos, ingresos y bienes. Está claro que además se debe hacer una inversión sustantiva en la gente y en las comunidades para promover mejoramientos en el nivel de vida. Si la gente no tiene un sumistro de agua potable, electricidad, transporte y oportunidades a educación básica, la tentación para ir a otro lugar será mayor. En tanto que la inversión en servicios de salud pública, jamás podrá contener la reciente alta tasa de emigración, la cual pareciera ser causada en gran parte por factores de "tirón" de alteradas expectativas entre los jovenes en vez de factores de "empuje", lo que haría que lugares como SJL fuesen deseados para vivir. Si SJL es un lugar más deseables para vivir, la probabilidad es mayor de que los emigrantes pudieran regresar periodicamente e invertir en las áreas cercanas a sus casas. Esto ayudaría a fortalecer las instituciones sociales rurales y de convivencias y dejaría las opciones abiertas a la gente. En el futuro la economía urbana puede ser menos atractiva en relación con la economía rural y la gente podría ser forzada a volver a casa y sembrar alimentos.

Recomendaciones para futuras investigaciones incluye la atención a estudio de : (1) Los supuesto ciclos del clima; (2) manejo de las tierras cultivables; (3) manejo de los riesgos por las familias y comunidades, incluyendo una inspección de las políticas relevantes; (4) nutrición y salud humana; (5) mitigación de la salinidad y desafio al congelamiento para las siembras importantes de alimentos; (6) causas de enfermedades en el ganado y soluciones con costos efectivos; (7) mejoramiento de los pastizales.

Recomendaciones para investigación de manejo incluye la atención a : (1) Cambiar el foco de atención de la investigación más allá de la estación, para entender mejor los problemas rurales; (2) incorporando mejor las ciencias sociales (especialmente economia del hogar y mercadeo) junto a agricultura tradicional e investigaciones biológicas; (3) adoptando un mayor pensamiento interdiciplinario, tan simple como dentro del campo de la biología; (4) aumentar las inversiones en personal y sitios claves; y (5) junto con cambiar el foco de la investigación fuera de la estación, reducir el énfasis en los estudios de siembras y ganado bajo condiciones óptimas.

Recomendaciones para la extensión incluye el compromiso de la gente del lugar para discutir: (1) Como mejorar la profitabilidad del mercadeo de la oveja; (2) cómo mejorar el manejo de las tierras cosechadas, con énfasis en el manejo de fertilidad del suelo; (3) cómo mejorar la efectividad y sostenibilidad de los sistemas de regadio; y (4) cómo mejorar la salud humana, nutrición y acceso a información sobre planificación familiar.

Recientemente se reunió información con respecto a eventos en el IBTA y SJL entre 1966-9. La decentralización del gobierno Boliviano llevó a la desaparición de IBTA hacia fines de los 1990s. Se ha envisionado que el IBTA será reemplazada por centros privados de investigación que solicitaran fondos y presentarán propuestas que traten problemas prioritarios en varias zonas ecológicas; este plan podría llevarse a cabo durante el año 2000. Muchos cambios interesantes han ocurrido en SJL. El informe del número de familias ha aumentado a 130, una dramática desviación de nuestra predicción en que el número de familias continuaria declinando a 80 en un futuro cercano. La lecheria se mantiene importante, pero hay un esfuerzo renovado para producir mejores papas para el mercado de consumo y el hogar. La tierra arada para el cultivo de papas ha aumentado dado a la mecanización y altos precios de la papa; todavia se informa de que la tierra está "cansada" y produce bajo su capacidad. Se han hecho algunos esfuerzos para rehabilitar los campos salinos, ésto gracias a fondos del Acta de Participación Popular. Las pequeñas lecherias continuan siendo ayudadas por donantes externos por al menos hasta el 2003. Considerando la sociedad local, es notable que la primera mujer joven que se graduó de enzeñanza secundaria lo hizo en 1999. Algunas otras observaciones de interes incluyen el incipiente "boom" de papas y un dramático aumento en residentes en SJL. Tenemos en mente la hipótesis de que la habilidad para obtener un ingreso más alto llevará a la gente a estar dentro y fuera de SJL. Esto valida la idea de que al invertir en comunidades rurales es importante dejar a la gente tomar ventajas de las oportunidades dinámicas en sectores rurales y urbanos. Esto beneficia tanto a la sociedad local así como al país entero.

8.1 Introduction

Here we review brief summaries by chapter and then derive some integrated conclusions across chapters. Recommendations are presented with respect to further research, outreach and policy consideration. Because several years have passed between the end of our field work and publication of this synthesis volume, we end with an epilogue that highlights changes and key events that happened at San José Llanga (SJL) and with collaborating institutions in Bolivia between 1996-9.

It is important to note that our conclusions and recommendations must be viewed with some caution. The joint IBTA/SR-CRSP project was active in the field at SJL for only four years (i.e., 1991-5) and this makes any conclusion somewhat risky. We were unable to conduct detailed research on such critical topics as agronomy, soil management, livestock marketing or management of dairy cattle. It is also inappropriate to try to generalise our findings beyond SJL because SJL has unique attributes of landscape position, market access, social capital and history of technology transfer. There is great utility, however, in knowing one place very well. San José Llanga does share some common features with other communities of the central Altiplano. What we can hope to achieve from the joint IBTA/SR-CRSP project is to influence general dialogue on rural development problems of the Andean zone and beyond.

8.2 Conclusions

This synthesis volume has focused more on general findings and general conclusions that emerged from dozens of empirical studies. Source materials include theses and technical reports, and readers are urged to consult these for detailed findings and detailed conclusions not reported here. It is also useful for readers to review Chapter 1: *Project objectives and research approach*.

8.2.1 Brief summaries by chapter

Given the length and diversity of this synthesis volume, a concise summary of main points for each chapter is useful. This also allows us to answer disciplinary questions posed in Chapter 1 (Section 1.4.2.4: *Sustainability and environmental degradation* and Section 1.4.2.5: *Other sustainability factors: Community leadership, new technology and urban markets*).

In Chapter 2 (*National, regional and local context),* one conclusion was that after centuries of oppression, changes in national policies since the 1950s appeared to be having some positive results for *Aymara* residents of the Altiplano, especially in terms of improved access to formal education, markets and production technology. Changes in land use policy resulting from the Land Reform Act of 1953, however, have led to more controlled access to higher-value lands on the central Altiplano in some cases, and this has undermined traditions of communal resource use. The Popular Participation Act of 1994 is a good example of a policy initiative that could yield benefits for SJL residents by increasing access to state revenues for local development initiatives. Some problems may persist, however, in terms of national policies that have discouraged some forms of food production and undermined traditional, but highly adapted, commodities such as camelids and indigenous cereal crops. With respect to selection of SJL as a research site, it was noted that the position of SJL in the middle of the Altiplano, with proximity to large urban markets and the Patacamaya Experiment Station, would confer special ecological, economic and technical attributes that could make generalisation of results difficult. The same features, however, particularly in terms of access to markets and technology, could make for interesting work to reveal effects of technology diffusion and economic change on rural communities.

In Chapter 3 *(Ecology and natural resources of San José Llanga)* the ecological system and climate regime were described. The system resembles "cold-desert shrub" analogues found elsewhere. Native vegetation was dominated by perennial grasses and shrubs found in dozens of community types. Land use was broadly described as rain-fed farming for food crops and forages (about 25% of the area), several forms of saline and fresh-water irrigated farming for food crops and forages (also around 25% of the area), and grazing on native vegetation with moisture variously supplied by rainfall and saline sub-irrigation (about 50% of the area). The cropping matrix was complex; households had land parcels scattered to mitigate risks (i.e., frost, moisture variability and soil pests). Based on 43 years of data, the average annual precipitation was about 406 mm, although with relatively moderate variability (CV = 22%). Although there was no statistical evidence of a long-term decline in precipitation, residents of SJL perceived that the climate was becoming drier--also supported by anecdotal observations that low-lying areas of SJL had been inundated less in recent years compared to the past. Analysis of seven-year running means suggested that precipitation at SJL may have a cyclic element of alternating wetter or drier periods on the order of 11 to 13 years in duration. If this was correct, SJL would currently be in the middle of a drier phase. Precipitation was delivered in a uni-modal pattern, as 78% occurred between November and March. The main growing season of January to April was characterised by variable rainfall, warmer temperatures and reduced risk of frost. The dry season occurred from May through October and plant production during this time was probably limited more by cold temperatures and frost rather than moisture *per se*. High water tables underlying many range sites, for example, would allow some grasses to access moisture and thus have traces of green tissue well into the dry season. Vegetation dynamics were thus influenced by climate and landscape characteristics. One major conclusion from ecological studies was that it was difficult to generalise about resource degradation. The landscape position of SJL makes it a sink for soil, nutrients and salts--this means it is a particularly difficult site for humans and livestock to degrade, especially compared to hill-slope systems, for example. Geomorphic units differed with respect to land use and sources and patterns of degradation. Although grazing over hundreds of years has probably helped alter the rangeland component of the fluvio-lacustrine plains, contemporary effects of grazing in sacrifice areas nearer settlements appeared relatively minor overall and would be very difficult to address via changes in grazing management. Rather, pervasive influences of salinisation, flooding and drought suggested that abiotic factors overwhelm human factors in explaining condition and trend of most range sites. In contrast to range, the cultivated lands of the alluvial terrace and deltaic deposits may be under more risk from mis-management, although variability in rainfall can obscure effects of humans. The deltaic deposits were threatened by irrigation with saline water, while it was speculated that changes over the past 30 years in soil management (i.e., increased use of chemical fertilisers relative to manure and more tractor tillage relative to animal-drawn tillage) may have contributed to an alleged decline in crop productivity on the alluvial terrace. Effects of humans were not always interpreted to be potentially negative, however. This was best illustrated by the diversion of an ephemeral, fresh-water river channel to create the alluvial fan. The alluvial fan represented an expanding centre for forage and food crop production vital for today's agropastoral system.

In Chapter 4 *(Household economy and community dynamics at San José Llanga)*, it was concluded that the community of SJL has always been dynamic in terms of population and economy. Traditions and modern technologies have been combined by SJL residents in recent times to create a diverse and opportunistic capacity to respond to changing economic conditions, in contrast to some tenets of a mainstream modernisation paradigm that predicts specialisation resulting from market integration and adoption of new technology. In addition, traditional forms of resource sharing persist at SJL that help residents, regardless of economic status, be productive through access to land, labour and capital in the absence of government social insurance mechanisms and in the presence of increased controlled access to higher-value crop lands among wealthier households. Resource sharing has been facilitated by pervasive emigration of SJL residents from both ends of the economic spectrum. Emigrants typically kept links to SJL and contracted resident care-takers to manage resources through a variety of reciprocal agreements. Emigration, both on a short- and long-term basis, has always been vital for SJL. The number of households was around 60 in the 1890s, climbed to 125 by the 1970s, and could fall to 80 in the future. Most recent dynamics have been due to emigration from SJL to urban areas, related to changing aspirations of youths for improved standards of living. Drought can exacerbate rates of emigration. These and other factors have all contributed to what we saw as generally positive trends in the local economy and degree of food security at SJL. Different commodities met varied economic objectives for households. In general, food crops (i.e., indigenous potato, cereals, etc.) and Criollo sheep were consumed in-kind while cross-bred sheep, milk from improved dairy cattle, and improved lines of potatoes tended to be sold for cash. Women controlled sheep sales and used the money for household welfare expenditures. Sheep were routinely sold throughout the year—supply therefore did not appear to be strongly linked with seasonal fluctuation in demand in most cases. Improved dairy cattle were also important to diversify capital assets. Income from milk sales may have been controlled more by males. In terms of labour, males and females shared many productive tasks, but females tended to cover the sheep domain. Women reported that adoption of improved technology and management practices had tended to increase their workloads in some cases. Wealthier households also appeared better able to embrace novel enterprises like smallholder dairying. Both patterns suggested that adoption of new technology was not neutral with respect to gender or wealth class. Although the community appeared to be prospering in many respects, the longer-term implications of a high degree of household wealth stratification remained unclear. The base of social capital at SJL was very strong and leaders have taken initiative to improve living standards. Formal education has been widely embraced by SJL residents, but local opportunities for youths (especially females) to attend secondary school have been limited. Although food security in terms of energy and protein may be sufficient, dietary deficiencies in some micro-nutrients may occur. Public health (i.e., sanitation), women's reproductive health and child illness and morbidity require attention. Women have little access to the family planning information they desire.

In Chapter 5 *(The grazing livestock of San José Llanga,)* it was concluded that the grazing system appeared remarkably efficient, with effective use of range, fallow fields and pasture in well-defined seasonal patterns. Challenges imposed by a complex matrix of controlled-access and communal access land, as well as seasonally dynamic patterns of forage quantity and quality, were ably met by experienced female youths who commonly served as shepherds. Sheep were able to gain weight throughout most of the year because they were guided to high value, remnant plots of forages even during the most stressful periods. This illustrated the key role that clever herding played in this system. Overall, the grazing system of SJL was closed in that animals were not allowed to enter other cantóns, even during drought. Landscape and hydrological features combined to produce a *de facto* deferred grazing system on the fluvio-lacustrine plains. Livestock types were typically complementary in terms of grazed diets, so resource competition was not judged to be a critical issue. The managers would probably attempt to address forage scarcity by selling sheep and intensifying cut-and-carry feeding for high-value dairy cows. Producers attempted to sell sheep to make room for the upcoming lamb crop, interpreted to indicate that they were conscious of stocking rate and grazing capacity. Similarly, it has been suggested that numbers of Criollo cattle have been reduced in some cases to make way for more improved cattle. Sheep management was characterised by low-input methods, although pervasive hands-on attentiveness served to greatly limit mortality of adults and lambs to very low levels. Morbidity due to disease and parasite challenges for sheep was high, however. In terms of productivity of wool and milk, fertility rates for ewes and growth rates for lambs, Criollo animals were less productive than improved crosses. There was some indication that young improved animals had higher rates of mortality than Criollo animals. Representation of Criollo and improved crosses was mixed throughout the cantón. Settlements having access to plots of cultivated forages under irrigation tended to have a greater proportion of improved sheep in their flocks.

In Chapter 6 *(Household socioeconomic diversity and coping response to a drought year at San José Llanga),* households were broken out into a number of socioeconomic groups. Two major divisions were called "active" or "passive" and these were delineated on the basis of age of household heads and size of the labour pool, which supported theory. Active households were more at a mid-stage of the life cycle. They were twice as numerous and had far more resources than passive households made up of retirees. Further segregation of active households occurred primarily in relation to relative dependence on improved livestock breeds and secondarily in relation to dependence on cultivated forage and dairying, while passive households were further divided on the basis of number of adult household members. Various socioeconomic groups were contrasted in terms of cash and in-kind income as affected by variable rainfall years. It was expected that households more dependent on crops or having lower levels of income would suffer larger relative declines in income compared to households having more dependence on livestock or off-farm employment. The year 1993 was a time of near-average rainfall while 1995 experienced a 40% drop in rainfall compared to the long-term mean. Contrasts were based on 39 households distributed among four socioeconomic groups. Somewhat surprisingly, income rose in the drought year overall for all groups due in part to increases in commodity prices that ranged from 30 to 400% for food and forage crops and 17 to 50% higher for animals and animal products. Significant variation among subgroups was not detected, probably due in part to small sample sizes. A regression approach was used to analyse factors important in affecting change in per capita consumption between 1993 and 1995. Results supported the idea that sheep assets and remittances from off-farm employment helped mitigate fluctuations in consumption due to drought. This supported prevailing theory and illustrated the role of small ruminants, in particular, in helping buffer households from a drought perturbation.

Chapter 7 *(Patterns of technology adoption at San José Llanga)* described how the central Altiplano in general, and SJL in particular, have been exposed to changing markets and technology transfer efforts for over 30 years. In particular, USAID and other agencies promoted production of improved sheep and improved potatoes in the 1960s while smallholder dairying has been promoted on a subsidised basis since the late 1980s. While there has been a mixed outcome for some forms of producer cooperatives as well as for efforts to sustain rural finance initiatives, the long-term track record for introducing improved potato and sheep has typically been positive and sustainable. Improved sheep were co-dominant with Criollo sheep in many local flocks 30 years after dissemination. Improved potatoes were still commonly grown in the early 1990s, and associated support technologies such as chemical fertilisers and tractor tillage introduced as part of the "potato package" still predominated in agronomic practices. Recently, smallholder dairying has thrived and offers a concrete example of the importance of a multi-faceted approach to development, with components including improved infrastructure, technology, credit extension and establishment of marketing channels. The success of dairying reflects a need for higher and more reliable cash income in the community. Some adverse consequences of technology transfer have also occurred, however. These include potentially detrimental effects of chemical fertilisers and tractor tillage on sustainable cultivation practices, adoption of dairying by wealthier households that can further contribute to wealth stratification, and the spectre that the community could be vulnerable if price supports for dairying are withdrawn. From an historical perspective, technology adoption patterns at SJL have exhibited various ripple effects. Since any given new technology has been oriented to increase market participation, it is not surprising that success of technology has waxed and waned with market forces. In the 1960s there was a higher market demand for improved potato as well as for wool, while national priorities and interest of international donors to increase milk production were evident by the 1980s. Alfalfa was introduced as support technology for production of improved sheep in the 1960s. While alfalfa establishment had some notable success in the early years, it was argued that strong incentives to expand alfalfa were not realised until the 1980s and 1990s. The advent of improved dairy cows in tandem with rising need for cash incomes and fear of drought, spurred interest in expanding cultivated forage production. This, in turn, has stimulated efforts to irrigate larger areas of SJL as well as convert some food crop parcels into forage plots. One possible outcome is that the residents of SJL may compromise their ability to grow their own food under the assumption that incomes from dairying will allow them to meet their food needs from the marketplace. Expansion of cultivated forage has then come full circle to recently benefit production of improved sheep as an ancillary focus of livestock production. This historical analysis tells us that the dairy boom will also be ephemeral, and the community needs to mitigate risk and be prepared for new opportunities. Technologies, information and policies that encourage a "vigilant diversification capability" are therefore important.

8.2.2 What is the role of small ruminants, and can it be strengthened or improved?

It is interesting to note that the "major question" posed in Section 1.4.2.1 *(Focus on role of small ruminants in system sustainability and drought management)* can only be answered by integrating disciplinary results across chapters using a systems perspective. The major question was: "What is the role of small ruminants in sustaining agropastoralism on the Altiplano, and can this role be strengthened or improved through better use of technology or policy?" A classic answer to expect would be that sheep are indeed vital and we must make substantive investments in technology and policy formulation to boost sheep production and improve rangeland and rangeland management to strengthen the role of sheep in the system. As one can see from the following discussion, however, this classic answer could be off-track in terms of what really motivates and enables this community to improve their economic welfare at the present time.

Sustaining output from an agropastoral system requires an optimal combination of land, labour and capital (see Figure 1.1). Small ruminants at SJL contributed inputs to the sustainability of agropastoralism at SJL in several direct and indirect ways (Section 1.4.2.3*: Features of agropastoral systems*). Sheep provided: (1) Manure for crop production as an input to the land component; (2) income (i.e., cash and in-kind) for welfare purchases, cheap meat for diets and wool to help sustain the labour component; and (3) a source of liquid assets used for occasional purchase of system inputs (i.e., the capital component).

It was clear from work by the IBTA/SR-CRSP team that forces of modernisation, market integration and technology transfer have had the greatest potential to undermine the first interaction above, namely the sustained and extensive use of sheep manure for fertilising potato crops. The alleged decline in crop productivity on the alluvial terrace could be related, at least in part, to the shift from manure to chemical fertilisers over the past 30 years. Chemical fertilisers provided short-term boosts to potato production and were reportedly much easier to handle than bulky manure. Manure could also contribute weeds to fields, but in one sense weeds could have utility as forage so the "weed factor" was not all negative. Listing benefits and costs for either practice makes it difficult to decide which is more appropriate (see Section 3.3.4.1: *Sustainability of the alluvial terrace*). The trend of declining use of manure may also have been exacerbated by emergence of manure markets, a drop in the labour pool due to emigration, and an increasing incidence of absentee ownership of crop lands—care-takers may be more inclined to expend less effort and apply chemical fertilisers. Although it has been contended that low rainfall is the best hypothesis to explain perceived declines in crop productivity (Dr. J. de Queiroz, IBTA/SR-CRSP, personal communication), the issue of possible mis-management of soil fertility cannot be ignored given the critical nature of crop production for food security—it is a highly viable alternative hypothesis. The need for residents of SJL to maintain suitable levels of crop production cannot be over-emphasised. The thought that people could compensate for declines in crop production by purchasing more food from the marketplace is a risky proposition given the recent history in Bolivia of inflation, for example (see Section 2.2.2.3: *National highlights of social history: 1951 to 1996*). There is little doubt that management of cultivated soils is a key area for further investigation (see next section).

If we are conservative and assume that lack of sheep manure on soils is an important issue to address given that little new research information is likely from SJL, then we simply would need technologies, policies and outreach education that help shift more manure back onto farmers' fields. Producing more sheep is not an answer here. Patterns of marketing and grazing efficiency suggest that SJL was routinely filled to the brim with sheep. Lifting the lid on carrying capacity for sheep at SJL could be a difficult, expensive and risky proposition.

One problem with trying to adequately answer the "major question" above is that the question implies that sheep are an isolated component of the production system. It was clear from work by the IBTA/SR-CRSP team that sheep were not isolated, but rather an integrated link within a complex socioeconomic web. Team members were emboldened to study the whole system because they realised early on that studies of sheep in isolation would be less relevant.

While sheep were virtually the only realistic source of manure for the cropping system, other and newer components like dairy cattle and wage employment can also provide income and/or assets to sustain the labour force and replenish capital at SJL. These two system functions have thus become more complicated because diverse options now exist. One could argue, for example, that given a choice of investing in more sheep (range), more dairy cattle (pasture), or even education of one's children in the current economic climate, the marginal risks and returns should first favour investment in cattle or education as evidenced by our observations. Forage improvements for range would be highly problematic due to predominance of communal land tenure and risks of drought, floods and shifting saline ecotones. It is clear that the stimuli for recent investment in pasture improvements have been dairy cattle, not sheep.

Keeping an "on-farm" focus at the moment, the suite of policies and technologies that have recently transformed households at SJL have involved smallholder dairying. This is not to say that sheep production is not vital for the sustainability of the system, but that there is less to be gained from sheep interventions at this point relative to cattle for those households with both options. Sheep are thus a low-input system component while returns to cattle require and probably merit higher levels of investment. Dairying seems to provide the income incentives that even dissuade some household heads from emigrating out of SJL, so it has powerful implications for community stability.

It is important to note, however, that the relatively modest investment required to maintain sheep as a small but reliable source of food and income for households underscores the importance of sheep in the system—especially for the poorest families. In this light it is useful to recall the variability among households in terms of wealth, resource access and production strategies. Some households are in an active (mid-career) phase, while others are in a passive (retirement) phase. Resource endowments for forages, water and cultivation can vary markedly among households, dictated to a large extent simply by where people live. It is therefore wise to not embrace a "one size fits all" mentality when considering the utility of specific development interventions. A broad spectrum of choices is most desirable.

For households interested in investing further in sheep production some simple outreach and applied research could be proposed. Since sheep production has traditionally been a low-input enterprise with a somewhat inelastic supply to market (see Section 4.3.3: *Household production system*), getting producers aware of cost-effective productivity gains may be contingent on improving their market awareness (see next section).

Finally, work of the IBTA/SR-CRSP team revealed that an objective of "sustaining agropastoralism on the Altiplano" goes far beyond the question of whether or not to invest in livestock to better maintain local soils, incomes and assets. It was clear that there must also be substantial investment in rural people themselves. The emigration of people from SJL to major metropolitan areas has reportedly occurred because of altered lifestyle expectations, not because they have been pushed by pervasive resource degradation (see Section 1.4.1: *Research setting* and Section 4.3.1: *Human population and resource base*). As long as a majority of emigrants find happiness and suitable options elsewhere, there is no reason to compel them to return to SJL as agropastoralists at the present time. We feel it is in the best long-term interests for Bolivia, however, that cultural and economic linkages be maintained and strengthened between urban and rural areas. This allows society to nurture cultural roots, reduce socioeconomic risks and obtain the best of both worlds. For example, despite the dominance of urban economies and values in contemporary Bolivia, a future episode of inflation or recession could compel many recent urbanites to return to rural areas to produce their own food. Rural areas should thus be maintained in a favourable manner so that such a return could be efficient and feasible. The problem then becomes how to encourage future generations of emigrants to periodically return to communities such as SJL and re-invest time and other resources in their communities. The answer seems to be found in values which have promoted policies like the 1994 Popular Participation Act and subsidisation of smallholder dairying. In tandem with innovative leadership such as that found at SJL, these policies offer the financial and technical resources to better provide services (i.e., potable water and water delivery systems, freshwater irrigation, electricity, public health and secondary education) vital in maintaining an attractive fabric of rural life. Such interventions would help fortify a cultural home base that would appeal to future migrants and encourage both their periodic return and retention of socioeconomic ties between urban and rural areas. The residents at SJL have already been taking this approach, and we hope policy makers will follow their lead (see Section 8.4: *Epilogue 1996-9*).

8.3 Recommendations

Some major recommendations are presented below for further biological, ecological and social research, research management, education of scientists and community outreach. Readers should also consult theses and technical reports for more details.

8.3.1 Research

8.3.1.1 Trials, studies and surveys

Recommended future research involves basic and applied topics. Some questions merit highly controlled experiments while others require social survey and economic analysis to better understand broader dimensions of technical issues. The work presented in this volume offers many ideas for future research. A few of the more important and generalised ideas are as follows.

(1) One of the findings that deserves more basic research attention from climatologists is the apparent 11- to 13-year cycle of precipitation that emerged from our analysis of seven-year running means (Dr. H. Alzérreca, rangeland ecologist, unpublished analysis). If such a cycle exists it would provide critical information for rural producers as well as policy makers. For example, if dry phases could be predicted, producers could adjust their plans accordingly in terms of relative emphasis on crop and livestock production components and their pursuit of off-farm employment. A better understanding of local precipitation patterns would also help clarify causes of an alleged decline in crop production in places like SJL;

(2) Another high priority would be to focus on the management of rain-fed cropping systems on

the central Altiplano. Alleged declines in yields of food crops need to be investigated using a step-wise approach including participatory rural assessment (PRA) and controlled trials. In cases where detailed research is not possible for financial reasons, feasibility of farmer-managed trials could be explored. This has the dual advantage of getting some research done under tight budgets as well as getting producers directly involved in dialogue concerning cultivation practices. Soil fertility management (i.e., manure versus chemical fertilisers), tillage management (i.e., modifications of tractor tillage practices), improved erosion control (i.e., use of inter-crops, windbreaks, etc), and novel inter-cropping schemes are all viable topics for further study. Preliminary trials were conducted by the joint IBTA/SR-CRSP project concerning possible forages to incorporate into fallow fields at SJL. Results are reviewed in Annex A. Promising species include annuals such as *Bromus catharticus, Chenopodium petiolare* and *Taraxa tenella* as well as the perennials *Parastrephia lepidophylla* and *Eragrostis curvula*;

(3) Socioeconomic and policy research could focus on ways to improve household-level risk management, with an aim to find ways to further enhance coping responses to dynamic markets and climate patterns. Like previous "booms," the dairy "boom" will end some day, and communities like SJL should already be thinking about how to position themselves to take advantage of new opportunities. Interventions could involve how to improve the use of information for planning purposes and facilitate economic diversification at the household level. There should also be a review of relevant policies that affect various forms of commodity production on the Altiplano. Policies should be harmonised with rural development objectives and marketing capabilities to promote a diverse mix of profitable options for producers. Effects of the Popular Participation Act on community development should be studied. Effects of the dairy subsidisation programme that has affected so many households at SJL need thorough monitoring and evaluation. The issue of the costs of subsidisation of smallholder dairying in light of the apparent social benefits for the central Altiplano is important. Means to augment traditional social insurance mechanisms through national policy could also be considered. Our work testifies to the positive role that infrastructure and markets can have on mitigating drought impacts for rural people on the Altiplano. More research on drought effects is needed, however, particularly in terms of technologies and policies to help people cope with multiple-year droughts;

(4) Patterns of human nutrition and health at SJL suggested potential problems with micronutrient deficiencies, maternal well-being and childhood illness (Murillo and Markowitz 1995). Such patterns revealed from social survey and diet recall need to be verified with more rigorous clinical analysis. Some human nutritional and health problems could be addressed through improved delivery of public services and outreach (below);

(5) How to mitigate effects of salinisation and frost on fodder and food-crop production via technology and/or management. One approach to mitigate salinisation effects could be to improve the efficiency of using precipitation for irrigation via water spreading methods. On-station research has traditionally focused on crop selection based on productivity under optimal conditions (Yazman 1995). This focus should shift to crop selection based on salinity and frost tolerance;

(6) Verify causes of livestock morbidity as in Villanueva (1995) and identify cost-effective and socially acceptable means to address livestock morbidity problems. Perhaps the most cost-effective gains in livestock production could be achieved by reducing morbidity through better health management. The increasing level of monetisation and market awareness among producers at SJL may help elevate perceptions that morbidity can reduce profitability in meaningful ways; and

(7) Range improvements for site improvements or rehabilitation. The joint IBTA/SR-CRSP project contributed some work at SJL and Santiago de Machaca that examined performance of introduced and native grasses and halophytic (e.g., salt tolerant) plants (see Annexes B and C). While these trials had some promising results, the aforementioned risks of improving range sites suggest that range investments should ideally come from external donors and not community residents. The unique ecology of the Altiplano has made introduction of exotic forages and crops problematic. More attention to promising native plants, or at least those exotics with demonstrated potential under harsh conditions, is warranted (Yazman 1995). Indigenous knowledge should be used by scientists as a starting point. Priorities should be for species suitable as forage and soil conservation.

8.3.1.2 Management of research

As elsewhere in similar situations world-wide, Bolivian institutions such as IBTA have been steeped in protocols that promote technical, biological investigation and highly disciplinary research. Some points below are modified from Yazman (1995).

(1) The traditions of IBTA have involved a focus with on-station research (Coppock 1995; Yazman 1995). While on-station research has advantages in terms of experimental control, problems can occur when trying to identify real constraints faced by producers on-farm. It is notable, however, that on-station work has yielded significant achievements in terms of genetically improved sheep. We advocate more attention be shifted to off-station research, embracing a participatory process that includes all producers regardless of wealth and gender;

(2) Integrate social and biological sciences. Research projects that aspire to achieve high levels of adoption of new technology by producers must take into account social and economic factors that shape rural societies. National research organisations should seek collaborative agreements with non-governmental organisations (NGOs) active in social science analysis. One vital component would be comprehensive marketing studies and regular PRAs (i.e., outreach) that identify problems and opportunities that should guide technical research. Our work revealed that residents of SJL were highly sensitive to market signals. Before national research organisations invest in technology development they should first ensure that products can be effectively marketed;

(3) Integrate livestock and crop research. Efforts by the joint IBTA/SR-CRSP project indicated that household decisions regarding resource allocation were complex. Producers clearly understood that changes in one component of their system had implications for other components. New technologies may not be adopted because of their negative impact on other components of the production system. Research programmes need to consider the integrated nature of production systems on the Altiplano to create technologies that will have high rates of adoption. One means to improve this area is to better integrate livestock, forage and food crop research.

(4) Invest more in professional and technical staff. There should be a continuous process of training technical staff in new research techniques and keeping them abreast of recent scientific developments. Participation in international electronic conferences may be one cost-effective means to do this. In the longer term, national organisations need more collaborative research programmes with external entities to improve staff-training options. Investments in laboratories need to be maintained. Qualified researchers and technicians must be adequately compensated to mitigate high rates of turnover;

(5) Place more emphasis on range management within the realm of general forage research. It is often the case that the only economically viable means to improve rangelands is through improved management rather than intervention with introduced forages. A sole reliance on forage intervention can be risky (Annexes A-C); and

(6) Reduce emphasis on station-based development of "elite" livestock breeds. All too commonly agricultural research systems invest a substantial proportion of scarce resources in maintaining station-based livestock with the goal of developing new breeds. Station-based herds and flocks are generally too small to produce the records needed to identify genetically superior individuals with high confidence. Feeding and management conditions on-station are much different from those on-farm. Selection criteria of researchers often differ from those of farmers. Successful breed development programmes elsewhere (i.e., the US Holstein programme) are based on collection of production records from animals on-farm. Selection of animals with superior traits occurs with researchers collaborating with farmers and ranchers. We recommend that national research organisations take a similar approach.

8.3.1.3 Education of scientists

In support of the points made above, it is clear that applied scientists need to be exposed to interdisciplinary research and on-farm participatory techniques. To be most effective these scientists also should have motivations that value assisting rural people solve their problems. If this value system is in place then issues of interdisciplinary science and directly engaging producers begin to solve themselves. Researchers should not see their output as merely publications, but also in terms of how their work translates into positive human impacts. Such criteria could become part of the annual evaluations of scientific staff.

We were very pleased with the training component of the joint IBTA/SR-CRSP project; indeed it is serving as a model for training in the GL-CRSP (Dr. D.L. Coppock, Utah State University, personal observation). The 27 Bolivian students who completed their research projects often lived together in the field and shared a crowded and active workspace back in the office in La Paz. Most of our students came from urban backgrounds. If they initially had any apprehension about working among the campesinos of SJL and elsewhere, it soon evaporated. They learned to appreciate the complex dimensions of rural problems and how their small piece of research fit into a bigger picture. It is our view that more young scientists should be trained in this manner. This cadre of students should have a major impact on future research and development on the Altiplano.

8.3.2 Outreach

As previously mentioned, there were notable topics at SJL that merit more research. There were other problems, however, that may simply require outreach for substantive improvements to be made. Outreach, in turn, may identify new research questions. Many topics are possible, and priorities should reflect what the people perceive as important. To this end, the participation of women, the primary flock managers, should be facilitated with appropriate attention to presentation format. Some of our ideas are listed below. The format would be to hold community seminars or workshops on:

(1) Price fluctuations for lambs, and whether it could be useful for producers to consider forms of reproduction management, health management and/or nutritional management in order to capture more profits from periods of peak demand (see Section 4.3.3: *Household production system*). Such a strategy would vary from the traditional pattern of uncontrolled breeding and selling animals when income is needed, regardless of price. The Cantón of SJL is a community in economic transition. Human behaviour there appears to have a mix of traditional and contemporary elements. Market awareness for sheep production may be fairly recent and exploring this issue may have merit. If it does not have merit, extension personnel and researchers could learn why. Preliminary results from nutritional trials with grazing rams suggested favourable benefit:cost ratios from feeding 300 g/hd/day of a supplement comprised of ground alfalfa hay, ground barley and brans of wheat and *quinoa* (Annex D);

(2) Ways to increase the application of manure on crop lands, assuming that this would be beneficial for soil structure and fertility. This would need to be linked to applied research. The potential utility and sustainability of simple equipment such as wheelbarrows or spreaders could be examined. Altered herding or coralling practices could be reviewed;

(3) Ways to improve irrigation methods; and

(4) Ways to improve child nutrition and health and increase access to family planning information.

8.4 Epilogue 1996-9

Since closure of the joint IBTA/SR-CRSP project in Bolivia at the end of 1995, a number of events have occurred that merit follow-up discussion. In some instances these clearly challenge the notion that we can predict dynamics of complex systems even a couple years into the future.

Starting in the early 1990s, IBTA was in a continual process of review and renovation. As this occupied IBTA staff it also affected the SR-CRSP. Attempts were underway to reorganise IBTA to make it more responsive to needs of rural people, improve the quality and relevance of research, upgrade staff and enhance morale (Dr. D. L. Coppock, Utah State University, personal observation). A general trend towards decentralisation in the Bolivian government ultimately led to the demise of IBTA by the late 1990s. There is an effort underway at this writing to create private research foundations in the year 2000 (Dr. C. Valdivia, University of Missouri, personal observation). The idea is to have four privately funded research centres that will solicit and fund proposals aimed at solving problems according to priorities identified in recent field assessments and reviews of technology and literature. One such centre would be responsible for research in the Andean zone.

The Cantón of SJL has experienced interesting changes. Except if noted otherwise, the following details were reported by Mr. Pedro Marca, county agent and resident of SJL, as told to Dr. Corinne Valdivia (University of Missouri, personal communication) in November, 1999.

Today SJL is a community of some 130 households. This appears to markedly contradict predictions that SJL would gradually shrink to 80 households as a result of emigration and passing of the older residents (see Section 4.3.1.2*: Living standards, household structure and human population dynamics*). Apparently a number of emigrants have returned to SJL in the past four years.

Fourteen new households have also become established since 1996 as a result of young people at SJL getting married and deciding to settle. The reason that emigrants have returned to SJL, or young people have elected to stay, is reportedly due to an incipient "potato boom." Higher potato prices have apparently been important in encouraging growth in the local population.

Smallholder dairying remains as an important economic activity at SJL, but it appears more concentrated in the main *Barrio* and adjacent settlements. It would thus be interesting to find out if some households have indeed become specialised in dairy production given a longer period of time and relatively stable market opportunities. More distant settlements such as *Inkamaya* and *Espíritu Willq'i* have prioritised production of improved potato for market sales, followed by sheep production. Dairying is not important for people in these settlements. Apparently the issue of improving irrigation, and hence expanding cultivated forage production, has still not been solved in places like *Inkamaya* and *Espíritu Willq'i*. There have also been reports that DANIDA (the Danish development agency) has provided USD 10 million for further development of the dairy industry on the Altiplano for five years starting in 1998 (Dr. C. Valdivia, University of Missouri, personal communication). The funds will largely be used for in-kind credit schemes. In addition to providing technical assistance to farmers, research is being planned by DANIDA to monitor the potential vulnerability of dairy producers to price supports and the effects of dairying on the environment (Dr. C. Valdivia, University of Missouri, personal communication).

Land use patterns have changed at SJL. Some cropping areas formerly designated for growing "bitter" potato have been converted to alfalfa. Apparently the emphasis on bitter potato has declined in favour of improved potato, which is now even used to make traditional foods like *chuño*. The producers are apparently responding to favourable conditions for potato marketing. There is even discussion as to whether to form an association of potato producers. Attempts are being made to reclaim some of the saline rangelands. One NGO is working with households at SJL to rehabilitate parts of the fluvio-lacustrine plains. This effort is founded on planting promising halophytic species (see Annex C). Funds were obtained from the Popular Participation Act to initiate this activity. The fact that this has emerged as a priority for some households undermines the assertion that the sheep/range component of the system would be a lower priority than the dairy/pasture component (see Section 8.2.2: *What is the role of small ruminants, and can it be strengthened or improved?*). More information needs to be known, however, concerning the choices available to producers involved in rehabilitation of saline lands. For example, range improvements may be the only option they have for increased productivity if they are non-dairy households. The potential risk of planting halophytes, however, appears to be mitigated by the use of public funds.

In general, producers still feel that the crop lands of SJL are "tired" and producing below potential capacity. Larger amounts of land have been tilled because of tractor availability and emergence of higher prices for potatoes.

Finally, in terms of social issues it has been reported that nine young women have graduated from the secondary school at SJL in 1999. These are the first females to do so (C. Jetté, UNDP, personal observation).

If we can assume that information on recent trends at SJL is accurate, it is very illuminating in terms of human-related forces that govern system dynamics. Given that people largely control the fate of several key resources at SJL, forces that affect human decisions are paramount. Perhaps the most important decision is whether or not a person decides to live at SJL. This profoundly affects resource use and allocation. The recent build-up in household numbers, particularly in conjunction with a possible potato boom and the perception that the crop land still seems "tired" tells us alot. It lends credence to the hypothesis that perceptions about income drives many decisions of where campesinos will live. Prospects for lower incomes drives people out of SJL, and prospects for higher incomes brings people back. This suggests that the emigrant experience is less satisfactory than proposed earlier, at least in terms of the ability of most emigrants to secure higher incomes in urban settings (see Section 4.4: *Conclusions*). This complicates the notion of push and pull factors by making it a "chicken-and-egg" debate. Clearly, however, if environmental degradation was important enough to keep people out of SJL, they would not have come back. We would speculate that the incentive of higher commodity prices apparently is strong enough to over-ride other considerations. The observed pattern could also validate the idea that an important development strategy is to invest in rural communities so that they remain viable places for people to live. Using technology and policy to maximise options allows people to take advantage of dynamic rural and urban sectors. This also has benefits for the nation.

Literature cited

Coppock D.L. 1995. Range ecology and range animal nutrition. In: Johnson S. (ed.), *SR-CRSP Annual Report 1995.* Management Entity, SR-CRSP (Small Ruminant Collaborative Research Support Program), University of California, Davis, California, USA. pp. 91-118.

Murillo C. and Markowitz L. 1995. *Food and Nutrition in San José Llanga, an Agropastoral Community in the Central Altiplano of Bolivia.* IBTA/SR-CRSP (Instituto Boliviano de Tecnología Agropecuria/Small Ruminant Collaborative Research Support Program). IBTA 173/Boletín Técnico 41/SR-CRSP 39, La Paz, Bolivia. 37 pp.

Villanueva E. 1995. *Caracterizacion del Sistema de Manejo y Produccion de Ganado Ovino en Una Comunidad del Alitplano Central*. BS tesis, Universidad Tecnica de Oruro, Oruro, Bolivia. 99 pp.

Yazman J. 1995. *Informe Final*. IBTA/SR-CRSP (Instituto Boliviano de Tecnología Agropecuria/ Small Ruminant Collaborative Research Support Program). La Paz, Bolivia. 58 pp.

Annex A

Improving fallow fields with forages and manuring at San José Llanga

Mejoramiento de los campos de descanso con forrajes y estiércol en San José Llanga

by Guillermo Prieto, Julio Cesar Montecinos and João S. de Queiroz

Summary

Interventions to improve fallow field management could help reduce wind erosion, improve feed supplies, and enhance soil fertility. We used an experimental approach for a preliminary evaluation of the productivity of three introduced forages, each seeded with or without manure with minimal soil disturbance. Data were collected on plant cover and air-dried biomass after one growing period. Manuring had a much greater effect on plant biomass compared to the effects of seeding. *Eragrostis curvula* showed some promise as a seeded forage. Although effects of manuring were pronounced, labour constraints may preclude practical application of this intervention.

Resumen

Las intervenciones para mejorar el manejo de campos en descanso, pudieran reducir la erosión eólica, mejorar el abastecimiento de alimentos y realzar la fertilidad del suelo. Para ello experimentamos con una evaluación preliminar de la productividad de tres forrajes introducidos con semillas, con o sin abono de estiércol y con un mínimo de perturbación del suelo. Los datos fueron colectados en base a cubierta y la biomasa seca después de un período de crecimiento. Plantas tratadas con abono túvieron un mayor efecto en la biomasa, comparado con el efecto de semillar. *Eragrostis curvula* mostró algo de futuro como semilla forrajera. Aunque los efectos de abono fueron pronunciados, el aumento del uso de mano de obra podría hacer imposible la aplicación práctica de esta intervención.

Problem Statement and Approach

Fallow field management is important at San José Llanga (SJL). It has been recognised that improved management of fallow fields could benefit the production system in several ways. If new forage and cover crops could be inserted it is likely that wind erosion could be lessened, feed supplies could be improved, and soil fertility could be enhanced. Reductions in length of fallow may be one artifact of increasing pressure on resources at SJL, and this can compromise recovery of soil fertility.

The approach we used was experimental. Three 400-m^2 exclosures were constructed in fallow fields occurring on different soil textures. These were loamy, silty-loam and sandy loam soils. Exclosures were divided up into plots, with five replicated plots per treatment. The treatments involved seeding (using minimum soil disturbance) of *Melilotus officinalis* (sweet clover), *Eragrostis curvula* (an African species) and *Agropyrum intermedium* (a West Eurasian wheatgrass) with or without manuring at a rate of 4 t/ha. Work was initiated at the end of the dry season in late 1994. Data on plant cover and air-dried biomass responses were collected at the end of the dry season in October, 1995. A two-way ANOVA was used for data analysis.

Results

General results for biomass are depicted in Table A1. They illustrate the overall variability due to soil type, and were interpreted to show that regardless of soil type, manuring typically doubled (at least) the herbaceous biomass on fallow fields. It is notable, however, that seedings in the absence of manuring were often not appreciably different from controls. The effect of seedings was concluded to be nominal, regardless of manuring or soil type. As in the trials at Santiago de Machaca (Annex B), many seeds were contributed by the manure itself, and these commonly overwhelmed effects of experimentally seeded species. It was concluded, as at Santiago de Machaca, that introductions of exotics were problematic here. There were some observations, however, which suggested that *E. curvula* could be promising. More trials with *E. curvula* could be warranted,

Table A1. *Total biomass production (kg DM/ha) of herbaceous vegetation according to soil type and manure amendment (with or without) in fallow fields at San Jose Llanga*[1]. Source: Coppock (1995) adapted from work done by Prieto et al (IBTA/SR-CRSP, unpublished analysis).

Treatment	Soil					
	Loamy-Silty		Loamy-Sandy		Loamy	
	With Manuring	Without Manuring	With Manuring	Without Manuring	With Manuring	Without Manuring
Eragrostis curvula	955	440	896	393	1 006	806
Agropyron intermedium	868	423	897	395	1 346	766
Melilotus officinalis	1 051	476	1 249	607	1 155	617
Control	751	439	792	648	1 002	599
Total	3 626	1 778	3 834	2 042	4 508	2 788

[1]Treatments involved seedings with species listed above. The control had no additional seeding. Note, however, that contributions of seeded species to biomass totals were minor compared to others already present as seeds in the manure amendments. Main effects of manuring and soil type were significant in the ANOVA ($P<0.05$).

especially if it is evaluated in monocultures with better soil preparation prior to seeding. This type of trial on farmers' fields only represents a small beginning of work required on this topic. Other activities of the joint IBTA/SR-CRSP project have identified a variety of native annuals and perennials which could receive more research attention as interventions for fallow fields. These include *Chenopodium petiolare, Taraxa tenella, Bromus catharticus, Festuca orthophylla, Nasella pubiflora* and *Stipa mucronata.*

Manuring proved to be an excellent means to obtain, over the short term, significant increases in forage from annuals in all sites examined. The problem remained that labour constraints would probably preclude manure spreading by farmers. The remaining option would involve using animals as mobile manure spreaders on fallow fields, but it is unclear as to whether the campesionos have sufficient herding labour to carry out such maneuvers given the interspersion of fallow fields with current crop production.

Literature cited

Coppock D.L. 1995. Range ecology and range animal nutrition. In: Johnson S. (ed), *SR-CRSP Annual Report 1995*. Management Entity, SR-CRSP (Small Ruminant Collaborative Research Support Program), University of California, Davis, California, USA. pp. 91-118.

Annex B

Range improvements at Santiago de Machaca
Mejoramiento de los pastizales en Santiago de Machaca

by Julio Pablo Valencia and João S. de Queiroz

Summary

Santiago de Machaca is a higher elevation site where camelids and sheep are produced and *thola*-dominated shrubland is common. Interventions to improve productivity of this shrubland could involve restoration of soil fertility, selective removal of larger shrubs, and seeding using introduced species. We used an experimental approach for a preliminary evaluation of these methods. Data were collected on germination and establishment of seeded species as well as cover and air-dried biomass of all plants over two years. In general, there were some positive and additive effects of manuring and *thola*-thinning with those of seeding on plant response variables compared to control plots, but this varied by soil type and was short-lived due to stress imposed during the cold dry season. Manure also contributed seeds of native species to the plots. We concluded that while our approach had merit, research should focus on native forages and include an economic assessment.

Resumen

Santiago de Machaca es un lugar ubicado a altitud mayor en donde se cría camélidos y ovejas, en donde la *thola* es la planta dominante. Para mejorar la productividad de este matorral intervenciones tales como la restauración de la fertilidad del suelo, sacar las malezas de gran tamaño y siembras usando especies introducidas. Para ello realizamos experimentos a forma de evaluación preliminar de esos métodos. Los datos fueron colectados de la germinación y establecimiento de las especies plantadas como también de la cubierta vegetal y biomasa seca de todas las plantas por dos años. En general, hubieron algunos efectos positivos y agregados del abono de estiércol y la disminución de thola con respecto a aquellas plantas que respondieron en forma variable al semilleo, comparadas con el área de control. Sin embargo, éste cambio se basó en el tipo de suelo y fué de poca duración dado al stress impuesto durante la época fría y seca. Por otro lado el abono de estiércol incluyó semillas nativas a las áreas de estudio. Concluimos que mientras nuestros experimentos tuvieron mérito, la investigación deberá concentrarse en forrajes nativos e incluir un evaluación económica.

Problem statement and approach

Whether or not range degradation has occurred, and the role of people and their animals in degradative processes, remains controversial for the Bolivian Altiplano. While environmental degradation is most apparent on cultivated hillsides and where shrubs have been over-harvested for fuel, it is more difficult to assess degradation on the numerous range sites which have adjusted to heavy grazing over hundreds of years. To complicate the range picture further, there is great variation in the susceptibility of different range sites to degradation due to soil types, landscape features and dominant plant species. Exploratory studies were conducted by the joint IBTA/SR-CRSP project concerning extent and causes of range degradation at San José Llanga (SJL) and a hillside system at Santiago de Machaca (SM). Conclusions pertaining to degradation were varied. One inference from work at SJL was that range sites in the flood plains were probably relatively stable in terms of plant species composition and soil structure (see Section 3.3.4.4: *Sustainability of the fluvio-lacustrine plains*). In contrast, results from nearby SM were interpreted to suggest that the shrubby range dominated by *thola* (*Parastrephia lepidophylla*) could be considered degraded on the basis of accelerated losses of top-soil in shrub interspaces. It was also likely that the sites at SM have endured many years of nutrient depletion from redistribution of nutrients from rangeland to livestock corrals via animal feces (Norton 1994). Based on these findings, the next step was to test appropriate, low-input techniques which could improve forage value of *thola*-dominated range sites at SM. Santiago de Machaca is at a higher elevation than SJL and is subjected to a harsher climatic regime. Unlike SJL, camelids remain a mainstay of the economy at SM (Norton 1994).

The approach was experimental. Two fenced exclosures, each over 5 000 m^2 in area, were erected in *thola*-dominated sites, one on each of two soil types, Cambisols and Luvisols. These communally owned sites have a history of heavy grazing by camelids and sheep, and were rain-fed. In each exclosure the following treatments were replicated three times on randomly distributed, small plots: (1) Control (no manipulations); (2) seeding the plot with a new herbaceous species only; (3) seeding and adding manure to the top soil; (4) seeding and thinning out potentially competitive *thola* shrubs; and (5) seeding with both thinning of shrubs and manuring.

Species seeded on the Cambisols were: *Eragrostis curvula*, a plant native to East Africa, at 4 kg/ha; *Medicago sativa* (15 kg/ha); and *Agropyron elongatum*, native to Eurasia, at 10 kg/ha. Species seeded on the Luvisols were *E. curvula* (4 kg/ha); *Bromus bellegardi*, native to Europe, at 11 kg/ha; and *Bromus catharticus*, native to the Andes, at 11 kg/ha. After raking the top 5 cm of the soil surface with *thola* branches, seeds were broadcast and then covered over with the disturbed soil. Seeding was carried out at the beginning of the rainy season. Manure was applied at a rate of 4 t/ha, a rate used by campesinos to fertilize potato crops. *Thola* plants were selectively extracted; only shrubs > 40-cm tall were taken out, which corresponds to the size used for fire wood. Data were collected on germination and establishment of seeded species, as well as general measures of cover and biomass for vegetation overall. Data collection occurred over two years. Data were analysed using a two-way ANOVA.

Results

Seedings initially had high rates of germination and establishment in the first wet season. Seedling populations, however, were severely reduced during the subsequent six months of cold, dry weather, regardless of soil type (not illustrated).

One set of data pertaining to biomass and cover response to seeding, *thola* thinning and manuring are displayed in Table B1. Note that data from seeded plots reflect overall means across the three seeded species for each soil type. In general, responses of cover and biomass were qualitatively similar. The following discussion, therefore, will focus on biomass to illustrate trends.

On Luvisols, seeding alone resulted in a 21% increase ($P<0.05$) in biomass compared to the unseeded control. Adding *thola* thinning or manuring in isolation to the seeded plots resulted other biomass increments of 23 to 29% over seeding alone, but there was no apparent synergism from combining *thola* thinning and manuring together (Table B1). Plant response from the manuring plus seeding or *thola* thinning plus seeding treatments exceeded that of unseeded controls by 52%.

Patterns for Cambisols differed from those on Luvisols. On Cambisols, neither seeding alone, or seeding plus manuring, resulted in significant changes ($P<0.05$) in biomass compared to unseeded controls (Table B1). Adding *thola* thinning, however, to seeded plots did increase plant biomass by 48% compared to unseeded controls. Adding manuring to *thola* thinning did not result in additional increases. It was observed that after *thola* thinning occurred on Cambisols, the main increases in herbaceous biomass were attributable not to seeded species, but to increases in indigenous taxa such as *Stipa mucronata, Nasella pubiflora* and *Calamagrostis* sp. after reduction of competition from *thola*.

These results point to the heterogeneous constraints affecting net primary production of herbaceous plants here. On Luvisols it appeared as though negative influences of *thola* were less pronounced than they were on Cambisols; this could be related to plant root competition being mediated differently by varied soil textures. Cambisols may have larger residual populations of native herbaceous plants compared to the Luvisols. In addition, Luvisols may be more nutrient deficient than the Cambisols, hence the apparently greater response of the Luvisol plant community to manuring. Effects of manuring were difficult to interpret, however, because manure provided other indigenous seeds in addition to nutrients.

In general, contributions of seeded species were often minor in total cover and biomass compared to those of indigenous herbaceous species, whether the latter came from the site

Table B1. *Average percent cover and herbaceous biomass (kg DM/ha) for range plant communities on two soils subjected to various treatment combinations using thinning of shrubs* (thola; Parastrephia lepidophylla) *and manure amendments at Santiago de Machaca* [1]. Source: Coppock (1995) adapted from work done by Valencia and de Queiroz (IBTA/SR-CRSP, unpublished analysis).

	Cover %		Biomass	
Treatment	Luvisols	Cambisols	Luvisols	Cambisol
Seeded				
Thola unchanged; No manure added	3.6 b	7.3 b	222 b	407 b
Thola unchanged; Manure added	4.5 a	6.8 b	287 a	364 b
Thola thinned; No manure added	3.5 b	11.0 a	273 ab	520 a
Thola thinned; Manure added	4.1 a	11.5 a	284 a	518 a
Unseeded				
Control (no manipulations)	2.8 c	6.2 b	184 c	350 b

[1]See text for discussion of treatments. Entries within the same columns accompanied by the same letter (a,b) were not significantly different ($P<0.05$).

or were imported as seeds via manure. These observations tended to support the proposition that climatic constraints in places like SM constitute a severe obstacle to range improvements using exotic plants, even plants successful elsewhere on the Altiplano. Research should probably be re-directed towards promising local forages and the role of manuring and *thola* thinning, including economic and social analyses of the real costs and benefits of range rehabilitation. Our experience can also be interpreted to suggest that valuable research resources for technology development may be best used in range sites having the highest potential, such as naturally irrigated *bofedales*.

Literature cited

Coppock D.L. 1995. Range ecology and range animal nutrition. In: Johnson S. (ed), *SR-CRSP Annual Report 1995*. Management Entity, SR-CRSP (Small Ruminant Collaborative Research Support Program), University of California, Davis, California, USA. pp. 91-118.

Norton B.E. 1994. Range ecology. In: Johnson S. (ed), *SR-CRSP Annual Report 1994*. Management Entity, SR-CRSP (Small Ruminant Collaborative Research Support Program), University of California, Davis, California, USA. pp. 3-20.

Annex C

Performance of introduced halophytes at San José Llanga

Capacidad de desarrollo de halófitas introducidas en San José Llanga

by Guillermo Prieto, João S. de Queiroz and Jaime Valdivia

Summary

Large areas of the rangelands at San José Llanga are salinised. Reclaiming some of these sites using halophytic (salt tolerant) forage plants could be useful. We undertook a preliminary evaluation of the performance of two native halophytes, namely *Atriplex alimus* (144 seedlings) and *Suaeda foliosa* (500 transplants). Material was planted in exclosures on several soil types and monitored for about two years. For *Atriplex alimus*, results were highly variable depending on location, as survival rates varied from 9 to 70%. *Atriplex alimus* seems to be a promising species here with suitable rates of growth and nutritive value. Results for *S. foliosa,* however, were less favourable as over 95% of transplants died.

Resumen

En San José Llanga existen grandes áreas salinizadas. Lo que podría ayudar a la recuperación de algunos de esos sitios sería el usar plantas forrajeras halófitas (tolerantes a la sal). Para ello decidimos hacer una evaluación preliminar del comportamiento de dos halófitas nativas, *Atriplex alimus* (144 plántulas) y *Suaeda foliosa* (500 transplantadas). Este material fue plantado en áreas protegidas en varios tipos de suelos y observado por dos años. Para el *Atriplex alimus*, los resultados fueron altamente variable dependiendo del lugar, con tazas de sobrevivencia variando de 9 a 70 %. *Atriplex alimus* pareciera ser una especie prometedora en este lugar, con tazas de crecimiento y valor nutritivo adecuados. Los resultados para *S. foliosa*, sin embargo, fueron menos favorables ya que sobre el 95% de las transplantadas murieron.

Problem statement and approach

Salinity of soil and water is a major constraint that limits net primary production in large expanses of flood-plain rangeland of San José Llanga (SJL). Soil salinity is due to local geology and is not a human-induced phenomenon. Because the area has a long history of salinisation, several indigenous plant species have developed adaptations to tolerate high levels of salt in the environment. Some of these taxa (i.e., *Atriplex* spp., *Suaeda foliosa*, *Distichlis humilis* and *Hordeum muticum*) are palatable and important forages for sheep in the Central and Southern Altiplano; sheep even tend to be distributed in the more saline areas of the Altiplano. One problem, however, is that large portions of saline areas are either barely vegetated or completely denuded. Soil research indicates that this extreme condition is likely due to high levels of salinity in conjunction with ephemeral flooding. In other cases the situation may be exacerbated by inappropriate stocking because such sites are already low value and therefore neglected, unregulated and poorly managed.

There were very large acreages of denuded, saline soils at SJL. Given the high efficiency with which existing grazing resources were used (see Chapter 5: *The grazing livestock of San José Llanga*), the production system could be markedly improved if some of the saline wastelands could be reclaimed, thereby expanding the forage base. With this thought in mind, range ecologists initiated a trial to evaluate the performance of two promising halophytic forages, *Atriplex alimus* and *Suaeda foliosa*.

For *Atriplex*, one 400-m^2 exclosure was established in each of three sodic-soil types in the flood plain of SJL. One was on a loamy-sand, another on a loamy-clay and the third was on a loamy-clay-sand. One hundred and forty four seedlings were transplanted in each exclosure at the end of the dry season in December, 1993, giving each plant about one-third of a square meter in which to grow. Plant survival was evaluated in 1994 and 1995. Aboveground biomass, nutrient content of biomass (i.e., CP, ADF, and

NDF), and plant height were evaluated in October, 1995, using standard procedures (AOAC 1980).

For *Suaeda*, one 400-m^2 exclosure was established in each of three locations. One was in barren land, where the soil was hyper-sodic and heavily textured from flooding. Another was in a nearly denuded area where the soil was also hyper-sodic with a medium texture; plants here included the "cushion" plants *Anthobrium triandrum* and *Salicornia pulvinata*. The last exclosure was placed in a transition zone between the latter and one having moderately sodic, medium-textured soil with plants including the shortgrass *Distichlis humilis* and *A. triandrum*. Five hundred units of vegetative material (i.e., complete plants or parts of plants with roots) were extracted from *Suaeda foliosa* rangelands in the Caracollo and El Choro saline floodplains, located 150-km south of San José Llanga. Each exclosure received 167 units of plant material, which gave each roughly 0.4 m^2 in which to grow. These were also planted at the end of the dry season in 1993. It was intended to monitor the same features for *Suada* as for *Atriplex*. Results were originally reported in Coppock (1995).

Results

For *Atriplex*, results were highly variable depending on exclosure location. Establishment of *A. alimus* was highly successful on the loamy-sand site, with a survival rate of around 70% by 1995. On the loamy-clay and loamy-clay-sand sites survival was lower at 33% and 9%, respectively. Biomass in 1995 varied from 23 to 200 g DM/plant. Crude protein values of leaf plus stem material varied across sites from 6.7% (loamy-sand) to 10.5% (loamy clay) and 11.7% (loamy-clay-sand). These figures suggested, in general, that *Atriplex* could be quite suitable as a source of protein for grazing stock. The critical soil parameters at the loamy-clay site (where establishment and growth of *Atriplex* were most successful) included a pH of 8.8, an electrical conductivity of of 4.7 mmhos/cm, a cation exchange capacity of 7.7 meq/100 g, and a sodium content of 0.90 meq/100 g. These can be used as indicators to map out the extent of the flood plain that could be most suitable for establishment of *Atriplex alimus*.

In contrast to *Atriplex*, results have been uniformly disappointing for *Suaeda foliosa.* Survival rates of 0, 2 and 5% were recorded across the three exclosures, precluding any other data collection.

It was uncommon to find exotic plants which survive and grow in the Altiplano. *Atriplex alimus*, however, appeared promising. More work is required on this species in order to clarify constraints for plant establishment, the reproduction capabilities via seed and vegetative material, and plant persistence under grazing. None of the *Atriplex alimus*, for example, were observed to reproduce themselves. The disappointing results obtained with *S. foliosa* may be related to site selection (growing conditions may have been too extreme), method of transplantation and possibly a low level of soil moisture at the time of trial initiation. Lessons could be learned from IBTA regarding *Suaeda* transplantation methods; in a neighboring community IBTA has successfully revegetated large areas by transplanting young, but well-developed, plants of *Suaeda foliosa* that were also producing seed.

Literature cited

AOAC (Association of Official Analytical Chemists). 1980 *Official Methods of Analysis*. 13th edition. AOAC, Washington DC, USA. 1016 pp.

Coppock D.L. 1995. Range ecology and range animal nutrition. In: Johnson S. (ed), *SR-CRSP Annual Report 1995*. Management Entity, SR-CRSP (Small Ruminant Collaborative Research Support Program), University of California, Davis, California, USA. pp. 91-118.

Annex D

Nutritional supplementation of grazing sheep at San José Llanga during the dry season

Suplementación nutricional de las ovejas en San José Llanga durante la época seca

by Ximena Sandy, Einstein Tejada and Jim Yazman

Summary

During the dry season sheep must graze native plants that have a low nutritive value. This can lead to low forage intake and poor rates of weight gain. Supplementing sheep with small amounts of higher quality feeds can improve forage intake and weight gain. We undertook a study to evaluate these issues over a four-month dry season. We used 10 rams, with two fistulated at the esophagus to assess diet composition and quality and eight others to assess fecal output and diet intake. All animals grazed by day under the management of a campesino family. One group of five was a control (grazing only) while the other group received a 300 g daily supplement of ground alfalfa hay, barley, wheat bran and *quinoa* bran in addition to grazing. Grazing sites varied throughout the study and influenced results. Positive effects of supplementation on intake of organic matter were observed in several, but not all, instances. Supplemented rams gained 2.4 kg/head during the trial while unsupplemented rams lost 3.2 kg/head. This and similar forms of supplementation could be considered as an intervention here. This requires a more comprehensive evaluation including identification of potential social and economic constraints.

Resumen

Durante la estación seca, las ovejas deben pastorear especies nativas con un bajo valor nutritivo. Esto puede llevar a una baja cantidad de forraje consumido y a una baja taza del aumento de peso. Al incluir un suplemento de alta calidad en la dieta puede aumentar el consumo y al mismo tiempo aumentar el peso de los animals. Para ello hicimos un estudio con el fin de evaluar este tema. El estudio se realizó en un período de cuatro meses durante la estación seca. Para determinar la composición y calidad de la dieta, usamos 10 carneros, con dos de ellos fistulados en el esófago y las 8 restantes para determinar el contenido fecal y la dieta ingerida. A todos los animales se les hizo pastorear durante el dia bajo el manejo de una familia campesina. Un grupo de 5 se usó como grupo control (solo pastorear) mientras que el otro grupo recibió un suplemento de 300 g diarios de heno de alfalfa molida, cebada, afrecho de trigo y afrecho de quinoa además del pastoreo. Los sitios de pastoreo variaron a travéz del estudio e influenciaron los resultados. Los efectos positivos de suplementación al ingerir materia orgánica fueron observados en varias pero no en todas las ocasiones. Los carneros suplementados subieron 2.4 kg/ cabeza durante el experimento, mientras que los carneros sin suplemento perdieron 3.2kg./ cabeza. Formas similares de suplementación podrían ser considerada como una intervención. Sin embargo, ésto requiere de una evaluación más comprensiva incluyendo la identificación de problemas potenciales en cuanto a lo social y económico.

Problem statement and approach

The dry, winter months of June through September are critical to sheep productivity on the central Altiplano. During this time sheep primarily graze fallow fields and native range. Development of strategies to improve sheep productivity require an understanding of the utilisation of existing forage. Previous research by the joint IBTA/SR-CRSP project characterised botanical composition of sheep diets using ocular methods (Cáceres et al 1995). This was followed by attempts to estimate diet quality and nutrient intake using chemical analyses of hand-plucked forages in conjunction with observed bite sizes and biting rates (Lopéz et al 1995). Although such methods have logistical advantages under difficult field conditions and are useful for baseline descriptions, they also have significant problems of inaccuracy and bias. Our first objective in this work was to determine how much forage sheep consumed from the rangeland in the dry season; we expected intake to be low, in part because of poor nutritive value. The second objective was to assess whether supplementation with small amounts of higher value feeds could increase intake of poor-quality range vegetation. With these precise objectives in mind, it was important to have accurate and unbiased data in an experimental format. We needed alternative methods. One alternative for determination of diet composition and quality involved collecting ingesta samples (extrusa) in a small cloth bag anchored under a hole (or fistula) in the throat (esophagus) of a grazing animal. The ingesta was then dried and chemically analyzed (AOAC 1980). An alternative for estimating intake involved knowing diet digestibility and fecal output. The latter can be achieved using fecal collection bags, while the extrusa samples from the esophageal fistulation are suitable for determination of digestibility using laboratory methods. Ten rams in total were used to quantify diets and estimate intake. Two of the rams were fistulated at the esophagus for diet sampling. Eight other rams [four Criollo and four cross-bred (i.e., Targhee or Corriedale X Criollo)] were used to estimate fecal output with fecal-collection bags emptied every 24 h during a five-day collection period over four months. The 10 animals were evenly divided into two treatment groups, one supplemented and the other a control. The supplemented rams received 300 g/head/day of a supplement consisting of ground alfalfa hay, ground barley and brans of wheat and *quinoa* (*Chenopodium quinoa*). This supplement had a crude protein (CP) content of 13.5%, and an organic matter digestibility (OMD) of 75%.

All 10 rams were run together in one flock under the management of a campesino family. The flock grazed on three types of range during the study period: (1) *Tholar/pajonal*, an upland type dominated by shrubs (*Parastrephia lepidophylla*) and perennial grasses (*Festuca orthophylla)*; (2) *q'auchi/gramadal*, a lowland type having halophytes (*Suadea foliosa)* and shortgrasses (*Distichlis humilis);* and (3) *pajonal*, an intermediate type dominated by perennial grasses (i.e., *Muhlenbergia fastigiata, D. humilis).* Nutritive value (CP and *in sacco* OMD) for extrusa was determined. Organic matter intake (OMI) was estimated as a quotient of fecal output and digestibility of extrusa (Leaver 1982). Finally, ram performance was assessed by weighing at the beginning and end of the trial period. Data were analysed using *t*-tests.

Results

Campesino families at San José Llanga (SJL) used crop residues, fallow fields and native range as principal sources of sheep forage. The pattern of resource use was determined by land owned, forage availability, labour and restrictions dictated by the community. During the present study (i.e., June through September) the monthly pattern of resource use by the research flock varied. In June and July the main sites used were *tholar/pajonal* and *q'auchial/gramadal*. In August this shifted more to *pajonal* and *q'auchial/gramadal*; by September the flock was increasingly found back in *tholar/pajonal*. This was a potential complication for interpretation of results.

Results were interpreted to indicate that OMI tended to increase as the dry season progressed from June to September (Table D1). This may have reflected attempts by the rams to maintain nutrient intake as forage availability and quality declined; the animals may also have been allowed to feed for more hours per day to facilitate such behaviour. While the observed range of OMI from 1.0 to 2.4% of body weight (BW) was well within accepted figures for range animals in general, values observed earlier in the year appeared to be below the range of 2.0 to 2.6% of BW reported for sheep by San Martín et al (1988) in the Peruvian Altiplano and 2.1% of BW observed by Yupton et al (1991) for sheep grazing the dry, northern coast of Peru. The lower relative values for sheep at SJL may reflect a lower nutrient content of grazed forage compared to these other situations.

The CP content of extrusa initially tended to decrease over time, especially when grazing occurred in the *tholar/pajonal* and *q'auchial/gramadal* (Table D2); this is typical for rangeland environments. Diet quality did not continue to decline throughout the dry season in the *pajonal*, however. An increase in extrusa CP occurred between August and September for animals feeding in the *pajonal*.The water table at SJL was often high, and this may offer an explanation. Some native forages of the *pajonal* have deep roots and initiate vegetative growth in September when air temperatures increase. The increase in nutritive value of extrusa during

Table D1. *Average monthly consumption of organic matter (OM in g/day) and consumption as a percentage of body weight (% BW) for rams grazing native rangeland at San José Llanga*[1]. Source: Coppock (1995) adapted from work done by Sandy et al (1995).

	Range Site					
	Tholar/Pajonal		*Q'auchial/Gramadal*		*Pajonal*	
Month	g OM	% BW	g OM	% BW	g OM	% BW
June	695.8	1.6	560.7	1.3	--	--
July	452.2	1.0	600.9	1.6	531.4	1.4
August	--	--	765.5	2.4	821.6	2.1
September	913.2	2.4	--	--	729.8	1.9
Average	678.1	1.7	642.3	1.7	694.3	1.8

[1]Intake determined utilizing eight rams fitted with fecal collection bags and two rams fitted with esophageal fistulae. See text for descriptions of range sites.

Table D2. *Content of crude protein (%CP) and percent digestibility of organic matter (% OM) in extrusa samples collected from esophageally-fistulated rams grazing native rangelands at San José Llanga*[1]. Source: Coppock (1995) adapted from work done by Sandy et al (1995).

	Range Site					
	Tholar/Pajonal		*Q'auchial/Gramadal*		*Pajonal*	
Month	% CP	% OMD	% CP	% OMD	% CP	% OMD
June	10.8	54.7	10.7	48.1	--	--
July	9.3	48.2	8.3	43.2	10.7	50.9
August	--	--	8.0	52.8	9.6	53.1
September	7.9	55.8	--	--	11.0	55.4
Average	9.3	52.9	9.0	48.0	10.4	53.1

[1]Average of analyses of extrusa collected from two fistulated rams. See text for descriptions of range sites.

Table D3. ***Effects of nutritional supplementation on consumption of organic matter [% of body weight (BW)] for rams grazing native rangeland during four months of a dry season at San José Llanga*[1,2].** Source: Coppock (1995) adapted from work done by Sandy et al (1995).

	Range Site			
Month/ Supplementation	*Tholar/ Pajonal*	*Q'auchial/ Gramadal*	*Pajonal*	Average
June				
With	1.9	2.4	--	2.1 a
Without	1.6	1.3	--	1.4 b
July				
With	1.3	2.1	1.7	1.7 a
Without	1.0	1.6	1.4	1.3 b
August				
With	--	2.3	1.3	1.8 a
Without	--	2.4	2.1	2.2 a
September				
With	2.3	--	3.0	2.6 a
Without	2.4	--	1.9	2.1 b
Average				
With	1.8 a	2.3 a	2.0 a	2.0 a
Without	1.7 a	1.7 b	1.8 b	1.7 a

[1]Consumption for each group (with and without supplementation) estimated from complete fecal collection with four rams and collection of a diet sample with one esophageally-fistulated ram. See text for description of supplementation.

[2]Entries accompanied by different letters (a,b) differed significantly ($P<0.05$) according to *t*-tests.

September may reflect an opportunity for rams to select new vegetative growth.

Results in Table D2 were interpreted to indicate that sheep could select a diet with relatively adequate levels of CP, despite the senescent state and apparent poor quality of range vegetation in general. Growing rams grazing *pajonal* pastures in September, for instance, would probably show a greater response to energy supplementation than to supplements high in CP.

Considered throughout the study period, the OMI of supplemented rams was similar to that of unsupplemented rams in the *tholar/pajonal* sites, but varied, positive effects of supplementation were apparent for animals feeding in *q'auchial/gramadal* and *pajonal* locations (Table D3; P<0.05). This difference in response to supplementation probably resulted because of variation in baseline dietary levels of CP which occurred when animals fed on different sites. For example, the greatest effect of supplementation appeared to occur for animals on the *q'auchial/gramadal*, where dietary CP for control rams was lowest (i.e., 8.4%). In contrast, dietary CP for rams averaged 11.2% on *tholar/pajonal* and 10.2% on *pajonal*, where little or no effects of supplementation on OMI were observed. These results were similar to those reported by Villalobos (1994) for steers grazing similar vegetative types in Mexico where the magnitude of response to supplementation increased as crude protein content of available forage decreased. Effects of supplementation on OMI also varied according to month, with three of four comparisons significantly different (Table D3; P<0.05). Interpretation of lack of effect of supplementation in August was paradoxical and suggested a need for more detailed research concerning interactions of supplements with an ever-changing diet composition on the range.

Weight changes of rams were directly related to level of OMI. Supplemented rams gained 20.5 g/head/day for a total of 2.4 kg/head over the four-month trial period. Unsupplemented rams lost 26.4 g/head/day for a total loss of 3.2 kg/head. The largest weight loss occurred during September. Considering the cost of the supplement (approximately USD 0.09 per kilogram) and the value per kilogram of live sheep in the weekly market (USD 0.93), supplementing rams with 300 g/head/day provided highly positive returns. Without considering costs of transporting supplement ingredients and additional labour and infrastructure involved in feeding the supplement, the estimated benefit:cost ratio was 1.48, indicating a return of USD 1.48 for every dollar spent. Actual returns may be much lower under normal management situations in SJL. The results, however, suggested positive returns for investment that should be investigated further as the market situation becomes more integrated.

This material highlights general findings. For a full detailed report on this work readers should consult Sandy et al (1995).

Literature cited

AOAC (Association of Official Analytical Chemists). 1980 *Official Methods of Analysis*. 13th edition. AOAC, Washington DC, USA. 1016 pp.

Cáceres M., Ortega M. y Yazman J. 1995. *Comportamiento y Sobreposición Alimenticia de Tres Especies Domésticas (Ovinos, Bovinos y Equinos) en el Altiplano Central de Bolivia*. IBTA/SR-CRSP (Instituto Boliviano de Tecnología Agropecuria/Small Ruminant Collaborative Research Support Program). IBTA 155/Boletín Técnico 23/SR-CRSP 21. La Paz, Bolivia. 29 pp.

Coppock D.L. 1995. Range ecology and range animal nutrition. In: Johnson S. (ed), *SR-CRSP Annual Report 1995*. Management Entity, SR-CRSP (Small Ruminant Collaborative Research Support Program), University of California, Davis, California, USA. pp. 91-118.

Leaver J.D. (ed). 1982. *Herbage Intake Handbook*. The British Grassland Society. Hurley, Maidenhead, Berkshire, UK. 143 pp.

Lopéz Z., Ortega M. and Cáceres M. 1995. *Contenido Nutricional de la Dieta al Pastoreo en Tres Especies de Ganado (Ovinos, Bovinos y Equinos) del Altiplano Central de Bolivia*. IBTA/SR-CRSP (Instituto Boliviano de Tecnología Agropecuria/Small Ruminant Collaborative Research Support Program). IBTA 159/Boletín Técnico 27/SR-CRSP 25. La Paz, Bolivia. 32 pp.

San Martín F., Bryant F., Arbaza T., Farfán R. y Rosales A. 1988. Comparación de la selectividad y nutrición entre camélidos sudamericanos y ovinos. I. Composición botánica de las dietas de llamas, alpacas y ovinos. En: *Investigaciones Sobre Pastos y Forrajes de Texas Tech en el Perú.* INIA/SR-CRSP (Instituto Nacional de Investigación Agroindustrial/Small Ruminant Collaborative Research Support Program) 4:47-64. Lima, Perú.

Sandy X., Tejada E. y Yazman J. 1995. *Consumo Estimado en Ovinos Pastoreando Praderas Nativas de Altiplano Central Boliviano Durante la Epoca Seca*. IBTA/SR-CRSP (Instituto Boliviano de Tecnología Agropecuria/Small Ruminant Collaborative Research Support Program). IBTA 157/Boletín Técnico 25/SR-CRSP 23. La Paz, Bolivia. 31 pp.

Yupton J., Aguilar C. y Villena F. 1991. Selectividad y consumo de caprinos y ovinos en una pastura natural de la costa norte del Peru durante la época seca. En: *Investigaciones Sobre Pastos y Forrajes de Texas Tech en el Perú*. INIA/SR-CRSP (Instituto Nacional de Investigación Agroindustrial/Small Ruminant Collaborative Research Support Program) 6:41-52. Lima, Perú.

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