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

2001

Chapter 05: The Grazing Livestock of San José Llanga: Multiple-species Resource Use and the Management and Productivity of Sheep

David Layne Coppock
Utah State University, layne.coppock@usu.edu

Isaac M. Ortega
Small Ruminant Collaborative Research Support Program

Jim Yazman

João S. de Quieroz
Small Ruminant Collaborative Research Support Program

Humberto Alzérreca-Angelo
Utah State University

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

by D. Layne Coppock, Isaac M. Ortega, Jim Yazman, João S. de Queiroz and Humberto Alzérreca

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 cáracteristicas 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).

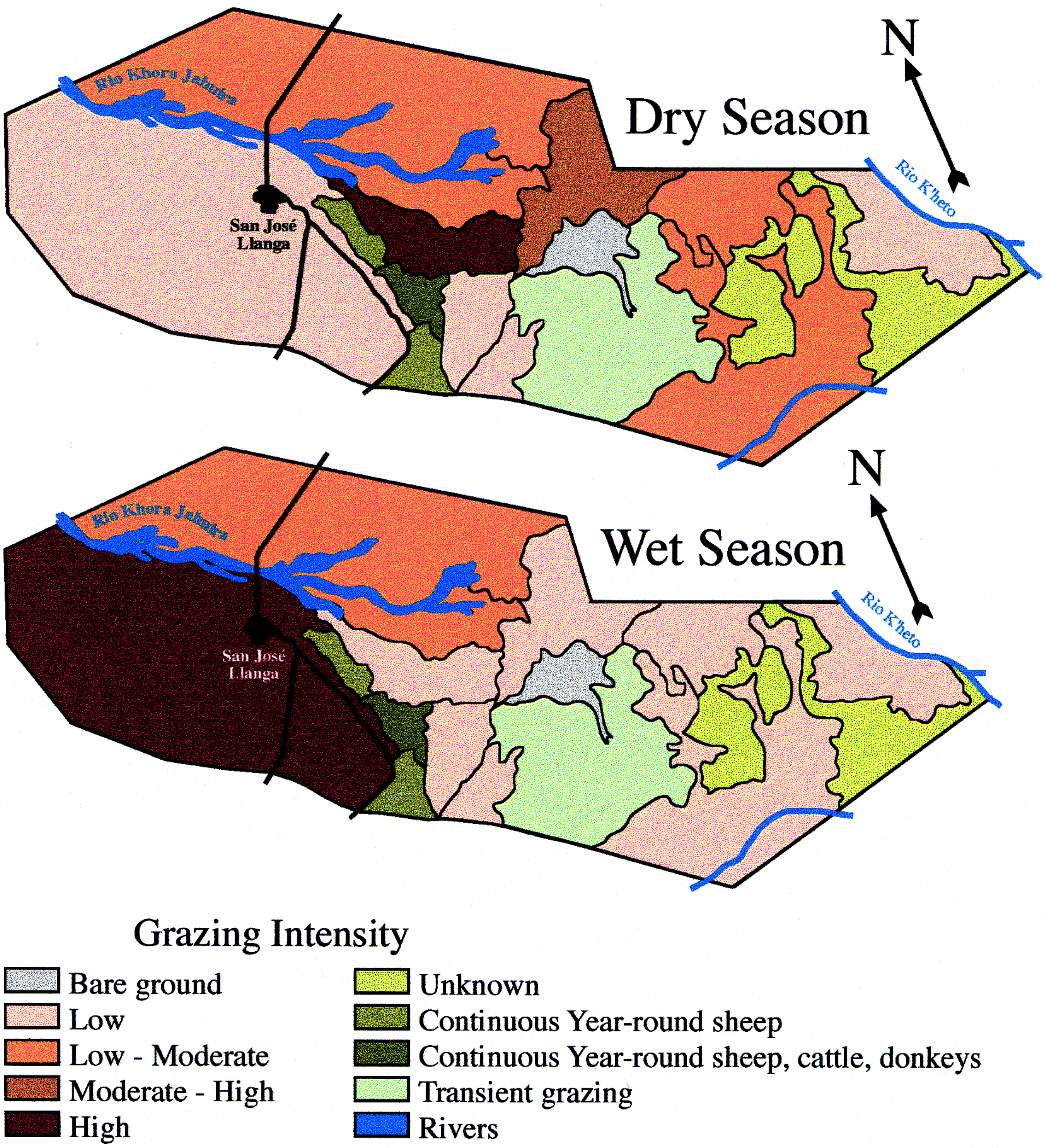

Figure 5.1(a,b). Maps of livestock grazing intensity throughout the Cantón of San José Llanga during the: (a) Dry season and (b) wet season of 1992-3. Source: Maps produced by Dr. I. M. Ortega from information collected by Massy and Cáceres (IBTA/SR-CRSP, unpublished data)

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

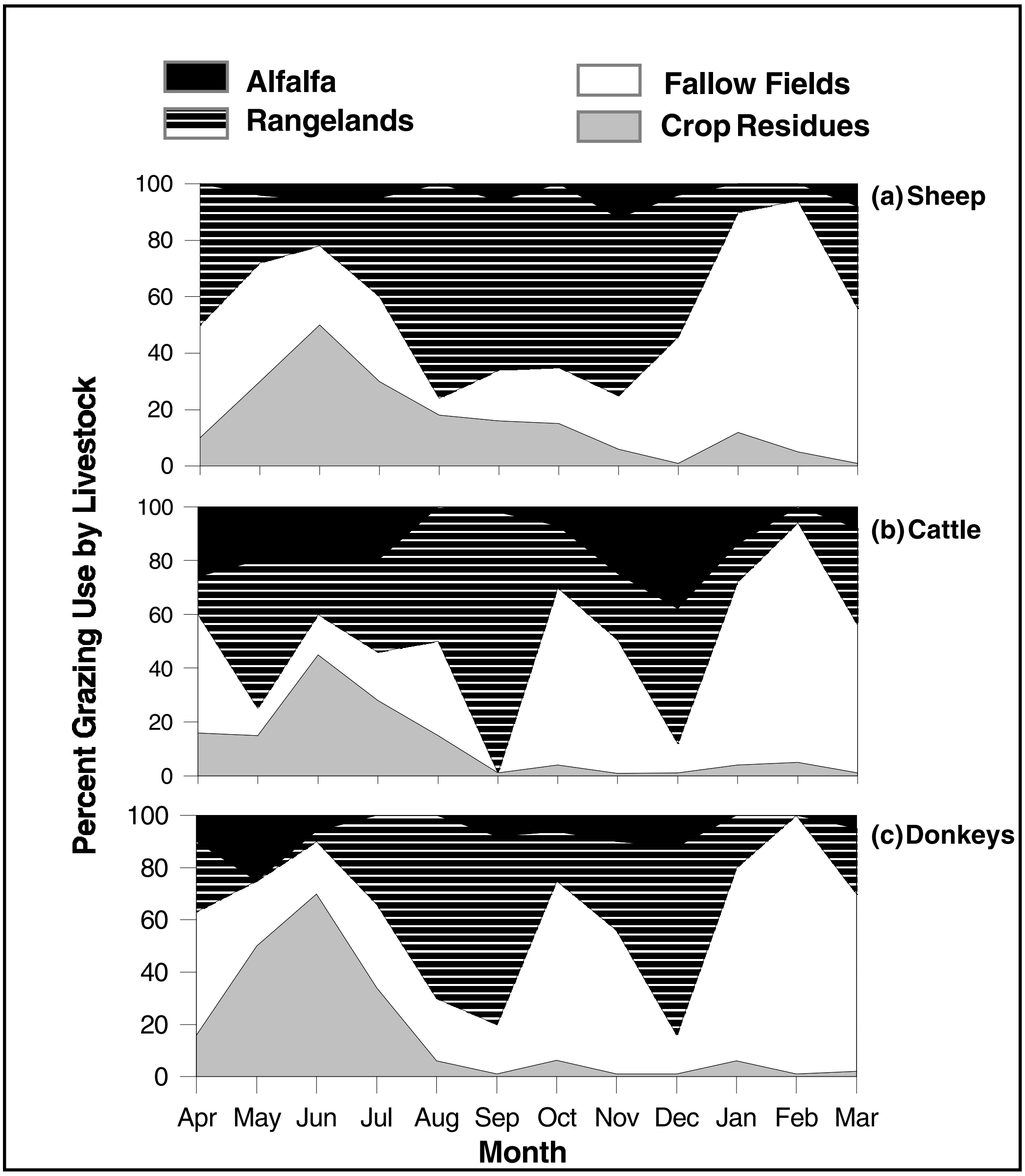

Figure 5.2 (a-c). *Percent of feeding time spent by livestock on four types of grazing sites throughout the Cantón of San José Llanga during 1992-3: (a) Sheep; (b) cattle; and (c) donkeys. Each monthly data point is based on 12 days of observation for each livestock species. The rainy period is approximately 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,

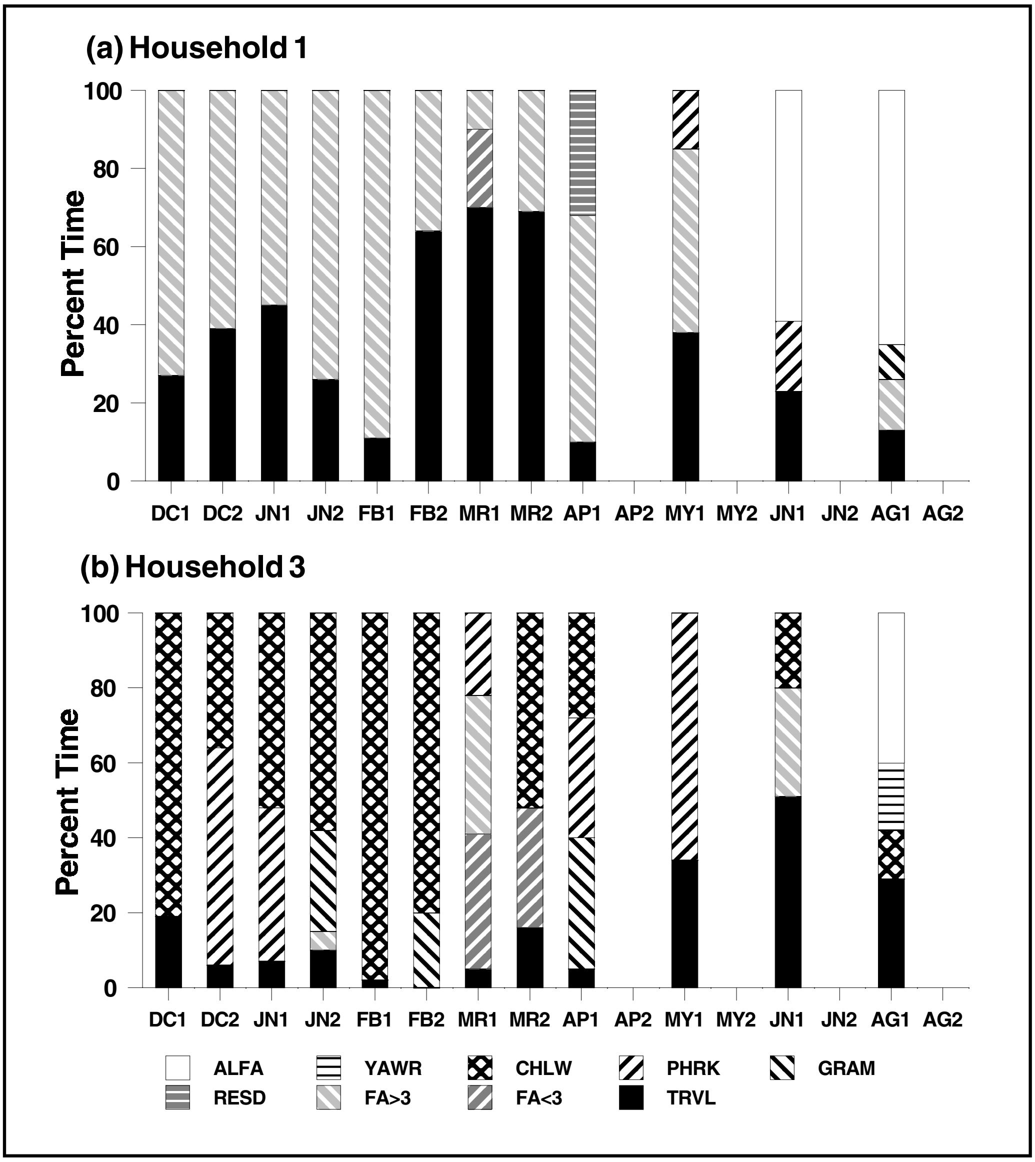

Figure 5.3 (a,b). *Grazing strategies (percent of time) for sheep flocks held by: (a) a land-limited family, and (b) a family well-endowed with land from December, 1993, through August, 1994. Activities are coded as TRVL (traveling) or feeding on: FA<3 (fallow less than 3 y old); FA>3 (fallow more than 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*).

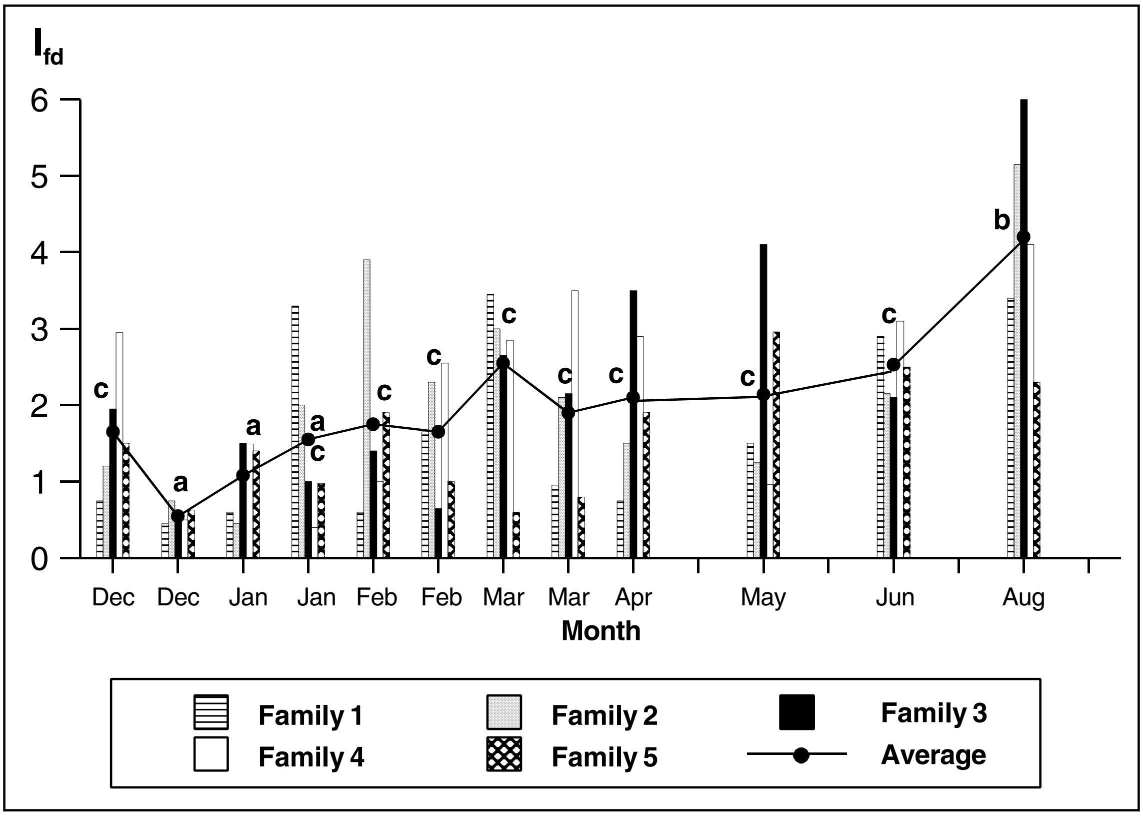

Figure 5.4. *Effects of household and month on a daily grazing index (I_{fd}) calculated for herded sheep flocks from December, 1993, through August, 1994, at San José Llanga. The grazing index is a cumulative measure of the quantity and quality of forage patches encountered by a flock of a given household 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

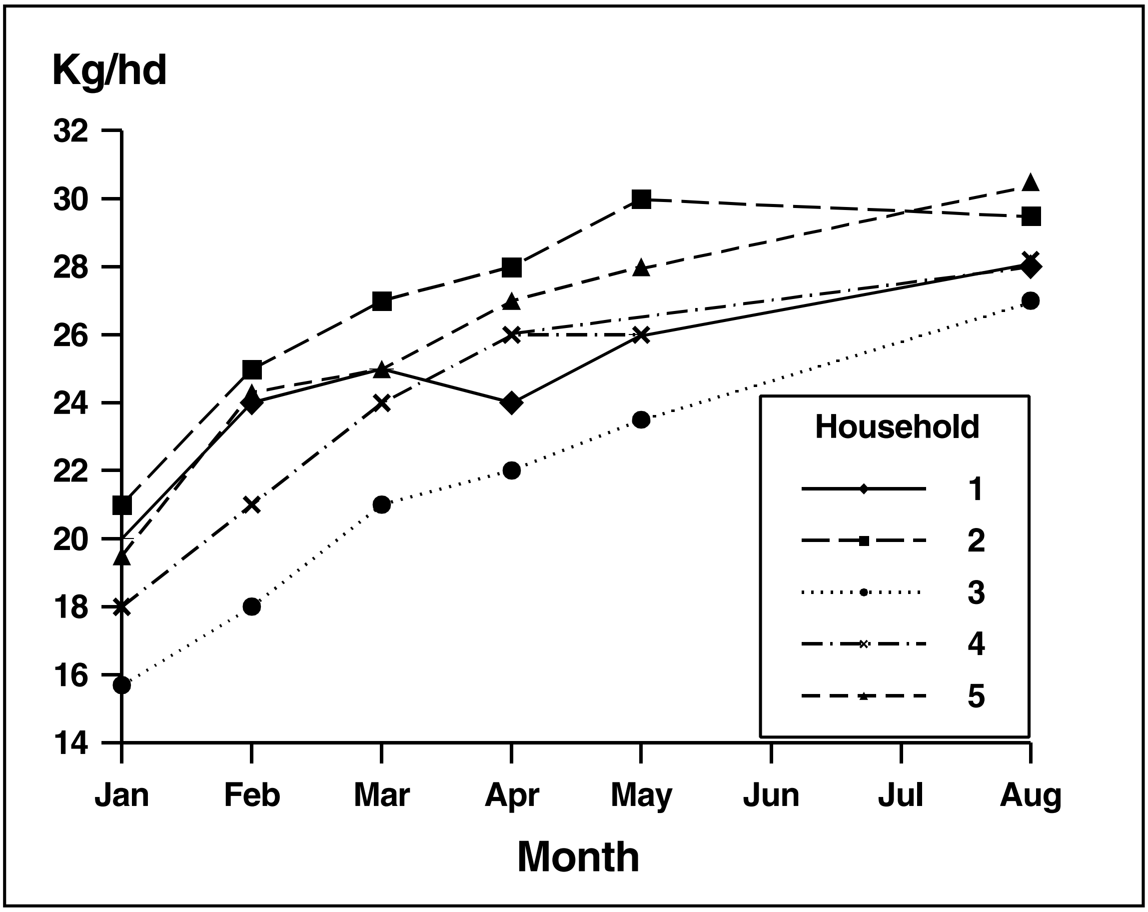

Figure 5.5. *Monthly average liveweights of lambs reared by five households from January to August, 1994, at San José Llanga. Each data point is the mean of five animals.* Source: Dr. J. de Queiroz et al (IBTA/SR-CRSP, unpublished data)

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

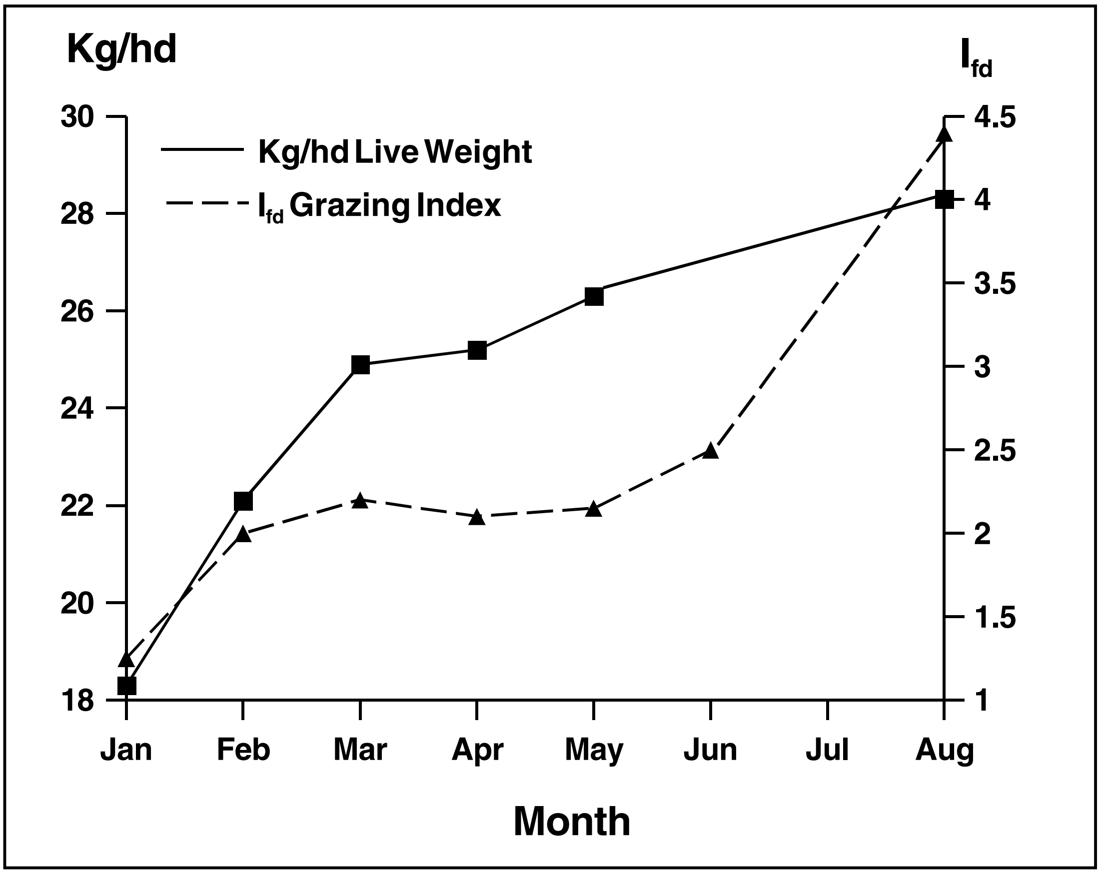

Figure 5.6. *Monthly time series of mean liveweights of lambs and the daily grazing index (I_{fd}) for sheep flocks from December, 1993, through August, 1994. Each data point for lamb weights is the mean of 25 animals. The grazing index is a cumulative measure of the quantity and quality of forage patches 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

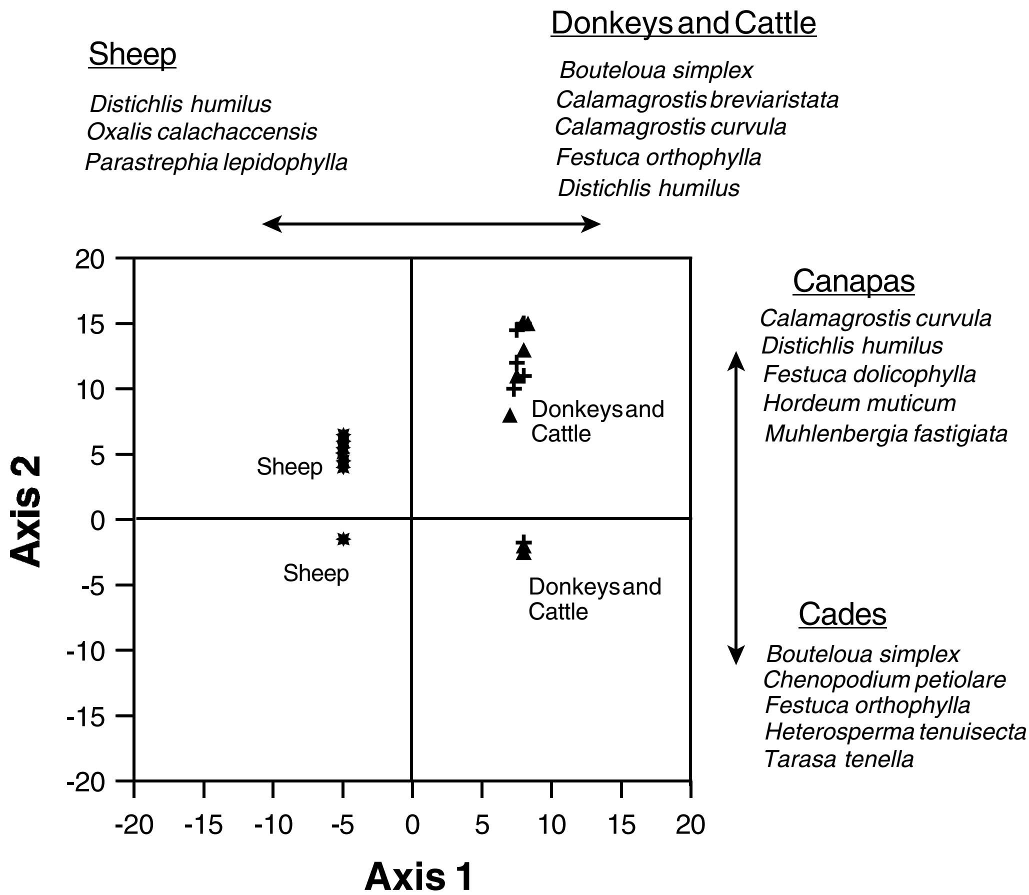

Figure 5.7. *Canonical discriminant analysis for grazed diets of sheep, cattle and donkeys in the Cantón of San José Llanga throughout the year of 1992-3. The analysis was based on 264 000 observed bites of forages.* Source: Cáceres (1994, 51)

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).

				Similarity Index		
Plant community	Season	Intake	Feeding time	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

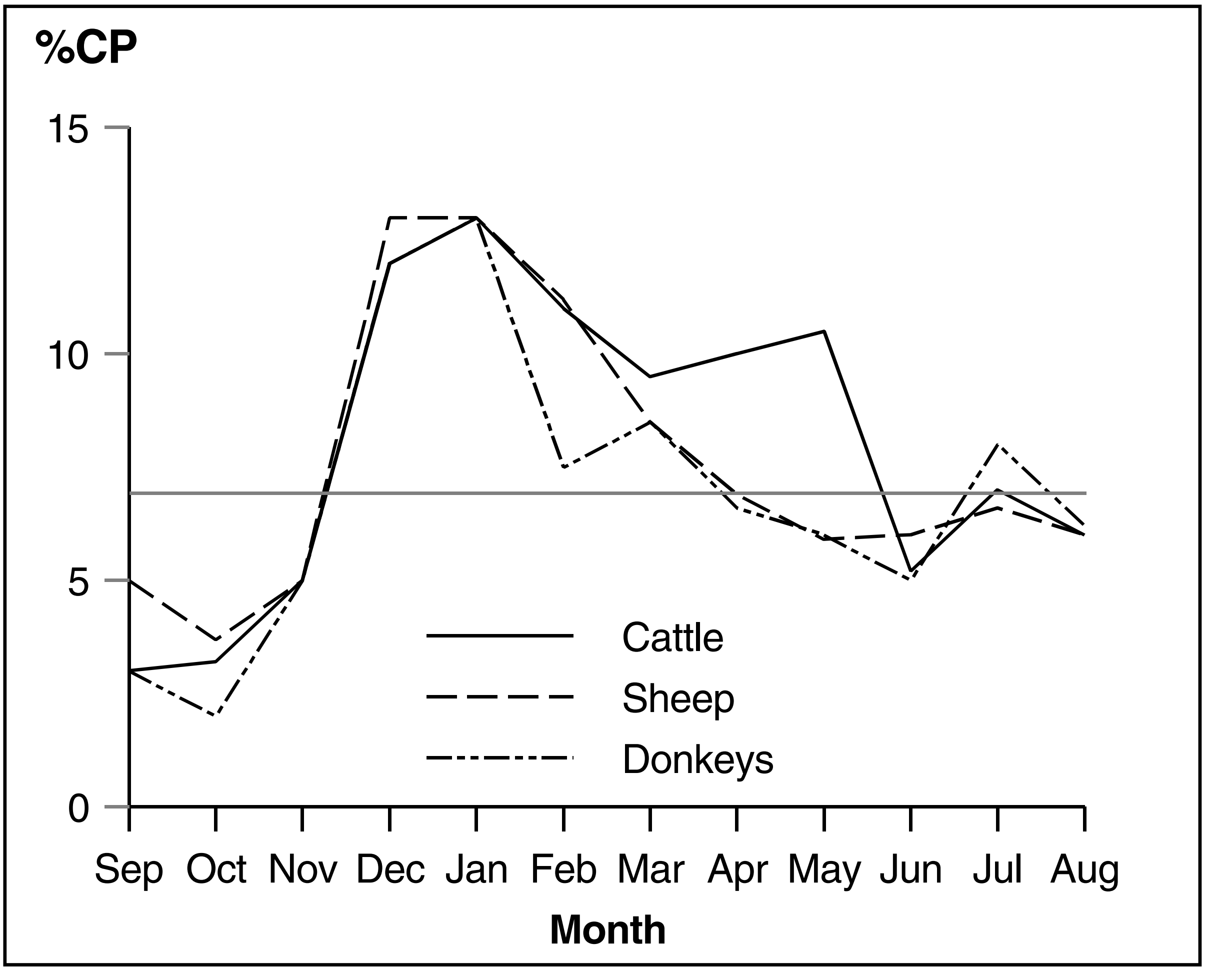

Figure 5.8. *Dietary crude protein (CP) dynamics for sheep, cattle and donkeys grazing five* cades *(agricultural) sites throughout 1992-3. Values are reported on a DM basis.* Source: Lopéz (1994, 38)

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

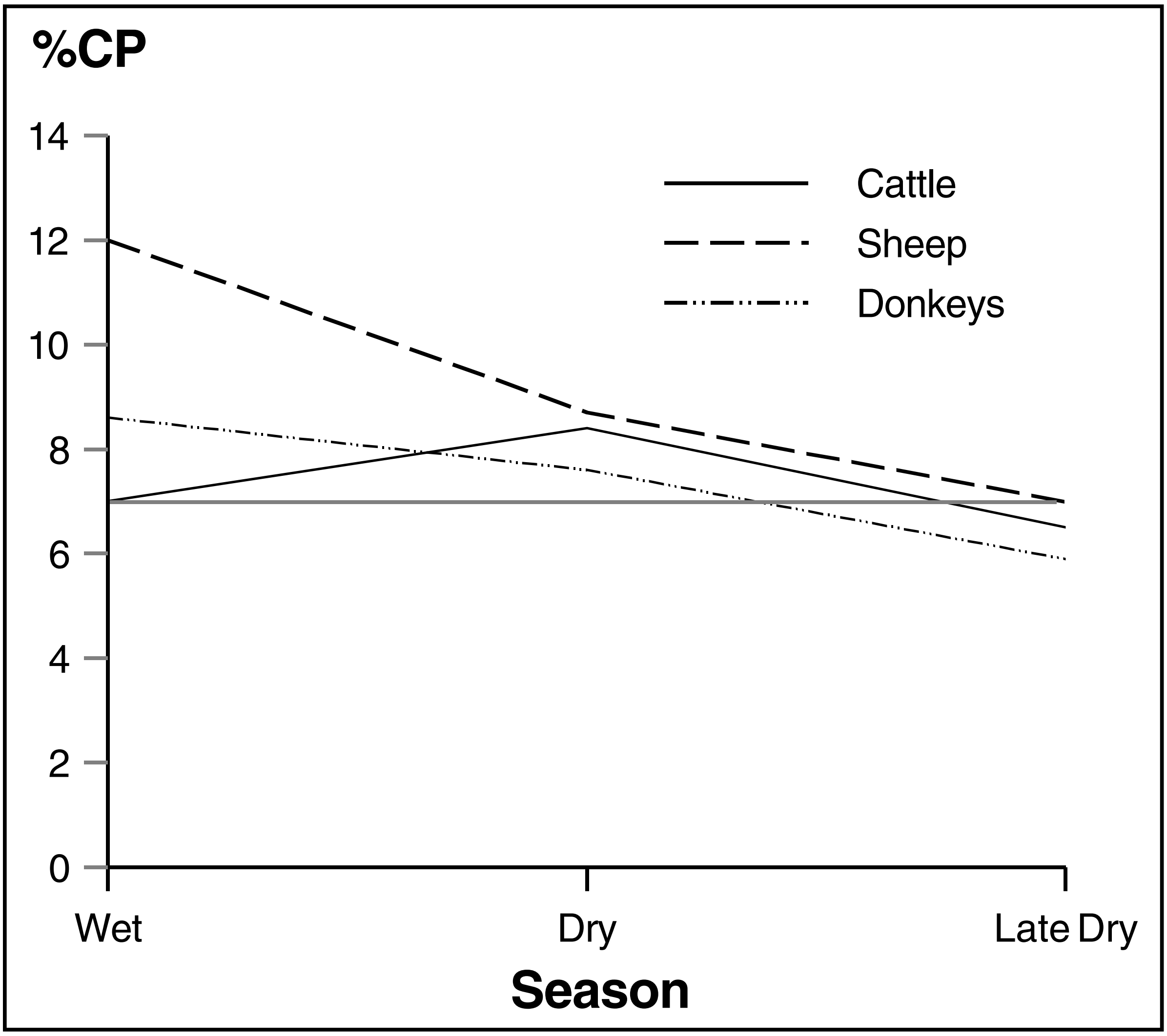

Figure 5.9. *Dietary crude protein (CP) dynamics for sheep, cattle and donkeys grazing four* canapas *(range) sites throughout 1992-3. Values are reported on a DM basis.* Source: Adapted from tabular data in Flores (1995, 114)

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.

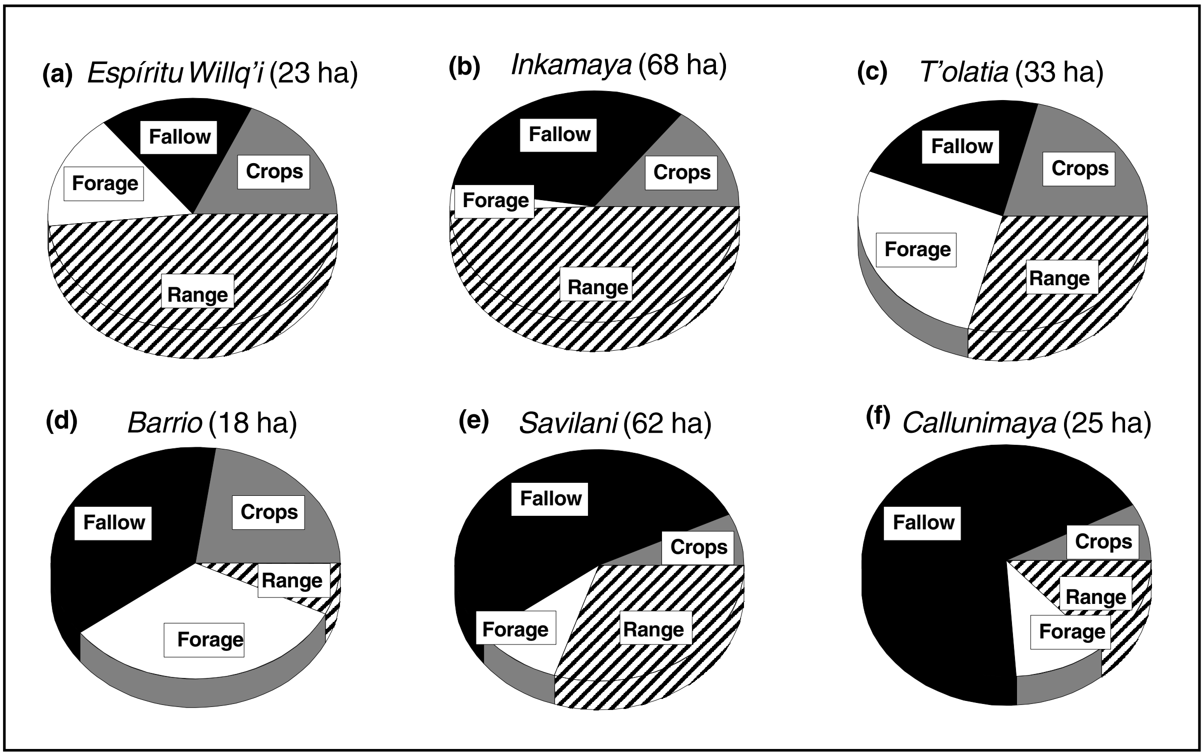

Figure 5.10 (a-f). *Variation in land resources for six settlements (or neighbourhoods) at San José Llanga. Sites markedly differed in the proportion and absolute quantities of high-value land for irrigated forage and lower-value range. This variation in turn influences breeds of sheep and cattle held 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.