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An Ecological History of Tintic Valley, Juab County, Utah

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AN ECOLOGICAL HISTORY OF TINTIC VALLEY,

(JUAB COUNTY) UTAH

by

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ABSTRACT

An Ecological History of Tintic Valley,

Juab County, Utah

by

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Utah State University, 1996

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Department: Rangeland Resources

This work was a case study of historical ecological change in Tintic Valley, Juab County, Utah, an area historically impacted by mining and ranching activities common to much of the American West. The temporal framework for the study was approximately 120 years, the period of direct Euroamerican influence. In recognition of the ecological implications of cultural change, however, the impacts of prehistoric and protohistoric human activity on study area landscape patterns and processes were also explicitly addressed.

The study included a narrative description of historic land uses and ecological change in Tintic Valley, and examined the changes in landscape patterns and processes so revealed within the context of the state and transition model of rangeland dynamics. The case of Tintic Valley thus served as a test of the heuristic utility of the theory of self-organization in ecological systems, within which the state and transition model is embedded. This theoretical framework in turn was used to gain insight into the present state of the Tintic landscape, how that state has changed over time, and the nature of those forces leading to transitions between system states in the historic period.

The study employed archival research, personal interviews, repeat photography, field surveys, aerial photographs, and a geographic information system (GIS) to identify, describe, and quantify historic-era change in Tintic Valley landscape level patterns and processes. The analysis revealed dramatic change in both the landscape vegetation mosaic and the channel network of the study area over time. Evidence was found for direct anthropogenic influence in precipitating those changes, primarily through tree harvesting associated with mining and ranching activities and through the effects of historic roads and railroads on the Tintic Valley gully network. Results supported the working hypothesis of a change in system state in the Tintic Valley landscape in the historic period.

Taken together, historical narrative and theoretical context permitted a degree of prediction with respect to potential future conditions for the study area under different management scenarios. Future research directions and implications of the research results for ecosystem management are also discussed.

255 pages

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CHAPTER I

INTRODUCTION

This work is a study of historical change in landscape patterns and processes in Tintic Valley, Juab County, Utah. The history of Tintic Valley, once one of the most productive mining districts of the United States, has been rich and at times colorful (Notariani 1992). Major ore bodies in the East Tintic Mountains, containing gold, silver, lead, zinc, and copper, have been worked continuously since 1870 (Pampeyan 1989). The notoriously inefficient industrial processes associated with the early mining, milling, and smelting of Tintic's ores, however (Raymond 1873b), along with activities associated with early ranching, agriculture, and urbanization, led to significant ecological change in Tintic Valley following Euroamerican settlement.

The extensive and highly variable nature of human use of the Tintic landscape suggests the need to understand the relationship of that use to observed changes in landscape pattern and process. This work is an attempt to describe and, where possible, quantify some of those uses and associated ecological changes. While the temporal framework for the study is approximately the past 120 years, the influence of human activity in the prehistoric and protohistoric eras upon study period landscape patterns and processes is also explicitly addressed (Chapter III).

This study employs archival research, personal interviews, repeat photography, field surveys, aerial photographs, and a geographic information system (GIS) to identify, describe, and quantify historic-era change in Tintic Valley landscape patterns and processes. Chapter IV chronicles major historic impacts of Tintic's early mining industry, livestock, agriculture, and fire. Chapter V focuses on changes in the Tintic Valley vegetation mosaic over the study interval, as revealed by both stand transitions and overall landscape change. Chapter VI examines historic era geomorphological change as reflected in the dynamics of the Tintic Valley gully network over time. Together, results of this largely descriptive analysis suggest significant change has occurred in the study area over the study interval.

Although Tansley (1935) early recognized the critical role of *Homo sapiens* in global ecological processes, ecologists have generally oversimplified the history of human impact on ecosystems (Foster et al. 1992). The inevitability of such simplification reflects two problems intrinsic to historical ecological research--the fragmented historical record and our limited understanding of the systems we study. Thus, the great value of a descriptive ecological history lies in its potential to reveal aspects of the system of interest previously unknown to the investigator. Rather than attempting to explain specific phenomena of interest, as is the case in an experimental study, descriptive research seeks simply to answer the question "what is" as a prelude to addressing the issue of "how this came to be so."

Once a degree of familiarity with the history of the system of interest has been achieved, however, it seems useful to move beyond description to enquire into the implications of that history from the perspective of known or theorized ecological processes. To the extent that known conditions appear to fit theoretical models of ecosystem dynamics, the case study may serve as a test of those models. If hypothesized ecosystem dynamics appear confirmed by actual patterns of change as revealed by the historical narrative, prediction with respect to future behavior of the system becomes plausible (Havstad and Schlesinger 1996).

Therefore, although this work is a case study of ecological change within a single eastern Great Basin landscape, an attempt has been made to move beyond historical narrative to place the specific details of change in Tintic Valley landscape patterns and processes within a broader context of ecological theory. The case of Tintic Valley has thus served as a test of the heuristic utility of that theoretical framework. This in turn has lent insight into the present state (von Bertallanfy 1950, Chorley 1962, Westoby et al. 1987) of the Tintic landscape and how that state has changed over time (Chapter II). Together, historical narrative and theoretical context have permitted a modest degree of prediction with respect to anticipated future conditions for the study area (Havstad and Schlesinger 1996).

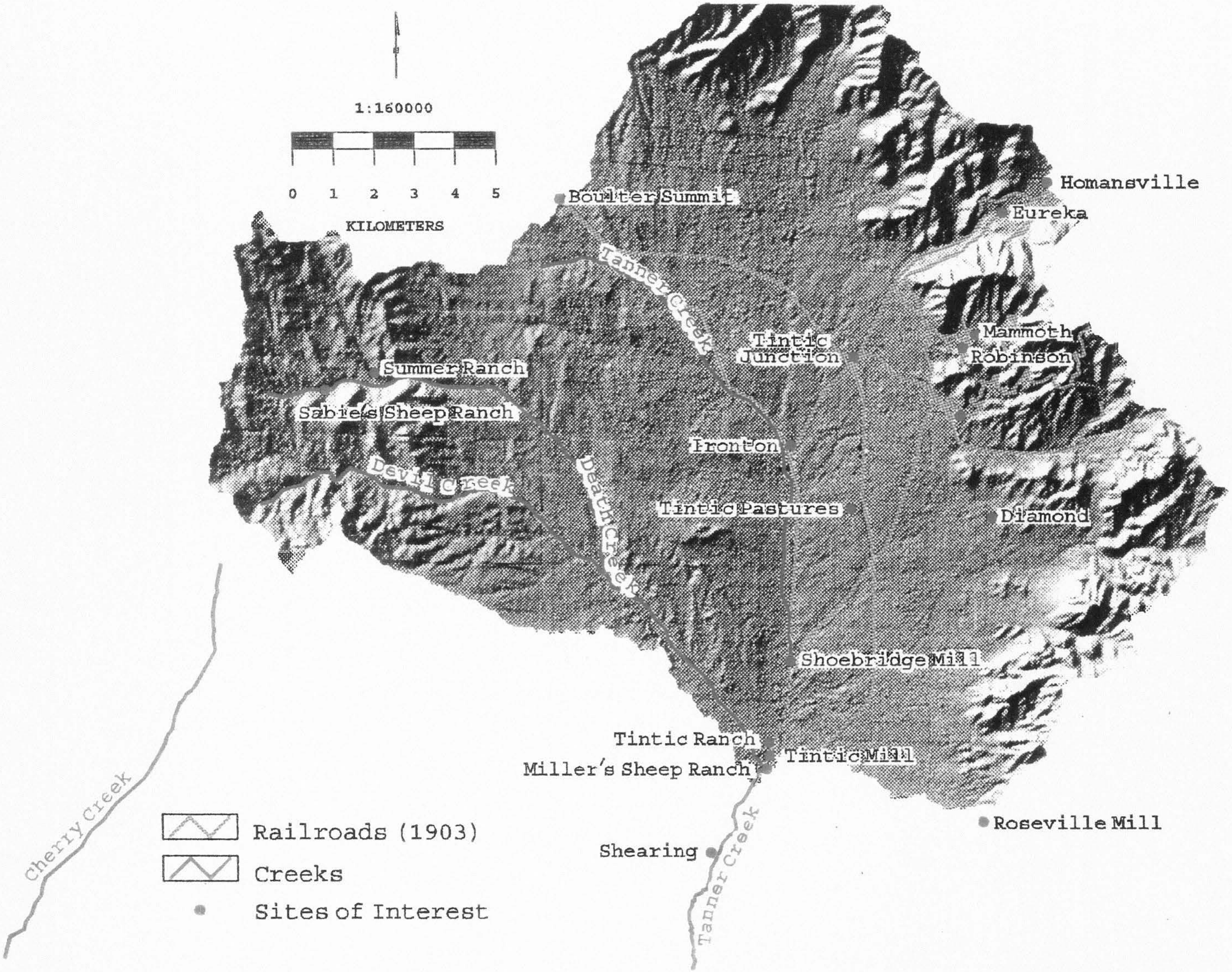
Worster (1995) has argued that the role of a historian is clarification. It is hoped that this work will lend clarity to questions surrounding the nature of change in the Tintic Valley landscape in the historic period, and thus provide insight into the historical ecological dynamics of a unique Intermountain area. By placing the current dynamics of Tintic Valley within an historical and theoretical context, discussion of desired future conditions for the Valley may also be facilitated. Further, by examining specific changes in Tintic Valley landscape patterns and processes within the context of ecological theory, that theory itself may be rendered more accessible to system managers. Finally, insights from the historical dynamics of Tintic may help lend clarity to the often vituperative debate over land use in the Intermountain West, and perhaps suggest fruitful directions for the future of natural resource management and ecological restoration in the region.

Geology

The study area is defined by the upper Tintic Valley drainage basin, an area of approximately 29,000 hectares located in north central Juab County (figure 1). Tintic Valley lies in west-central Utah, southwest of Utah Lake at the eastern edge of the Great Basin (figure I.1). The Valley is defined by the West Tintic Mountains to the west, rising to 2457 m at Maple Peak, and the East Tintic Mountains to the east and north, reaching an elevation of 2505 m at Tintic Mountain. Both ranges are volcanic in origin, with the Maple Peak and Tintic calderas strongly influencing the structure of the West and East Tintic ranges, respectively (Stoeser 1992).

The two calderas are associated with independent volcanic rock sequences, separated by, but apparently extending beneath, the approximately 14 km-wide Tintic Valley. The Valley floor lies at approximately 1725 m and appears to have formed by east-west extension and the accumulation of 1800 to 2100 m of fill, much of it alluvial in origin. A major range-front fault lies along the east margin of the Valley and the Valley itself appears to be underlain by a major thrust fault that forms a detachment underlying the Valley and the West Tintic range, and continues at least several kilometers to the west (Stoeser 1992).

Fig. 1. Location map. Study area with locations mentioned in the text.



1:160000
0 1 2 3 4 5
KILOMETERS
Boulter Summit
Homansville
Eureka
Tanner Creek
Tintic Junction
Mammoth
Robinson
Summer Ranch
Sabie's Sheep Ranch
Devil Creek
Death Creek
Fronton
Tintic Pastures
Diamond
Shoebridge Mill
Tintic Ranch
Tintic Mill
Miller's Sheep Ranch
Roseville Mill
Shearing
Tanner Creek
Cherry Creek
Railroads (1903)
Creeks
Sites of Interest

Soils

The approximately 29,000 ha study area includes three soil Orders, 11 Great Groups, 34 Seris, and 64 soil Phases. Xerollic Mollisols predominate (Trickler and Hall 1984).

Climate

An incomplete record for the Valley floor, measured at Utah State University's Tintic Pastures between 1940 and 1983, yielded a 20-year average annual precipitation of 360 mm (see appendix 2). The 90-year median precipitation measured at Elberta, Utah, approximately 9 km east of the Valley, is 270 mm. Precipitation occurs primarily as winter snow, but high intensity rainfall events associated with convectional summer storms are common. Annual temperatures, as measured within the study area at Eureka, Utah, range from a January low of -29°C to a July high of 37°C, with a normal range of -8° to 30°C.

Vegetation

The study area supports a variety of plant communities. Dominant species range from aspen (*Populus tremuloides*) and Douglas-fir (*Pseudotsuga menziesii*) at high elevation sites in the East Tintic Range to lower elevation saltgrass (*Distichlis spicata*) and sedge (*Carex spp.*)-dominated communities (Welsh et al. 1993). The vegetation mosaic of the study area is characterized by sagebrush steppe (*Artemisia* *spp.*) on both lower and higher elevation sites, and a wide, dense, mid-elevation pinyon-juniper (*Juniperus osteosperma-Pinus monophylla, P edulis* and their intergrades) woodland belt, interspersed with grass and shrub-dominated openings. Small stands of maple (*Acer spp.*) and gambel oak (*Quercus gambelli*) are common in draws on north-facing slopes, and curlleaf mountain mahogany (*Cercocarpus ledifolius*) is an important component of higher elevation woodland sites. While sagebrushes (including *A. tridentata* and *A. nova*) and rabbitbrush (*Chrysothamnus spp.*) are the dominant shrub species of the study area, greasewood (*Sarcobatus vermiculatus*), Fourwing saltbush (*Atriplex canescens*), and winterfat (*Ceratoides lanata*) (Welsh et al. 1993) dominate some lower elevation sites.

Herbaceous species present include multiple members of the *Sitanion, Agropyron, Poa, Festuca, Oryzopsis, Eriogonum, Gutierrezia, Senecio, Descurainia, Astragalus, Lupinus, Erodium, Epilobium*, and *Penstemon* genera. Seeded Eurasian grasses include crested wheatgrass (*Agropyron desertorum)* and intermediate wheatgrass (*A. intermedium*). Common noxious exotics include *Halogeton glomeratus, Salsola kali, Centaurea spp.*, and *Bromus tectorum* (Welsh et al. 1993).

Wildlife

Tintic Valley supports a wide variety of bird species, including the scrub jay (*Aphelocoma coerulescens*), pinyon jay (*Gymnorhinus cyanocephalus*), turkey vulture (*Cathartes aura*), redtail hawk (*Buteo jamaicensis*), marsh hawk (*Circus cyaneus*), golden eagle (*Aquila chrysaetos*), American kestrel (*Falco columbarius*), and an array of songbirds (Robbins et al. 1966, Grayson 1993). Sage grouse (Centrocercus urophasianus), once common in the study area (*Eureka Reporter*, August 21, 1914; August 15, 1919; September 1, 1922; September 5, 1924; September 9, 1927; July 25, 1929; August 18, 1932), are now rare (Steele McIntyre, personal communication).

Mammalian predators include coyote (*Canis latrans*), gray fox (*Urocyon cinereargenteus*), striped skunk (*Mephitus*), mountain lion (*Felis concolor*), and bobcat (*Lynx rufus*). White-tailed deer (*Odocoileus virginianus*) are common, as are packrats (*Neotoma cinerea*), cottontails (*Sylvilagus spp.*), jack rabbits (*Lepus spp.*), and numerous species of mice (Grayson 1993, Gottfried et al. 1995).

Human use of the Tintic landscape has been varied and, in the historic era, intensive. An examination of the nature and ecological consequences of this use forms the basis of the following chapters.

CHAPTER II

BIOCYBERNETIC PERSPECTIVES OF THE GREAT BASIN TOTAL HUMAN ECOSYSTEM

Worster (1995) has suggested that ecology emerged from a biology newly "historicized" by Darwin. While explicitly recognizing change, this ecology remained rooted in the view that change was both orderly and directional, and thus essentially predictable. This ordered view of nature has been upset in recent decades by the emergence of a disturbance-based ecology in which heterogeneity of system patterns and processes in both space and time, the attendant potential for multiple system states, and the often quintessential role of human beings in ecosystem processes are all explicitly recognized (Vogl 1980, Pickett and White 1985, Pickett and Ostfeld 1995).

The Great Basin Total Human Ecosystem

Naveh (1987a) and Naveh and Lieberman (1984) have defined the Total Human Ecosystem (THE) as a totality of physical, ecological, geographical, and cultural phenomena. As such, the THE constitutes the highest organizational level of ecological systems, integrating the biosphere, the geosphere, and the technosphere in landscape units. In this context, human culture can be seen as an emergent, regulative, ecosystem property (Naveh 1987a). Description of the evolution of the human-modified landscape must thus include cultural and conceptual space, the

Noosphere of de Chardin (1966) (Vernadsky 1945, Naveh 1987a).

Biocybernetics

Biocybernetics is "...the theory of regulation in biological and ecological systems, enabling their self organization by positive-deviation amplifying feedback loops" (homeorhesis) "and their self stabilization by negative-deviation reducing feedback loops" (homeostasis, quasi-equilibrium) (Naveh 1987a, p. 24). As such, biocybernetics is relevant to the relationship between biotic and abiotic landscape elements and landscape processes as affected by human land-use patterns. The theory of self-organization of complex systems (von Bertalanffy 1950, Naveh 1987a, Cincotta et al. 1991, Kauffman 1995, Perry 1995) is used here to explain the interaction of human culture and environment in the creation of complex cultural/ecological systems driven by the maximization of human management objectives (Cincotta et al. 1991). The concept is applied to hypothesized landscape dynamics within the aboriginal Great Basin woodland/steppe landscape system of Tintic Valley.

Changing Ecological Paradigms

The view of Intermountain West landscapes as pristine, stable, and in equilibrium with climate prior to the arrival of Euroamericans has become increasingly untenable (Denevan 1992, Tausch et al. 1993, Gottfried et al. 1995). Recently developed models of vegetation dynamics, including the state and transition model and the concept of thresholds (Westoby et al. 1987, Friedel 1991, George et al. 1992), have offered an alternative, dynamic view of ecological systems, and the emergence of what Pickett et al. (1992) have referred to as a new, "non-equilibrial" paradigm in ecology. This paradigm recognizes the "flux of nature," rather than the balance of nature (Pickett and Ostfeld 1995), acknowledges the role of history in ecological systems (Cincotta et al. 1991, Tausch et al. 1993), and views ecological systems as thermodynamically open (von Bertalanffy 1950).

Importantly, the new paradigm recognizes *Homo sapiens* as not only a component of ecosystems (Pickett et al. 1992, Pickett and Ostfeld 1995), but as "an exceptionally powerful biotic factor..." (Tansley 1935, p. 303) within those systems. This perspective has fostered the development of new disciplines in ecology, most notably landscape ecology, as a holistic science of man and nature (Naveh 1987b).

Application of this theoretical framework to the interpretation of historic landscape dynamics in the Intermountain West suggests that cumulative impacts of perturbations associated with Euroamerican settlement have resulted in state transitions throughout the region. Such change is epitomized by the conversion of sagebrush steppe to *Bromus tectorum* monoculture (Mack 1986, Billings 1990) and the invasion of steppe communities by woodland vegetation (Burkhardt and Tisdale 1976, Savage 1991, Archer 1994, Miller et al. 1994, Gottfried et al. 1995). Recognition that ecological systems change over time and that specific system states require specifically scaled disturbance for their structural organization and temporal persistence (Mutch 1970, Vogl 1980, Naveh 1987a, Turner et al. 1993) has helped explain why simple removal of a disturbance such as grazing or fire does not necessarily result in restoration of systems to their previous state.

Perturbation Dependent Systems

Landscapes exhibit two major groups of functions, with opposite regulating feedback mechanisms (Naveh 1987b):

1) biotic production and self-organization functions linked by positive feedbacks between photosynthetic/growth processes and energy/material/information fluxes and;

2) protection and self-stabilization functions linked by negative feedbacks between moderating processes of these same biotic processes and fluxes.

Perturbations can serve to shift system dynamics from homeostasis (steady state), maintained through balance of negative and positive feedback processes, to homeorhesis (steady flow) (Waddington 1975) via an increase in positive feedback processes (figure 2). When the spatial and temporal scale of perturbation is inappropriate relative to that of the perturbed system, positive feedbacks can lead to the crossing of critical thresholds to a new system state. The nearly universal degradation of global ecosystems over the past century and the pressing reality of global desertification (Schlesinger et al. 1990) have led to the general recognition of the role of perturbations that are improperly scaled relative to the system of interest in precipitating system transitions to less desirable states (Westoby et al. 1987, Billings 1990, Friedel 1991, Graetz 1991, Laycock 1991, George et al. 1992) (figure 2). Such perturbations include excessive grazing, excessively short fire intervals, and

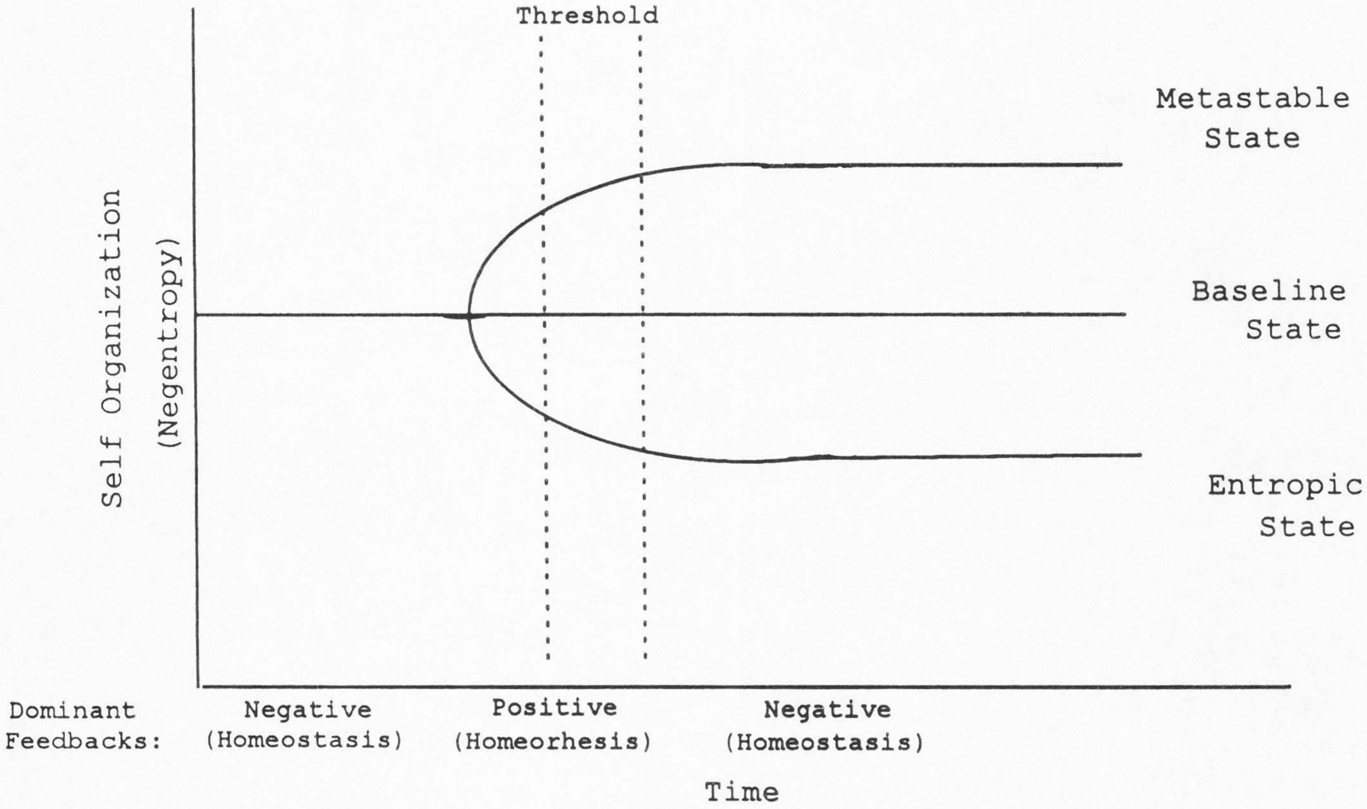


Fig. 2. Thresholds in self-organizing systems: relationships among system processes and system states.

repeated drought.

Less commonly addressed is the potential for perturbations that are appropriately scaled in space and time to lead to trajectories of desirable positive feedbacks (DeAngelis and Post 1991) capable of driving the system across a threshold of change to a more highly organized, metastable state (Naveh 1987a). Landscapes in which such a higher degree of organization has been initiated through a process of positive feedbacks precipitated by periodic natural and/or cultural disturbance are recognized as metastable perturbation dependent systems (Vogl 1980, Naveh 1987a) (figure 2). The flux of energy, matter and information is increased in such systems due to the evolution of increased self-organized complexity and the emergence of new system properties at that higher level.

Metastability resulting from perturbation-mediated positive feedbacks may be disrupted via change or cessation of the system-organizing perturbation (Naveh 1987a, DeAngelis and Post 1991). Restoration of a perturbation-induced metastable system state following its disruption cannot be achieved via protection from the system-organizing perturbation. Such "rest" may actually constitute a further disruption of the system. While it may permit "relaxation" of the system to a new homeostasis (Renwick 1992), it cannot result in restoration of the previous metastable state. Rather, reestablishment of the previous system state demands reestablishment of positive feedback-induced homeorhesis through reinitiation of a properly scaled system-organizing perturbation regime. Temporal and spatial scale and intensity of disturbance are thus critical factors in system organization and an "optimum" disturbance regime, or set of such regimes, can be hypothesized for a given management objective within a given system (Naveh 1987a, Graetz 1991).

Hypothesized Dynamics of the Pre-Columbian THE

The pre-Columbian dynamics of the Great Basin THE are here hypothesized to have been driven by moderating and organizing negative and positive feedbacks between vegetation and human cultural activities. On the one hand, environmental limitations acted to restrict the range of human impact on the land, including the use of fire, while on the other, human management acted to establish and maintain the system within a subset of environmentally delimited behaviors considered "most desirable" under culturally determined criteria. Under this hypothetical scenario, the historical period of regional landscape change can be explained by the breaching of the indigenous cultural ecological system by Euroamerican contact. This led to a change in spatial and temporal patterns of anthropogenic fire and resource use. At the same time, a radical increase in the intensity of a system organizing-perturbation, herbaceous herbivory, took place through increases in large game (Kay 1996), lagomorph (Milner 1989) and insect (Sutton 1988) populations, previously depleted by indigenous use, and the concomitant introduction of Euroamerican domestic livestock.

Increased impact of all classes of herbivores on the soil/litter/vegetation complex is similarly hypothesized to have resulted in an increase in the spatial scale of soil and water movement, culminating in increased systemic losses via an extended gully network and a resulting decline in system productivity. This process can be seen as "negative" homeorhesis, that is, a positive feedback cycle leading to a lower degree of system organization and complexity (figure 2).

By conceptualizing the indigenous woodland/steppe as a self-organizing biogeocultural system, the following dynamics can be hypothesized for pre-Euroamerican Tintic Valley.

The indigenous landscape system was managed under the aegis of the indigenous "tebiwa" (a bolson, or a single valley and its neighboring ranges) biogeocultural framework (Utah State University Associate Professor of Anthropology Steven Simms, personal communication 3/94). A relatively predictable quasi-equilibrium state was the desired condition and the system was managed accordingly. System management was effected with induced pulses of fire, arguably achieved via the careful monitoring of indicator variables by the indigenous manager so that the driving pulse of fire was maintained at the correct intensity (spatial and temporal) to increase system organization on the one hand, and avoid tipping the scales toward decreased complexity on the other. This suggests a range of disturbance frequencies and intensities within which the self-organizing tendency of the open system could be enhanced via such pulse disturbance (Naveh 1987a).

Monitoring and manipulating critical system variables, such as community and landscape fuel distribution, can be seen to be logical cultural adaptations to, and reinforcing feedbacks within, self-organizing systems (Cincotta et al. 1991), such as the hypothesized indigenous woodland/steppe ecosystem of Tintic Valley. I suggest that through management of pattern, the indigenous manager was able to manipulate process, as reflected, for example, in subsequent fire behavior. This positive feedback dynamic resulted in pushing the system into a new energetic state, a state subsequently maintained by negative feedback relationships among fire, plant communities, fuel dynamics, and cultural practices. This does not necessarily imply an intentional (self-aware) "ecological wisdom," viz., the myth of the ecological noble savage (Martin 1981, White 1984), but does suggest an empirically derived set of cultural feedbacks within the system, a reasonable probability in the face of 500 or more generations of indigenous human experience in the woodland/steppe.

Conclusion

At least two feedback mechanisms can be hypothesized whereby the indigenous woodland/steppe system became self-stabilizing and self-organizing: 1) anthropogenic response to fuel conditions--the culturally mediated decision to burn--and 2) fire response, whether wild or domestic, to fuel availability. This suggests indigenous fire frequency was relatively short in order to facilitate the prediction of fire behavior; this temporal scaling of disturbance would in turn serve as a self-organizing feedback within the system. Thus relatively frequent fire would tend to foster a plant community structure that could both recover within the short fire-free interval and provide the necessary continuous fine fuels for subsequent burns and facilitating prediction of fire behavior. Increased predictability implies increased information in the system, also recognized as decreased entropy and increased system organization (Naveh 1987a, Stafford Smith and Pickup 1993). This is consistent with the view that nonequilibrium system dynamics may generate increased order and organization through fluctuation (Naveh 1987a, Cincotta et al. 1991), in this case induced via anthropogenic fire.

The research presented in the following chapters takes as its working hypothesis the view that the indigenous woodland/steppe landscape of Tintic Valley exhibited complexity, order, and high energy dynamics as emergent properties (Salt 1979, Naveh 1987a, Allen and Hoekstra 1992) deriving from anthropogenic manipulation of the system, particularly through the use of fire to achieve explicit management objectives, including protection from wildfire (Stewart 1956, Pyne 1982, Kay 1995). It is specifically hypothesized that cessation of this system-organizing perturbation resulted in changes in both geomorphology (Chapter VI) and vegetation mosaic of Tintic Valley (Chapter V), phenomena common throughout the Intermountain West in the historic period. While this transition was almost certainly aggravated by land-use changes accompanying Euroamerican settlement, the theoretical framework presented above suggests that alteration of the indigenous fire regime alone would be sufficient to precipitate the landscape changes observed in the region in the historic period, even in the absence of Euroamerican land-use practices.

CHAPTER III

NATURAL RESOURCE MANAGEMENT

IN THE PREHISTORIC GREAT BASIN

> ...Time passed there, spring came, fall came, and they ate pine nuts over there on the other side of the mountains. My mother must have been born there then (during pine nut season). When my mother was born, my great grandfather's daughter-in-law was filling a water jug way high up there where a little bit of water is dug out, dug like this. I have seen the place. On this side of where they filled water they had a house.
>
> That old man went up there to the water to make a fire. There was burning on that day, it was blowing; when he went to get water it was blowing. He started a fire there where they say that he said pigweed, bunch grass, mustard and such would grow in the burn. They say they planted things this way and that with fire, with the finding of Indian food with this fire.
>
> Saying and thinking that, he started a fire, one this way, they say that was burning this way, burning all over, with the whole mountain burning. It burned like this. Wonder if my great grandfather had burns on his body by then? There was nothing but deerbrush, sage, rabbit brush, grass, this and that up there, and my grandfather jumped on that rock, they say. While my great grandfather was doing that and the fire was here around the rock like this, it brought him down (off the rock), and this burned, that burned, burning his skin, he was doing this with his hands (scratching his skin), just all over his skin. Thus it happened that he fell down, and falling down he crawled toward the water, they say....He died there in the water.... (Moon 1966, p. 66-67).

Introduction

Blackburn and Anderson (1993) and Lewis (1993a) have argued that the structure, spatial extent, and species composition of plant communities in the American West prior to Euroamerican arrival were largely maintained over time through ongoing, purposeful human intervention and that the term "domestication" can be applied to entire landscapes. It is the underlying assumption of this chapter that the pinyon-juniper woodlands and bunchgrass steppes encountered by Euroamerican settlers of the Great Basin were not untrammeled wilderness in equilibrium with the abiotic environment. Rather, the patterns and dynamics of these systems were a function of human management for specific objectives, including facilitation of hunting of large game, maximization of seed production, and increase in the predictability of resource availability. Tansley (1935) observed that human beings are "an exceptionally powerful biotic factor," and the role of human agency in changing ecosystems has been increasingly recognized in recent years (Thomas 1956, Darling and Milton 1966, Pickett and McDonnell 1993, Meyer and Turner 1994). In the displacement of indigenous cultures, Euroamerican settlement in the Great Basin radically altered the dynamics of regional ecosystems, with concomitant dramatic effects on landscape patterns and processes.

Environmental Management in the Prehistoric Great Basin

Lewis (1993b) has suggested that the complexity of indigenous environmental management practices stands in stark contrast to our own, which tend to be rooted in production of a small number of commodities. Underlying Lewis's argument is the observation that hunter-gatherers are dependent upon a wide array of ecological relationships and necessarily responsive to local environmental dynamics; not to be so would doom them to extinction. Indigenous natural resource management techniques are known to have included transplanting, water diversion and irrigation, coppicing, weeding and tillage of specific plant communities, along with harvesting strategies designed to ensure the regeneration of the harvested resource (Fowler 1986, Blackburn and Anderson 1993, Lawton et al. 1993).

Almost all Great Basin cultural groups listed by either Steward (1938) or Stewart (1966) practiced some form of environmental manipulation, yet Great Basin groups exhibited a high degree of variability in resource use (Downs 1966). For example, of the 44 species of grasses and other seed plants listed by Steward (1938) as important in the indigenous Great Basin economy, only seven were gathered by all the groups included in his study. While all groups used insects, no single insect species was utilized by all groups (Downs 1966). Similarly, not one of Steward's taboo resources was universally so among the groups.

Thomas (1983) reported construction of snow dams of brush and mud for water storage at repeatedly occupied winter camps. Wilke (1993) reported repeated harvests of bow staves from the same trees within specific stands of *J. osteosperma* in Nevada, and noted that *Cercocarpus*, *Amelanchier*, *Prunus*, *Quercus*, *Acer*, and *Salix* were all used for bow manufacture in the Great Basin. At the Bustos Wickiup Site in Nevada, Simms (1989) documented prehistoric clear-cutting of juniper for wickiup construction, with obvious influence on pinyon-juniper woodland spatial pattern and patch dynamics. Junipers were felled at either the trunk or root, using fire and stone axe(s). In the case of root felling, soil around the roots was excavated and a fire built under them. Log diameter averaged 15-20 cm, with some 30 cm in diameter. The site was a pinyon nut harvest camp used over many decades, thus justifying this high energy investment in housing construction.

One compelling indicator of the importance of active resource management by indigenous peoples of the region is the prevalence of epicormic branches and adventitious shoots in the material culture (Blackburn and Anderson 1993). Stooling or coppicing of *Salix* and *Rhus*, and firing of other species to enhance straight, vigorous growth for basketry, was reported by Fowler (1986). *Amelanchier* used in arrow manufacture and *Phragmites* use in composite arrows were only suitably formed when derived from recently burned stands of these materials (Blackburn and Anderson 1993, Charles Kay personal communication, May, 1995). Fowler (1986) also reported pruning of pinyon by breaking branch tips to enhance cone production.

Fire

The most effective and widely used management tool in the indigenous repertoire was certainly fire (Pyne 1982, Blackburn and Anderson 1993, Kay 1995). Sowing of wild seeds, commonly preceded by fall or spring burning, was widely practiced, although burning to encourage growth of wild plants, without seeding, was more common (Anderson 1993, Lewis 1993a). Fowler (1986) reported the use of fire for enhancement of seed, tobacco leaf and wildlife fodder production, and notes broadcast sowing, following spring burns, of *Nicotiana attenuata, N. bigelovii, Chenopodium, Descurainia*, and *Mentzelia dispersa*.

Lewis (1993a, p. 81) presented a Monterey, California, Presidio report dated

October 3, 1771 in which aboriginal use of fire is described: "The heathens...have the bad habit, once having harvested their seeds...they set fire to the brush so that new weeds may grow to produce more seeds, also to catch the rabbits that get confused and overcome by the smoke...." The conflict between the indigenous need for seed and the Europastoralist need for grass is implicit here, and can be envisioned as a recurrent theme throughout the early history of the rangeland West.

In August of 1843, Fremont (1844) suggested that fire prevented tree establishment on the lower Bear River near Tremonton, Utah. In October of the same year, traveling southeast of present day Boise, Idaho, Fremont noted that the grass was green wherever Indian-set fires had burned. Powell (1879) also concluded that Amerindian fires prevented the establishment of trees in grassland. Gruell (1985), after reviewing historical accounts of 145 fires, including nine reports in Utah, identified most of these as having been set by native people. He concluded that fire was a major perturbation in the interior West in the pre-Euroamerican settlement era, its absence helping to explain vegetation change in recent times. Barrett (1980) used interviews and historic journals to show that Amerindian fires were frequently both purposely and accidently set, and that the purposes of burning were multiple.

Disturbance and heterogeneity: Why burn?

The intermediate disturbance hypothesis (Huston 1979) suggests that within a given ecosystem, an optimum disturbance frequency exists in which species diversity will be maximized (DeAngelis and Huston 1993, Huston 1994). Longland and Young

(1995) have suggested that pre-settlement herbaceous plant diversity was probably highest in Great Basin landscapes with a high proportion of early seral plant communities. By creating and/or maintaining openings in the landscape vegetation mosaic, anthropogenic fire has the potential to contribute to patch maintenance, landscape heterogeneity and, consequently, biotic diversity.

Lewis (1993b) noted that the most important resources traditionally utilized by native Americans are commonly found in recently burned areas, including large and small game, fowl, grass and forb seed, berries, bulbs, etc. He argues that lightning-initiated fires are too infrequent, too irregular, and poorly timed with respect to indigenous management objectives. The potential for wildfire both to occur when valued resources are susceptible to destruction by fire and to direct system dynamics along a trajectory viewed as culturally undesirable suggests the necessity of conscious use of fire in indigenous landscape management. Lewis (1993b) has shown that fire practices of native peoples of California and northern Alberta resulted in fires that differed significantly, in both seasonality and frequency, from non-anthropogenic fires, with indigenous fire management directed toward maximizing the beneficial effects of fire on desired resources while minimizing negative effects, including the danger of wildfire.

Just as the modern resource manager seeks to increase the predictability of system behavior in response to management practices, so may increasing the predictability of resource availability be hypothesized as a probable objective of indigenous resource managers. Everett and Ward (1984) noted that the predictability of system response following fire increases relative to the recovery potential of remnant plants and decreases with an increase in the diversity of soil seed reserves and the size of the potential immigrant species pool. Following experimental manipulation of fire in pinyon-juniper woodlands of Nevada, they concluded that post-fire growth response is qualitatively predictable for root-sprouting shrubs, bunchgrasses, and a few perennial forbs, but little else. Unpredictability of post-fire response resulting from soil seed reserves is potentially readily subject to cultural mitigation by the sowing of desired species.

Malouf and Findlay (1986, p. 510) quoted Stewart: "Prior to the White man's arrival, Utes had regularly burned brush away from meadows, in order to provide open, clean, grassy pastures to attract wild game and thereby facilitate hunting. Mormons halted this practice and meadows turned into sagebrush-covered valleys (see Cottam and Stewart 1940) or... became agricultural fields." Other reasons to burn may have included entertainment, signalling, and maintaining or extending desirable human habitat (Jones 1969). Aesthetic concerns, centering around such ideas as "cleaning" or "taking care of" the landscape are also important reasons for burning in traditional indigenous cultures (Lewis 1989).

Big sagebrush (*A.tridentata*) and low sagebrush (*A.arbuscula*) are readily killed by fire, while grasses and other herbaceous species are stimulated by the resulting nutrient flush and reduction of competition for soil moisture (Wright et al. 1979). Browse tends to be improved in both quantity and quality by fire; berry-producing shrubs are common on burned areas. Biswell (1989) reported an increase in quail and rabbit populations on burned sites relative to unburned areas, and notes that hunting of such small game is easier in country opened by fire.

Annual burning following grass seed harvest appears to have been common among indigenous peoples of both California and the Great Basin (Blackburn and Anderson 1993, Lewis 1993a). Actual anthropogenic fire frequency in any given area would presumably have been a function of local population density and the perceived effects of such fire on the local resource base. Even in California, where precontact populations are estimated to have been among the highest in North America, densities were probably insufficient to result in burning of a majority of the vegetation on an annual basis (Lewis 1993a). Longland and Young (1995) noted that a fire frequency of less than 10-15 years would prevent bunchgrass steppe dominance by big sagebrush, suggesting annual burns were not necessary to meet at least some indigenous land management objectives. Biswell (1989) noted sequential fires separated by only one or a few years could act to establish a vegetation pattern that might remain relatively stable in the absence of fire for 70 years or more.

Seasonality of firing is an important determinant of system response (Biswell 1989). Behavior of fires set in early spring or late fall is generally more predictable, and thus less dangerous, than mid-summer fires, and morning or evening fires are less dangerous than mid-day fires. Certainly the danger of wildfire, whether anthropogenic or nonanthropogenic in origin, was (and remains) real throughout the region (Moon 1966), and indigenous fires did occasionally escape (Lewis 1993b). Nevertheless, natural fires are relatively unpredictable and may cause widespread destruction, while man-made fires, if well timed, are relatively predictable in behavior, result in rapid increases in useful production, and can help reduce wildfire unpredictability (Biswell 1989).

Management as an energy optimization strategy

Resource abundance alone cannot predict hunter-gatherer resource utilization patterns (O'Connell et al. 1982). For example, while grass seeds have been abundant in the Great Basin throughout the period of human occupancy (Grayson 1993), their use has varied widely over time. Thus it becomes impossible to reconstruct past settlement and subsistence patterns without reference to some explanatory principle other than resource abundance. Diet breadth models, derived from optimal foraging theory, predict that resources are included or excluded from the diet as a function of their caloric value relative to other available resources and the abundance of higher ranked resources (Simms 1987). This model suggests that any effort toward environmental manipulation must be justified by expected caloric returns. Reasons for burning might thus be ranked in importance similarly to fire's effect on desirable resources, e.g.; medium and large mammals, roots, grass seed, fish, etc. There would be little reason to burn if the result was to replace a higher ranked item with a lower ranked one, but good reason to do so in the opposite case.

Simms (1987) has noted that percent cover of a resource, such as Indian ricegrass, determines its search cost; costs increase, and return rates in terms of calories/hr decrease, as percent cover decreases. This is by no means a linear relationship. For example, 100% cover of *Allenrolfea occidentalis* (pickleweed) results in a return of 150 calories/hr, while 20% cover returns 143 calories/hr, 95% of the return of 100% cover. Pickleweed cover as low as 2% still returns 62% of the maximum, or 93 calories/hr (Simms 1987). Seeds of all types have a relatively low return rate (with notable exceptions, including pinyon), but are storable, offering the possibility of banking low-value resources against times of scarcity in higher value foods. Even seeds obtainable only at a net energetic loss, such as pickleweed, offer the benefit of storability for use in times of caloric shortfall (Simms 1987). This suggests that increasing cover of desirable species, and increasing predictability of encounter, would result in increased return rates for such resources. In this context, any management practice that native peoples perceived as increasing cover or predictability of encounter of desirable resources could be expected to have been employed. Use of fire, protoagricultural practices, and agriculture itself can all be seen as overt attempts to increase the spatial concentration and spatial and temporal predictability of resource availability.

Given the high energy value of game animals, environmental manipulation resulting in increased predictability of game encounter would be energetically justified. Increasing the spatial and temporal predictability of plant resources through fire could be expected to have similar implications for animal resources through its effects on browse and/or graze species phenology. Simms (1987) noted that the presence of agricultural fields in modern times is a factor in increased mule deer populations and a similar relationship is reported by Lewis (1993a) with regard to seasonal presence of game in anthropogenically manipulated stands of native forage species.

Grasshoppers may be a case in point. Widely consumed throughout the Great Basin, grasshoppers played an important role in regional human nutrition (Madsen and Kirkman 1988, Sutton 1988). Numerous species of grasshoppers were exploited and have been recovered from cave sites in the Eastern Great Basin. With the notable exception of drowned, salted, sun dried grasshoppers harvested along the Great Salt Lake shoreline, grasshoppers were caught by hand while immobilized by low, early morning temperatures, or by driving with beaters and/or fire into a pit or trench, which was then fired (Sutton 1988). While Kemp (1992) noted that grasshopper response to system patch dynamics is highly species specific, Fielding and Brusven (1993) suggested that decreased shrub cover due to wildfire may promote increased grasshopper densities.

In addition to the ecological impacts of fire used to drive or process insects, insect harvest itself may have impacted system dynamics. Ute harvesting of crickets may have served to control local cricket populations, with the historical 1848 plague of crickets in Salt Lake Valley a hypothesized direct consequence of displacement of cricket-eating indigenous people from the region in the 1840's (Madsen and Kirkman 1988, Sutton 1988). A Ute cricket drive in the mid 1800's involved excavation of crescent-shaped trenches (horns pointing up hill) 30-40 feet long and about one foot deep and wide in nearly continuous series across the slope. These were filled with dried grass, and crickets were driven from uphill into these trenches, which were then fired (Eagan 1917, described in Sutton 1988). Such a procedure suggests localized hydrological effects, in addition to impacts on insect populations and system dynamics via fire.

University of California geographer Richard Minnich (personal communication, March, 1995) has suggested that low frequency crown fires may have been the norm in prehistoric pinyon-juniper woodlands; however, crown fires were not the only determinant of woodland structure. Gottfried et al. (1995) have suggested surface fire frequency in pre-Euroamerican pinyon-juniper woodlands may have been as low as 15 to 20 years.

Lewis (1993b) has suggested that native use of fire involved a sophisticated understanding of the biotic and hydrologic factors and relationships involved. He suggested that ecotones have played an important role in human adaptation and evolution, and notes the role of fire in maintaining such edge environments. Winter camps of indigenous Great Basin peoples were commonly located along the lower pinyon juniper woodland/steppe ecotone, particularly on west-facing slopes, where prevailing winds tend to break up winter inversion layers (Thomas and Bettinger 1976). Thomas (1983), in his study of Monitor Valley, Nevada, viewed pinyon-juniper woodland as having high residential value due to relatively moderate winter temperatures; safety from summer lightning; abundant water; available fuel; snow-free areas in winter; availability of pine nuts and other seeds, roots, berries, and greens; and ease of access to both upland slope and valley bottom resources.

Thomas (1983) reported deliberate burning of brush in large upland tracts behind such winter camps, and the sowing of *Mentzelia* and *Chenopodium* into the cleared areas, with seed harvest following in the summer. This was apparently of relatively minor importance in terms of overall subsistence, but was probably practiced by many Great Basin peoples, resulting in clumped resource patches situated near residential sites (Thomas 1983). An additional reason for burning in the woodland zone around winter camps was for the preparation of seasoned firewood for the following winter's use (Lewis 1982).

The potential for the spatial relationship between winter camps and the woodland steppe ecotone to be both cause and effect of human settlement merits attention within the context of self-organization and the Total Human Ecosystem (Naveh and Lieberman 1984, Naveh 1987a). Lewis (1989) noted that it is not the fact of individual accounts of indigenous use of fire or the number of such accounts that lend support to the hypothesis of significant, ecosystem organizing anthropogenic fire. Rather, it is the consideration of fire as a component of system dynamics that supports the view invoked here. Given the effects of fire on those components of the system most important for human survival, it is logical to conclude that anthropogenic fire was indeed an important part of the pre-Euroamerican landscape.

Hunting nets and snares

Common in the hunting strategy of Great Basin peoples was the use of snares made of *Apocynum* and other fibers. Cordage was made from a variety of materials, including *Artemisia* and *Juniperus* bark, *Apocynum androsaemifolium, Yucca*, and

Urtica (Fowler 1986). A foot of *Apocynum* cordage would require five plant stalks, or 35,000 stalks for a 40-foot deer net (Blackburn and Anderson 1993). The use of *Apocynum* in the fabrication of rabbit nets, some tens to hundreds of meters long, has been reported in various Great Basin locations, with an implicit need for active management of the resource, most probably through fire in order to ensure the necessary quantity of production.

The complex ecology of culture, fire, and plant and animal communities was suggested in Thomas's (1983) description of a Washoe rabbit drive. The drive employed nets united into an enclosure some 200 yards long and 4 feet high. Rabbits were driven into the net, with 400-500 killed in a day, representing perhaps 600-700 kg of meat. Drives might be repeated a few miles away the next day (Thomas 1983). Milner's (1989) report of an 1841 account by a young Indian woman described entering Salt Lake Valley from a camp on the Green River on a trip with 150 men planning to trap beaver from the Colorado River to the Gulf of California. She describes the use of rabbit nets stretching "...for thousands of yards, some of them twelve to fifteen thousand paces. In the night the hares run and frolic against them and hang like fish" (Milner 1989, p. 174). The impact of this degree of predation on one of the region's primary herbivores is itself worthy of contemplation. More central to the present discussion, however, is the suggestion that "only careful and effective management could have supplied the phenomenal quantities of raw materials required" to support this degree of resource exploitation over time (Blackburn and Anderson 1993, p. 23).

Risk and predictability

Stafford Smith and Pickup (1993, p. 205) have noted that, from a management perspective, it is "easier to cope with risk in systems with low variability." Predictability can be seen as a key factor in the spatio-temporal scheduling of the hunter-gatherer procurement cycle. While the seasonality of indigenous resource availability was broadly predictable, careful monitoring was required to ensure success in resource encounter across a spatially and temporally variable landscape (Janetski 1991). Pinyon nuts, for example, require 26 months to develop following pollination. It is thus possible to predict the seed production of a pinyon stand 18 months ahead of maturity (Lanner 1981); even more certain is the prediction of where the crop will be poor (Thomas 1983). In an indigenous seed-based economy, maintenance of a palatable (i.e., edible seed producing) perennial bunchgrass system through the judicious use of fire could be hypothesized to reduce risk by maximizing both the useable production of the system and its predictability in space and time.

In this context, the conflict between Amerindian and Euroamerican views of fire can be understood as a conflict between two mutually exclusive strategies for management of ecological risk and stabilization of production, one developed *in situ* over a period of some 11,000 years and the other imported wholesale from an entirely different continent and cultural-ecological context. Euroamerican livestock-based economies demand the storage of large amounts of herbaceous biomass over winter. In the early history of the American West, this biomass was stored as standing dead and dormant material on rangeland (Young and Sparks 1985). This same biomass constituted the fine fuels essential for indigenous fire management practices. Originating in the more densely populated European environment, where biomass also played an important role as fuel, Euroamerican perception of biomass destruction by fire outside the context of the hearth would be seen as wasteful. Lewis (1989) has described the European view of fire as an evil force to be avoided, contrasted with the aboriginal view of fire as a positive force that *must* be used.

Fire

In light of the strikingly poor material culture of protohistoric Great Basin peoples (Fremont 1844), it is interesting to consider Riddington's (1982) suggestion that technology be viewed as a system of knowledge, rather than an inventory of objects. Thus,

> ...the essence of hunting and gathering adaptive strategy is to retain, and be able to act upon, information about the possible relationships between people and the natural environment.... these life-giving relationships are as much the artifacts of hunting and gathering technology as are the material objects that are instrumental in bringing them about (Riddington 1982, p. 171).

Fire is the most ecologically important component of the overall effect that hunter-gatherers have on their environment (Lewis 1989). Odum (1983) considered fire a major factor in the history of vegetation in most terrestrial environments and noted human beings have both increased and decreased its influence. Traditional fire practices are based on an empirically derived understanding of how fire influences the distribution and relative abundance of resources. Various intensities and frequencies of fire, at different seasons, serve to integrate spatial areas into communities and landscapes considered desirable under the normative standards of traditional land uses (Lewis 1989). Once initiated, the process of anthropogenic fire reconfigures fuel complexes in ways that helped eliminate wildfire (Pyne 1993). Subsequent fire, whether anthropogenic or otherwise, is subject to the anthropogenically established pattern of fuel availability. Even "natural" fires would be constrained by anthropogenic patch dynamics, reinforcing the existing landscape pattern.

In Australia, Aboriginal burns are scheduled around cultural calendars based on climatic and ecological events in a sophisticated annual sequence dictated by site-specific conditions and management objectives (Lewis 1989). Earlier drying sites are fired first, with subsequent burns moving progressively toward the center of flood plains. This results in a mosaic of resource availability, including the temporal extension of foraging opportunities for regional grazing species. Such regular, repeated disturbance also acts as a positive feedback on the delineation of the spatial and functional boundaries of these areas, as fire acts to homogenize within-stand characteristics while emphasizing and maintaining between-stand boundaries (Allen and Hoekstra 1992) and thus landscape heterogeneity.

Landscape-scale changes in the dynamics of woody and herbaceous species following the cessation of indigenous use of fire have been repeated across the region and, indeed, throughout the biosphere (Burkhardt and Tisdale 1976, Savage 1991, Archer 1994, Miller et al. 1994). The Australian National Parks and Wildlife Service has recently acknowledged the ecological importance of more than 35,000 years of aboriginal fire management on the Australian continent (Lewis 1989), and the essential role of fire is being increasingly recognized in the American West (Miller and Wigand 1994, Goodloe 1995).

A Tintic Valley Ethnography

Fowler (1982, p. 121) referred to "the short, but exceedingly important period between contact and first ethnographic description," emphasizing the need for caution in use of ethnographic analogy in the interpretation of specific sites and in extrapolation before the ethnographic era. A major problem with ethnographic studies in the Great Basin is the fact of early displacement of aboriginal groups from the most productive environments by white settlers. A notable exception to this early displacement is the Gosiute, who occupied areas unwanted by early settlers and thus remained relatively intact as late as the 1930's when Steward's field work was conducted (Thomas et al. 1986). If Tintic Valley was occupied by Gosiute, it may indeed have been undisturbed by Euroamerican intrusion until the Tintic war of 1856 (Gottfredson 1919).

Early historical references generally refer to Utah Lake as forming the western boundary of the territory of the Uintah Ute, the mountain range immediately west of Utah Lake serving to separate the Shoshone/Gosiute and Ute territories (Stewart 1966, Janetski 1991). Stewart (1966) placed Tintic Valley within traditional Shoshone/Gosiute territory as defined by the Indian Claims Commission in 1962, but also shows the Tintic Valley town of Eureka lying within Ute territory. This places the boundary between Ute and Western Shoshone/Gosiute territories at the West Tintic Mountains, rather than the East Tintic Mountains, and this is the division defined by the Doty treaty of 1863 (Stewart 1966).

Throughout the Great Basin, if a seasonal resource became highly abundant within a single *tebiwa*, neighboring groups might converge to harvest it without protest from the local group (Janetski 1991). Whether this implies Ute/Gosiute or Ute/Shoshone joint use of Tintic Valley in a good pinyon nut year, for example, is unknown, though it is known that Paiute, Ute, and Shoshone did intermingle (Downs 1966), and mixing and marriage between Shoshone and Ute was apparently common (Janetski 1991). Janetski (1991), in his comprehensive study of the Utah Lake (Timpanogot) Ute, noted that pinyon harvest in the East Tintic Mountains began with late September frosts, while the drier valleys to the west of the Lake were the setting for late fall rabbit and antelope drives, when the rabbits were fattest and antelope were banding together on winter range.

Thomas (1983) suggested that in a good year, 80-120 people could be supported all winter on about 90 km^2 of pinyon woodland. This is about the area of the Tintic Valley uplands occupied by pinyon-juniper woodlands in the protohistoric period (Chapter VII). The campground radius (1 km) would have fallen within the Valley proper, while the foraging radius (10 km) and logistical radius of 20 km or more (Thomas 1983) would have carried Tintic Valley residents into the desert to the west or Utah Valley and the Wasatch Front to the east.

Madsen (1982) noted that Dominguez and Escalante provided no evidence of pinyon use by Utah Lake Ute, but Janetski (1991) did report such use. The high productivity of the Utah Lake environment suggests that pinyon may have played a lesser role for the Timpanogot Ute than other groups in the region. If true, this would also suggest that someone other than the Ute may have been using Tintic Valley's pinyon woodlands, or at least its pinyon nuts. Gottfredson's (1919) account has suggested that no one wintered in Tintic Valley in 1856, despite the pinyon presence, but 1856 was well after the breakdown of the traditional subsistence pattern of the people of the region and the removal of most of them to reserve areas. Gottfredson's account also makes it clear that the area was known by the Ute, though this does not necessarily render it traditional Ute territory. The fact that the horse made travel between Utah, Cedar, and Tintic Valleys quite rapid suggests use of the area following introduction of the horse, but leaves unanswered questions about the earlier period. While traditional Ute territory may not have extended west of Utah Valley, by the time of the Tintic War, Utes had already been squeezed out of their traditional locations.

Simms (1989, p. 4) describing the Bustos Wickiup Site, noted,

> The area could be considered to be within a transition thought by Steward..., to occur along all cultural boundaries in the Great Basin. Transition zones are characterized by increased frequencies of bilingualism and intermarriage...and could have been used by people of varying linguistic and social groups, depending on the particular years or decades in question.

Tintic Valley may well have fallen into this transitional category. While Tintic Valley lies along the cusp of Northern Ute and Gosiute territory, it would appear to have constituted rich country in a Gosiute sense, and relatively poor country in a Ute sense (except as a seasonal source of pinyon and game).

Steward (1938) reported winter villages along the lower edges of the pinyon-juniper zone as a consistent pattern in the central valleys of the Great Basin, unlike marshland and lacustrine valleys where winter camps often occurred in association with these highly productive lowland resources. Drier valleys tend to be associated with higher mobility, for while pinyon and mountain sheep might be abundant in the uplands, other resources were not, so that following winter, groups tended to quickly disperse to more productive areas. According to Steward (1938), permanent association of family groups in the region occurred only at woodland ecotone winter encampments, where stored seeds (especially pine nuts), water, and wood were readily accessible and winter temperatures were relatively moderate. In areas of less resource abundance and high seasonal variability in resources, large populations could be accommodated only seasonally, if at all. Limited and seasonally variable resources imply a larger procurement area and high mobility, with winter village location subject to some limited variation. Tintic Valley would appear to meet the criteria of either the center of a large procurement area, or of a seasonal (e.g., winter village) procurement area.

Although no systematic survey of Tintic's archaeological resources has been conducted (Evie Seelinger, Utah State Historical Society Division of Archaeology, Salt Lake City, Utah, personal communication, July, 1994), amateur archaeologists have described Tintic Valley as "very rich" in artifacts, including Fremont pottery shards, particularly concentrated along the protohistoric pinyon-juniper belt above what may have been a seasonally wet meadow between lower elevation woodlands and the historically incised modern day channel of Tanner Creek (Jay and Marianne Nelson, personal communication, September, 1994).

While artifacts from the few officially documented sites within Tintic Valley are limited to "lithic scatter," archaeologically significant Fremont-associated sites are located both to the west, including corn-producing sites on Cherry Creek, and east, including pictographs and stone house structures (USHS 1996). Even if Tintic Valley itself was not a center of cultural activity, it fell well within the 10 km foraging radius (Thomas 1983) of these permanent sites and possibly lay within the logistical radius of the Nephi Mounds site, "one of the most important in the Eastern Great Basin" (USDI 1975, 1).

A plausible, if hypothetical, annual scenario for late prehistoric users of Tintic Valley includes a summer harvest of herbaceous seed, possibly followed by grasshopper and rabbit drives, burning of the landscape, and a check of the pinyon harvest potential. Grass seed may have been cached near promising pinyon groves, and the winter pinyon winter camps established there. In the spring, areas around the camp may have been burnt and sown to *Mentzelia, Chenopodium*, etc., before people left the area on their annual round, returning again for the seed harvest in late summer.

Transition: The Protohistoric Period

Following the establishment of Spanish rule in New Mexico around 1600, horses began to spread throughout the Southwest (Shimkin 1986). The Ute probably first became familiar with the horse around 1640, while under the peonage of Spanish Governor Rosas of Mexico (Stewart 1966). Colorado Ute territory was contiguous with the San Juan and Colorado Rivers and escaped Ute slaves may have brought the first horses north of the Colorado (Stewart 1966). By 1650 the horse was being used as a pack animal by native American buffalo hunters. Following the Pueblo revolt of 1680, the Ute began acting as intermediaries for distribution of the horse to Comanche, Shoshone, and other tribes to the north (Stewart 1966). Establishment of extensive stock ranching by the Jesuit missionary Eusebio Francisco Kino south of the Gila River in the 1690's (Hadley and Sheridan 1995) facilitated spread of the horse north and west (Shimkin 1986).

Arrival of the horse precipitated major socioecological upheaval throughout the region. Mounted Comanche and Ute began raiding Spanish New Mexico in 1706 (Stewart 1966). Raiding by the Comanche continued until a formal peace 70 years later. Responding to increasing pressure from peoples to the east, mounted Plains Shoshone began to move westward. Trade networks, extending as far north as the Snake River of Idaho and the Yellowstone River of Montana, began to develop following Spanish colonization of California and the opening of the Southeastern Great Basin by Escalante and Dominguez in 1776 (Callaway et al. 1986).

Although the institution of slavery was unknown to the pre-contact Ute (Malouf and Malouf 1945), once mounted, eastern Utes began raiding unmounted Western Shoshone and Southern Paiute for slaves, whom they sold to the Spanish

(Malouf and Findlay 1986). Escalante and Dominguez encountered several Eastern Ute camps (Malouf and Malouf 1945) of well mounted, tipi-dwelling people, cyclically engaged in bison hunting and already trading furs with Spaniards. The Western Ute had the horse by about 1800, obtained from either the Eastern Ute or the Spanish. Arze and Garcia, Spaniards who traded pelts at both Utah Lake and along the Sevier River in 1813, encountered mounted, armed, and decidedly hostile Utes (Malouf and Malouf 1945). This corresponds with Fremont's (1844) impression of the Utah Lake Ute some 30 years later. While the slave trade may have begun as early as the 1770's, the first official record appears in 1813, when Arze and Garcia left Abiquiu, New Mexico, for a trading expedition into the Utah Lake area, where Ute insisted they purchase slaves from them (Malouf and Malouf 1945, Malouf and Findlay 1986).

By the 1820's, the Spanish, Mexican, and Ute slave trade (Zavala 1979, Milner 1989) and the impact of the horse on intergroup warfare had depopulated the northwestern Great Basin and forced the Northern Paiute and Shoshone into more marginal areas (Callaway et al. 1986). More remote groups, particularly the Gosiute, were less impacted due to their spatial isolation and the ecological limitations of their environment, which protected them from incursion by Euroamericans and their livestock. Although Ute country was officially closed to Spanish travel and trade for 40 years following the Escalante and Dominguez expedition, clandestine trade was robust leading up to the formal opening of the Spanish Trail between Santa Fe and Los Angeles in 1830 (Callaway et al. 1986).

Gosiute and southern Paiute were especially victimized by the slave trade (Malouf and Findlay 1986). In "An Indian Girl's Story, 1841," the narrator reports, "When on serious alarms these Indians escaped for their interior deserts they carried baskets of water with them," and describes the Paiute's fear of the "Spaniards of Taos and California" (Milner 1989, p. 173). Although the Ute intermarried with Western Shoshone, Ute on horseback raided unmounted Western Shoshone, Gosiute, and Southern Paiute to meet the Spanish demand for slaves (Zavala 1979). Later, Utes sold Gosiute children to the Mormons by threatening to kill the children unless they were purchased (Malouf and Malouf 1945, Thomas 1983).

With a few local exceptions, Native American use of the horse in the Great Basin was initially limited by availability of both forage and water. By 1830, horses and horsemanship had spread throughout the Great Basin, stimulating trade, raiding, and slaving across the region and as far as Los Angeles and the Klamath River along the California-Oregon border (Malouf and Malouf 1945, Callaway et al. 1986, Shimkin 1986). This regional expansion of equestrianism suggests a radical transformation of the cultural ecology of the Great Basin between 1776 and 1830 (Simms and Stuart 1993). Depopulation was both a response, and a necessary precursor, to the extension of the horse culture into the region.

Depopulation

Sixteenth-century mortality of native Americans due to European disease of greater than 70% has been documented for parts of North America, but this question has not been explored for the eastern Great Basin (Simms 1990). The relatively dispersed population and generally arid environment of the Intermountain area may have helped slow the spread of disease in the region (Simms and Stuart 1993). Direct European contact began in the southeastern Great Basin with the Escalante and Dominguez expedition of 1776, while in the northeast Eastern Shoshone and Ute had regular encounters with North West Co. fur traders by 1800 (Hughes and Bennyhoff 1986). Trappers reached the Bear River by 1811, and over the next 30 years essentially exterminated the beaver as far south as the Salt and Gila Rivers of Arizona, radically altering regional hydrology (Johnston and Naiman 1990). The opening of the Spanish trail in 1830 and development of the Oregon Trail following 1840 resulted in rapid degradation of limited forage and water resources in the region and new avenues for the introduction of disease.

With the initiation of Mormon settlement in 1847, the usurpation of the most productive areas in the region accelerated, including the Ute stronghold of Utah Valley in 1849, precipitating rapid depopulation by native peoples through both armed conflict and disease. A cholera epidemic, for example, killed hundreds of Northern Paiute in 1850 in the Humboldt River Basin (Malouf and Findlay 1986). On the other hand, Mormon control of Utah sections of the Old Spanish Trail interrupted and finally ended the traffic in slaves (Malouf and Malouf 1945).

Euroamerican settlement in the mid-1800's affected all aspects of indigenous life, already significantly disrupted by cultural upheaval precipitated by contact. Resource areas were plowed and fenced; game movements and populations disrupted;

pinyon trees felled. Not surprisingly, settlers often chose to settle the same areas as indigenous people for reasons of water, fuel, forage, and landscape position.

Discovery of gold in California and Nevada in 1848 accelerated the rate of Euroamerican penetration into Shoshone territory, while discovery of the Comstock Lode in 1857 led to massive migration across the Great Basin to western Nevada through the 1860's (Thomas et al. 1986). The development of the region's mining communities meant the rapid depletion of local resources, from timber and soils to destruction of game habitat, water diversion, and the initiation of agriculture and livestock grazing.

The destruction of traditional sources of subsistence resulting from Euroamerican invasion of the landscape put indigenous people in the position of having to steal or starve (Malouf and Findlay 1986). Severe winters particularly forced the theft of livestock from Mormon herds. This situation precipitated the "Tintic War" of 1855-56, the first Euroamerican entry into Tintic Valley in the winter of 1856, and its naming after the leader of one of the last bands of the Ute Resistance (Church of Jesus Christ of Latter-Day Saints 1855, Gottfredson 1919).

Conclusion

Simms (personal communication 5/94) has defined environment as that external to an organism which impinges on its survival and reproduction, including social, biological, cultural, climatic, and geophysical factors. The structure of environment thus necessarily includes the physical and temporal arrangement of its parts, the cosmology underlying the culture and culture itself. Human culture is both part of the environment of its members and generally a conservative force with regard to its impact on human behavior. Culture offers an avenue for human adaptation to environmental change that is both more rapid and more subject to conscious human control than the vastly more conservative genetically based evolutionary change. This is certainly one reason why people have been able to persist in virtually every part of the biosphere while undergoing little if any physical evolution to do so. Human evolution has thus become largely a cultural, rather than a genetic, phenomenon; it is the fitness of behaviors, not of genes, that dominates the process of evolution in the human animal. Rather than grow fangs, we learned to work obsidian, and quickly, in evolutionary terms.

Environment has an effect on human culture in so far as it delineates to one degree or another the boundaries of ecologically viable human behavior. In a classic example of self-organization, culture both shapes and is shaped by the environment. To the extent that prehistoric or modern peoples have been able to manipulate the environment, we have displaced, or replaced, environment with culture. To the extent that environmental manipulation is beyond our ability, or turns to bite us from behind, material culture fails us.

Williams (1993) has suggested that "natural" landscapes are better viewed as relics of previous land use. In suggesting that culture is an emergent, regulative property of the Total Human Ecosystem, Naveh (1987a) placed culture at the boundary between the environmental and human realms, a function of the relationship between the two. The approximately 11,000-year record of human occupancy of the Great Basin suggests that the relationship between people and environment flourishes within strict, if elastic, boundaries, defined by human material culture on the one hand and environmental constraints on the other (Grayson 1993). Whatever the emergent, regulative characteristics of the indigenous Tintic Valley Total Human Ecosystem prior to Euroamerican settlement, cultural-ecological upheaval induced by disease, slavery, starvation, and warfare had begun to unravel that relationship half a century or more before a band of Mormon volunteers followed a renegade Ute named Tintic over the divide from Cedar Valley.

CHAPTER IV

HISTORICAL IMPACTS

> They are gone now. Fled, banished in death or exile, lost undone. Over the land sun and wind still move to burn and sway the trees, the grasses. No avatar, no scion, no vestige of that people remains. On the lips of the strange race that now dwells there their names are myth, legend, dust (McCarthy 1993, p. 246).

Introduction

As suggested in the previous chapter, historical impacts on pattern and process in Tintic Valley were almost certainly felt well before the first Euroamericans entered the Valley. With the initiation of Euroamerican land management activities, a period of dramatically accelerated change was initiated, one which continued into the twentieth century. This chapter uses the historical record to characterize, and where possible quantify, the nature of impacts on Tintic Valley induced by livestock, agriculture, tree harvest, and fire.

Livestock Impacts

Wagner (1978, p. 138) has argued that "...livestock grazing has surely been the most ubiquitous influence for change in the West." The early degradation of the region's rangeland has been widely reported (Griffiths 1901, USDA Forest Service 1936, Young and Sparks 1985). As early as 1867, Mormon Apostle Orson Hyde declared, "The grass is not only eaten up by the great amount of stock that feed upon it, but they tramp it out by the very roots; and where grass once grew luxuriantly, there is nothing but the desert weed..." (Peterson 1989, p.316).

By 1901, Griffiths reported a dramatic difference in condition between "the more favored and protected" privately held grazing lands and that of the publicly owned open range. He estimated a two-thirds reduction in forage production on the rangelands of Western Nevada and Eastern Oregon. Clapp (1936) estimated historic depletion of pinyon-juniper woodland and sagebrush steppe forage at 60% and 67%, respectively.

The 1935 Agricultural Adjustment Survey for Utah noted,

> Although there has been considerable change in the number of animal units in Utah during the last 35 years, there has been no sustained trend throughout the period. The number decreased about 10% from 1901 to 1905, and then increased to the peak of 1,094,400 in 1918. Since then there has been a reduction so that the number at present is only 6% above the low point of 1905 and is 37% below the peak year....Although there has been some year to year variation, no general trend in the number of animal units supported by pasture and range during the 35 year period is evidenced. On the surface this would seem to indicate that there has been little or no reduction of feed resources on rangelands. However, the continued maintenance of this number may have been at the expense of the future productivity of the ranges....
>
> Severe soil erosion or plant change and depletion is found mainly on the west desert area verging on the fall-spring range in Juab and Tooele counties.... this condition is due mainly to over-stocking....[In eastern Juab,]...over-stocking as well as improper seasonal use has resulted in the present condition... Ten years of subnormal rainfall...have greatly aggravated the condition (Bracken 1935, P. 41) .

A reduction in livestock numbers of 26% for the state was recommended (UAES 1935).

The first record of livestock presence in the study area is coincident with both the first Euroamerican entry into the Valley and with its naming. Gottfredson (1919) and Jenson (1941) described the punitive expedition, led by Deputy Marshal Thomas S. Johnson and carrying writs of arrest issued by Judge Drummond in Utah County, which left Provo for Cedar Valley on the 22nd of February, 1856, to apprehend a group of Ute cattle thieves led by one known as Tintic. A fight ensued in Cedar Valley in which five Utes, including a woman and Tintic's brother, Battiste, and one member of the posse were killed and several Indians wounded.

That night (Gottfredson 1919) or the night of the 26th of February (Jenson 1941), the survivors of this band killed two men and a boy who were herding sheep on the west side of Utah Lake. The posse found the group camped among junipers on the east side of Rush Valley, but were fired upon and returned to the fort at Camp Floyd in Cedar Valley. The next day, a company of 80 men under U.S. Colonel Conover continued the pursuit all day, camping in Tintic Valley, "just out of the mouth of a canyon." According to John Banks of Spanish Fork, a member of Conover's party, "The name of the place originated with this expedition, said valley being until that time unexplored by white men" (Gottfredson 1919, p. 103).

The next day they travelled southwest through deep snow, encountering numerous standing cattle frozen stiff, finally seeing smoke from the Indian camp. However,

> We did not like the location, as it seemed like we were marching right into the fortification of the savages. Passing a heavy body of cedars we found ourselves on the edge of the great desert, where we were pleased to discover some stock and we picked out the best beef from seventy-five head, having had nothing to eat that morning. Our Indian guide informing us that it was about six miles to the Sevier River, orders were given to march thither to water our stock....Our horses had been without water since we left the Utah

Lake... (Gottfredson 1919, p. 106).

This account attests to the relative remoteness of Tintic Valley in the early Euroamerican settlement era, yet suggests use of the Valley by equestrian Utes by the 1850's. Presence of frozen cattle in the Valley in the winter of 1856 suggests either stray stock had wandered north from the herds of settlers on the Sevier River, or had been driven into the Valley by Ute stock thieves.

By 1858, Tintic Valley, along with Rush and Cedar Valleys, was a source of hay for military herds at Camp Floyd (Smith 1858, Jenson 1941) and perhaps a source of pasturage as well (Smith 1859). Juab County's Minute Book C reports that on June 13, 1864, Mssrs. White, Greenhalgh and Clark of Pleasant Grove were granted a herd ground in Tintic Valley for the year (WPA 1941 n.p.). The same ground was granted to William B. Pace and one Mr. Haws of Provo on October 28, after the latter had stated that they had "purchased the improvements of Rust and Nebecker of Provo, and that White, Greenhalgh and Clark of Pleasant Grove had misrepresented to the Court pertaining the said improvements..." (WPA 1941 n.p.). Implicit here is that Rust and Nebecker held the disputed herd ground before June of 1864. This is supported by Harris (1961), who reported, without attribution, that in 1864 the entire Valley was granted by Juab County to Rust and Nebecker for grazing.

The first homestead in Tintic Valley was apparently that of John Boone, who constructed an adobe house and corral at Diamond Spring (Warren 1897, McCune 1947), just east of the future townsite of Diamond City, possibly as early as 1859 (Spendlove 1967). Boone brought a herd of cattle and horses to the "broad, grass-covered valley," (McCune 1947) but was eventually killed there by Indians (McCune 1947, Spendlove 1967). Perhaps it was the murder of Boone that led settlers in Utah County in 1866 to notify U.S. Col. Callister of Fillmore of their intent to "scour Rush and Tintic Valley for stock and Indians..." (Smith 1866, p. 2).

Wentworth (1948) listed Tintic Valley among the ranges grazed by the sheep, cattle and horse herds of the Bennion family by 1864; however, this almost certainly refers to the valley west of the West Tintic Mountains, drained by Cherry Creek (Young 1868), rather than the Tintic Valley of this study, drained by Tanner Creek.

Welch (1944), who derived his information from interviews with Samuel McIntyre Jr., Earl McIntyre, and Charles Crismon, reported that the McIntyre brothers, William H. and Samuel P. Sr., arrived in Tintic Valley in 1866 with their herd of Texas longhorns. This date is probably incorrect.

In his first application to the USDI Division of Grazing for a grazing permit, Samuel McIntyre Jr. stated that the McIntyre's had grazed "1500 to 3000 head of cattle and from 100 to 500 head of horses...since prior to 1873" (USDI 1936, p. 2). The 1866 date is also four years earlier than that reported by Sutton (1949b), who claims the brothers, raised in Salt Lake City, returned to their native Texas in "about 1870" to look into land left them by their father. They reportedly sold the land and purchased between six and seven thousand head of Mexican longhorns at $3.75 a head, with the intention of driving them to Utah more or less over the Chisholm Trail. They took eight months for the trip, arriving with most of the herd intact and taking up land in Tintic Valley, where they wintered their stock. In the spring, they sold them at $24.00/head and purchased cattle in what is now Omaha, driving them to Utah. It was apparently this second group of cattle, or part of it, which was traded in 1873 to George and Charles Crismon for majority shares in the Mammoth Mine (Welch 1944). The Crismons lost most of their herd in the hard winter of 1873.

When Brigham Young's party entered the valley of the Great Salt Lake in July of 1847, their new settlement was established on lands claimed by Mexico. Transfer of the land encompassing Utah to the United States occurred with the Treaty of Guadalupe Hidalgo on February 2, 1848; however, the area was not officially organized as a Territory of the United States until September 9, 1850.

According to Federal Law, unsurveyed lands could not be legally entered. There was no land office in Utah until February 17, 1855, and this office was soon closed, remaining so until April 1869. Thus, it was effectively impossible for residents of Utah to "locate," i.e., claim, a piece of land under the General Land Laws of the United States until April 1, 1869, when the General Land Office reopened in Salt Lake City (Sutton 1949a).

Maps accompanying Joseph Gorlinski's (1872-1874) General Land Office survey notes show three ranches in Tintic Valley at that time: Miller's Sheep Ranch at the site of what later became the McIntyre Tintic Ranch; Sabie's Sheep Ranch at the headwaters of Death Creek; and the McIntyre Ranch, located at the site of what later became known as the McIntyre Summer Ranch. Because Tintic Valley was not surveyed until 1874, homesteaders entering lands before that date technically had no legal status. This may explain why efforts to locate records of the Miller and Sabie ranches were unfruitful.

In 1885, of the eleven members of the newly incorporated Utah Cattle and Horse Growers Association, representing fifteen thousand head of cattle, only Samuel and William McIntyre listed Tintic Valley as their range (Grover 1885). Drought and poor grass production in 1886 led William H. McIntyre to move most of his cattle to Southeast Wyoming. That winter, 1886-87, was severe and heavy losses of livestock occurred across the Great Basin (Young and Sparks 1985). William H. McIntyre lost most of his herd (Sutton 1949b). The death of his son, William L., in the Death Creek flood of July 1888 (Steele McIntyre, grandson of Samuel McIntyre Jr., personal communication May, 1996), and the fact that Utah's ranges were becoming depleted by long and heavy use (Stewart 1941), led him to move the bulk of his ranching interests to Alberta in 1894. Cattle, including Black Galloways and Shorthorns, and horses were shipped by rail from Utah, with additional horses trailed overland to begin William H. McIntyre's Alberta herd (Carter 1966). Black Galloways remained the breed of choice for the Samuel McIntyre Investment Company's Tintic Ranch into the 1940's (James Neilsen, Range Foreman, McIntyre Ranch, 1937-1942, personal communication August, 1995).

Livestock numbers

Methods.--In order to derive an estimate of livestock numbers in Tintic Valley over the study period, all available Juab County livestock tax records, spanning the period 1871 to 1981, were reviewed. Livestock numbers were compiled from those reported for the Tintic District and for the towns of Tintic Valley, including Eureka, Silver City, Diamond, and Mammoth. Transient herd numbers recorded for the Tintic District were also included in the estimate of total numbers (figures 3 and 4). Because livestock numbers fluctuate within the year, the point at which herd numbers are reported for tax purposes, relative to the date of sale of stock, may lead to an underestimation of actual numbers of animals on the land (Pickard 1990). On the other hand, the number of livestock reported for Tintic Valley Districts probably reflects a grazing area larger than that of this study. It can only be hoped that the probability of thus overestimating actual numbers of livestock grazing within the study area is balanced by the tendency for tax rolls to underestimate those numbers in the first place.

An additional caveat is appropriate here; transient sheep numbers shown for the Tintic District in the Juab County tax rolls undoubtedly include sheep passing through the regional shearing station at Jericho, some five km south of the area included in this study. While major sheep migration trails historically passed both to the north and south of the study area (Clawson 1950), I have found no evidence of major sheep trails through the study area (Wentworth 1948, Clawson 1950). Thus, while transient sheep numbers taxed in the Tintic District appear high (figure 4), it is unlikely that these numbers reflect a concomitant degree of sheep herbivory on the vegetation of the study area.

This is not to suggest that sheep grazing was not historically a significant ecological factor in the study area, however. The *Eureka Reporter* (April 18, 1929)

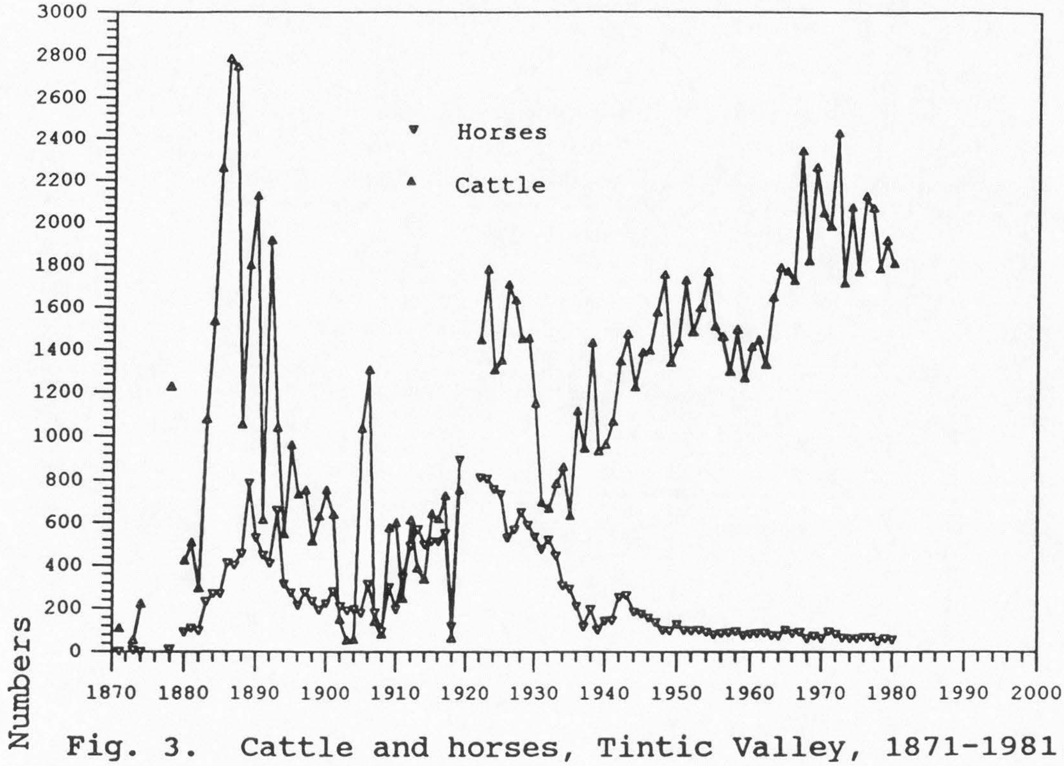


Fig. 3. Cattle and horses, Tintic Valley, 1871-1981.

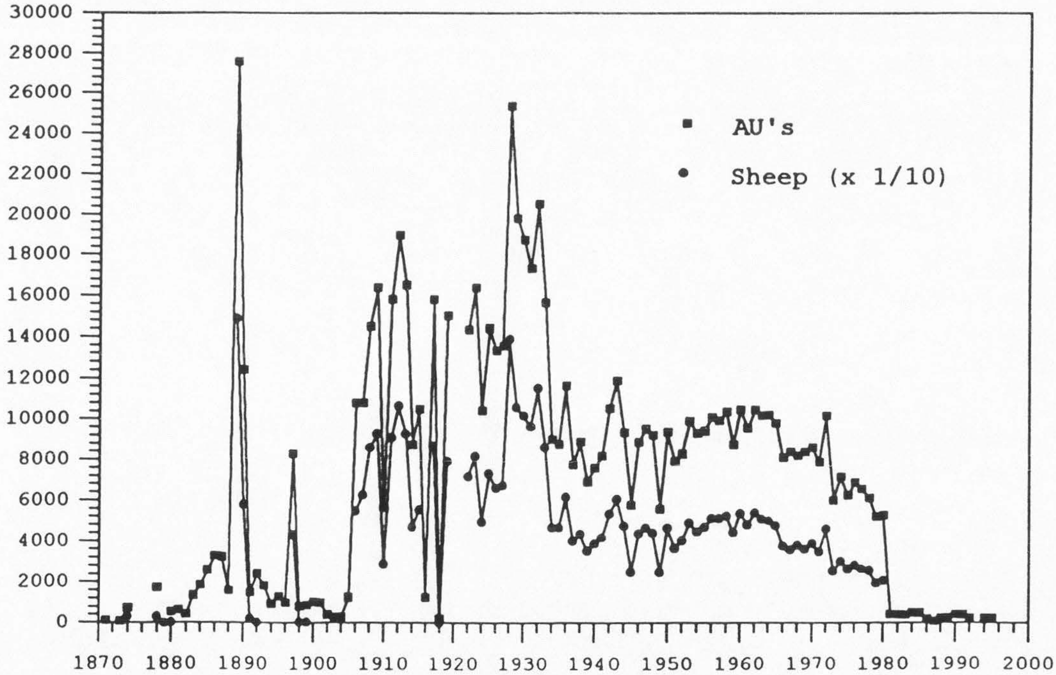


Fig. 4. Animal units and sheep, Tintic Valley, 1871-1995.

noted disparagingly the practice of feeding and bedding sheep on the roadways of Tintic Valley. The dry fall and winter of 1929 led to sheep being herded on the Boulter Summit where water could be brought to them by train (*Eureka Reporter*, December 19, 1929). Thousands of sheep were pastured on the Knight dry farm north of Tintic Junction (*Eureka Reporter*, April 30, 1931), and "several large bunches of sheep" were kept in the mountains surrounding the District, "some of them throughout the year" (*Eureka Reporter*, June 4, 1931). On at least one occasion, when deep snows in the West Desert made forage inaccessible, sheep were trailed eastward through the city of Eureka to winter in Utah Valley (*Eureka Reporter*, February 4, 1932). In the 1950's, use of the Tintic Pastures Allotment included the trailing of eleven bands of sheep on a designated trail along Highway 6. A 1967 entry in the allotment files of the Bureau of Land Management (BLM) mentions a sheep trailing route for use of the permittee of the Boulter Allotment, running from Tintic Junction to Jericho. Trailing was not to exceed 3 days in fall and 3 in spring, and not to exceed one half mile in width (USDI 1995).

Livestock numbers for the 1982-1995 period, not covered by tax records, were derived from individual allotment files of the BLM, Fillmore, Utah. These are expressed as animal units (AU's) only and encompass a smaller area (more strictly comparable to that of the study area) than do the tax records. These records are also incomplete, due to missing records for some allotments for some years. For all these reasons, these data cannot be considered strictly comparable to those derived via tax records. Interpretation of long-term trends in Tintic livestock numbers is thus based primarily upon the longer and more consistent tax record.

Results.--Although obscured by the period of incomplete record from 1871 to 1895, a steep rise in animal units in the early settlement period (1870-1890), particularly well reflected in cattle numbers (figure 3), is followed by a dramatic decline through about 1905. Whether this reflects an actual decline in livestock numbers or a decline in the diligence of the tax collector is uncertain. From about 1905 on, the AU curve (figure 3) rises steeply to a high, fluctuating, but remaining high until a sudden, permanent decline in about 1934, continuing to the present at fluctuating but low, even declining, numbers. While this is the general trend for AU's, sheep, and horses, cattle numbers exhibit an almost perfectly reciprocal trend in the post-1934 period, rising steeply and fairly consistently as other classes of livestock and AU's as a whole decline.

This analysis reveals that while cattle numbers in Tintic's districts have risen steadily since about 1930, AU's, driven primarily by sheep numbers (5 sheep = 1 AU), have gradually declined following a crash in the 1930-34 period. A parallel decline in horse numbers (1 horse = 1.2 AU's), beginning about 1920 and dropping steadily to near current numbers by about 1940, appears to have little effect on the animal unit curve. Horse numbers rose steadily to 1920, following a WWI low precipitated by the sale of a "large number" of McIntyre Ranch horses to buyers for the British and French cavalries (*Eureka Reporter*, September 24, 1916). The apparent post-1920 decline in horse numbers as reflected in the tax rolls may be misleading, however. As early as 1926, reports of large numbers of wild (and thus untaxed) horses to the west of the Tintic District were causing concern among graziers of the area (*Eureka Reporter*, December 3, 1926). Some 500 horses ran wild in the West Tintic Mountains into the 1940's (James Neilsen, personal communication August, 1995. Mr. Neilsen was Ranch Manager for the McIntyre Ranch for the four or five years preceding WWII). These animals do not appear in the tax rolls, and thus do not appear in figure 3.

Livestock impacts discussion

Trends in AU's in Tintic's tax districts revealed by this analysis appear to correspond with historical patterns reported from semiarid and arid regions of South Africa (Dean and Macdonald 1994) and Australia (Friedel et al. 1990). Pickard (1990, p. 252) argued that "a high biomass of grazing animals should indicate a high biomass of feed." His analysis suggests that the increased stock numbers seen on Australia's rangelands since the 1940's indicate an improvement in range conditions. The assumption underlying this conclusion, that livestock numbers are linked directly to available forage, is consistent with results reported from South Africa by Dean and Macdonald (1994). However, Dean and Macdonald (1994) argued that changes in the species composition of plant communities, losses of topsoil to erosion, and degradation of rangeland hydrological conditions have permanently reduced the potential for the rangelands included in their study to support domestic stock. Johnson et al. (1989) have reported similar trends for rangelands in Utah.

Taken in isolation, the rising cattle curve for Tintic, beginning in the mid-

1930's, could be explained under Pickard's (1990) model as an indication of improving range conditions. However, Dean and Macdonald's (1994) intimation of an irreversible state transition following intensive exploitation of forage resources in the early European settlement period in South Africa appears consistent with the precipitous, and apparently permanent decline in AU's on Tintic's rangelands after 1930. That Tintic's rangelands were probably both overgrazed and overstocked by the 1930's is supported by the fact that the Emergency Livestock Purchasing Program of the federal government, from the fall of 1934 to the spring of 1935, resulted in a 15% reduction in cattle in Juab County in 1934, followed by an additional 33% reduction in cattle and 2.5% reduction in sheep in 1935 (Smith 1935).

West (1989) reported a decline of approximately 50% in production of herbage and browse from pinyon-juniper woodlands and sagebrush steppe as condition declines from good to very poor. In 1980, 62% of Utah's pinyon-juniper rangelands were classified as in low or moderately low condition, with 48% of Utah's sagebrush steppe classified as in poor or very poor condition (West 1989). Dean and Macdonald (1994) concluded that primary productivity, rather than market forces and state policy, drives observed trends in livestock numbers in South Africa's Cape Province. Given the temporal coincidence of the precipitous decline in sheep-driven Tintic AU's and the initiation of rangeland reform under the Taylor Grazing Act of 1934, a similar conclusion seems inappropriate for Tintic's rangelands. Indeed, livestock numbers in the region continued to increase through the early 1900's, even as the capacity of the range to support those numbers declined (Astroth and

Frischknecht 1984).

The Taylor Grazing Act of 1934 was itself a response to dramatic degradation of the Western range (USDA Forest Service 1936); its passage was to no small degree a measure of that degradation (Johnson et al. 1989). It is, however, impossible to separate the impacts on livestock numbers of the administrative closure of the open range from the dramatic reduction in forage availability which precipitated that closure. More recent declines in AU's, again driven largely by sheep numbers, probably reflect the general decline in the fortunes of the Western sheep industry, rather than further degradation of forage resources, which are generally acknowledged to have steadily improved since 1934 (Johnson et al. 1989).

Finally, it is interesting to consider the observed dramatic decline in animal units in light of post-WWII efforts to increase forage production on Tintic's rangeland. Seeding of Eurasian perennial grasses, chaining of pinyon-juniper woodlands, brush control via herbicides, mechanical treatment and prescribed fire, and grazing systems designed to improve livestock production were all incorporated into the management of Tintic's ranges in the years following WWII. While these management interventions do not appear to have resulted in an increase in overall livestock numbers in Tintic Valley, they may have played a role in helping to stabilize those numbers.

Agriculture

Dry farming by Euroamericans in Juab County began in 1887, when David B.

Broadhead raised wheat and rye without irrigation at the mouth of Four-Mile Creek Canyon. After the apparently accidental discovery that dry farming of wheat was possible, Broadhead filed a homestead application on 160 acres of land, signing an affidavit that the land would raise crops without water. This statement led to his indictment for perjury by a U.S. grand jury. After his acquittal in February of 1888, he named his farm "Perjury Farm." Wholesale dry farming in the County began on the Levan Ridge after 1897, and in 1903, Dr. John A. Widtsoe and others established the Nephi Dry Land Experimental Station under the auspices of the Extension Division of the Utah State Agricultural College (McCune 1947).

In late May of 1911, J.C. Hogenson of the Utah State Agricultural College held a Farmers Institute in Eureka, at which he reported his impression of the potential for dry farming in Tintic Valley. While he spoke favorably of Tintic's possibilities as a dry farming region, he noted two potential problems: an annual rainfall of less than 10 inches (254 mm) and the 6000-foot (1829 m) elevation of the valley floor. Residents of the area called for development of a demonstration farm in the Valley. The suggestion, which Hogenson promised to take up with the Agricultural College (*Eureka Reporter*, June 2, 1911), was never acted upon.

Dry farming in Tintic Valley had already begun, however. The *Eureka Reporter* of October 6, 1911 notes, "Colin McMurphy, who harvested a good crop from his dry farm, is now engaged in the fall planting of grain." That fall saw the harvest of Tintic's first potato crop, some 2000 bushels harvested from the irrigated farm of Henriod and Foote (*Eureka Reporter*, October 13, 1911), which also produced 500 bushels of oats (*Eureka Reporter*, October 27, 1911). The first thresher ever to operate in the Valley threshed 475 bushels of wheat at the ranch of James Stark, west of Silver City in October of that year (*Eureka Reporter*, October 20, 1911).

On August 9, 1912 (p. 6), the *Reporter* announced that "it is an indisputable fact that dry farming pays, failures being practically unknown as [a] result of scientific tilling of soils." Only with the wisdom of hindsight can the words of Utah's Agricultural College President, John A. Widstoe, be seen as prophesizing doom to hundreds of Utah's aspiring dry farmers:

> We stand before an undiscovered land; through the restless, ascending currents of heated desert air the vision comes and goes. With striving eyes the desert is seen covered with blossoming fields, with churches and homes and schools and, in the distance, with the vision is heard the laughter of happy children. The desert will be conquered....Failures are practically unknown. ...Precipitation and weather conditions have become of minor, if not practically negligible quantities (*Eureka Reporter*, August 9, 1912, p.6).

This proclamation appears opposite a cartoon titled "The Song of the Country," in which fields of wheat, corn, and oats are depicted singing "How Dry I Am." Nevertheless, several large crops of grain were harvested in Tintic Valley in the fall of 1912 (*Eureka Reporter*, October 18, 1912). The following year, a record grain harvest for the region, produced on the Hassell-McIntyre Farm in West Tintic Valley, necessitated widening and repair of the road between that farm and the San Pedro Railway at Boulter Summit (the divide between Juab and Tooele Counties) to permit hauling of harvesting machinery, including a "traction engine and a modern threshing machine" from the train to the farm (*Eureka Reporter*, August 29 and

September 5, 1913). That year's yields from the Hassell-McIntyre Farm prompted the *Reporter* to declare, "The crops of the past few years have shown that dry farming in that locality is now past the experimental stage" (*Eureka Reporter*, October 13, 1913, p. 5).

By the spring of 1914, dry farms near Silver City were anticipating "big returns" (*Eureka Reporter*, May 15, 1914). The Knight Farm, owned and operated by Jesse Knight's Union Grain and Elevator Co. (UG&E), began operations, planting about 450 acres of wheat and 200 acres of barley and oats (*Eureka Reporter*, July 31, 1914). Yields from the Knight Farm that year were about 20 bushels to the acre (*Eureka Reporter*, October 2, 1914). "Large crops were also harvested at the Packard and Wing Ranches to the west of Tintic Junction and the yield on all the other dry farms in the Tintic Valley" for that year were reported as "entirely satisfactory" (*Eureka Reporter*, October 2, 1914, p. 1).

The modest, if nevertheless satisfactory, yields of 1914 were produced in a year described by J.W. Paxman, dry farm specialist of the Utah State Agricultural College, as "exceptional...such as...may not occur again in twenty years." Paxman was more impressed with the potential of the district than he was with the farming methods he observed being practiced there. He warned against annual cropping and failure to cultivate to sufficient depth, while praising Tintic's soils as "well adapted to dry farming...," capable of producing "...a crop with somewhat more careless methods than soils of other districts" (*Eureka Reporter*, November 13, 1914, p. 1).

In the summer of 1914, C.M. Temple, freight agent for the Salt Lake Route, declared, "The Tintic district is becoming known as one of the best dry farming sections of the state...yield(s) average twenty to twenty-five bushels to the acre, and the best farms, those that have been given the best cultivation and care, are running as high as forty-five bushels to the acre" (*Eureka Reporter*, July 10, 1914, p. 1). That this was little more than hucksterism is evident in correspondence between one J.A. Watson and the manager of the UG&E (Knight, n.d.[a]). Watson, having heard the UG&E had harvested 22 bushels per acre from 1500 acres of land in Tintic Valley in 1915, wrote to enquire into the cost of real estate in the area. He received this reply, dated August 21, 1917:

> We have been fairly successful in our operation, making a small profit out of the dry farm. You were evidently misinformed regarding the wheat crop that we raised in 1915. Our 1916 crop was fair, and also this season's. We have had two exceedingly dry summers, having had no rainfall between Spring planting and harvest. Our crop this year will average 15 bushels to the acre (Knight, n.d.[a]).

Such were the actual yields of the "best dry farm land in the state" (*Eureka Reporter*, July 31, 1914, p. 1). Optimism over the District's potential led the UG&E, in 1915, to construct a 50,000-bushel grain elevator (the first of several the UG&E eventually built in Utah and Idaho) on its land in Tintic Valley, adjacent to what was then the San Pedro Railroad (Knight, n.d.[a]); *Eureka Reporter*, August 20, 1915).

In 1916, Bert Blades planted 100 acres of wheat at the mouth of Jenny Lind Canyon (*Eureka Reporter*, November 3, 1916). By the summer of 1917 J.M. McShane declared,

> No better crops were ever seen in this valley than is at hand at this spring and the class is becoming more varied, for this year one can see from the roads

> wheat, both fall and spring seeding, rye, oats, barley, corn, fetereta [sic], alfalfa, and potatoes and all are looking fine and it is hoped that the good and favorable season will continue and allow a good harvest of all crops (*Eureka Reporter*, June 22, 1917, p. 2).

After a winter of heavy snow, in which losses of wheat seedlings to frost on the Knight Farm approached 50% (letter to J.W.Paxman from Manager UG&E., April 24, 1917, Knight, n.d.[b]), the fall of 1917 saw some 35,000 bushels of wheat shipped from Tintic Valley farms. With war-time prices reaching an unprecedented $1.78 to $1.90 per bushel and domestic rationing due to low supplies of wheat, Tintic's farmers prepared to increase their planted acreage in the coming year (*Eureka Reporter*, November 16, 1917).

The war, despite high prices, brought Tintic's era of dry farm boosterism to an end; the Valley's farms began to change hands (*Eureka Reporter*, January 4, 1918). With the suspension of pumping of water from the Centennial Eureka Mine, irrigation of the Henriod Ranch west of Eureka ceased, leading to its sale and conversion to dry farmed crops in 1918 (*Eureka Reporter*, June 7, 1918). Projected yields from about 900 acres of the Knight Farm for that year were 16 or 17 bushels to the acre (*Eureka Reporter*, August 2, 1918). The federal government's war time willingness to buy all available wheat at $2.00 per bushel probably contributed to the acceptance of this amount of production as "very satisfactory" (*Eureka Reporter*, August 2, 1918). By 1920, after losing money for several years (letter from the manager of the UG&E to John Brailsford, Tintic Junction. March 18, 1920, Knight, n.d.[a]), the 2700-acre Knight Farm was for sale (letter from the manager of the

UG&E to J. Brandt, Eureka Feb 24, 1920, Knight, n.d.[a]).

There is little mention of farming in the *Eureka Reporter* after 1919; the 1921 season was declared "disastrous" for the grain farmer (*Eureka Reporter*, November 11, 1921) and in 1925 "the Japanese farm located to the west of Eureka" received a shipment of some 1800 baby chicks (*Eureka Reporter*, April 10, 1925, p. 3). Dry farms in the valley continued to be sold, with the Knight Farm, minus roughly 3 acres of ground including the grain elevator and railroad siding, finally changing hands in 1927 (letter from Vice President of the UG&E to J.W. Paxman, Nephi, May 10, 1927, Knight, n.d.[b]). Upon the sale of the Knight farm, the *Eureka Reporter* published this epitaph to Tintic's dry Farm era: "Some years ago there was a great rush for Tintic Valley dry farm land and many thousands of acres were cleared and planted. Some excellent grain crops were harvested there but...most of the farms have been abandoned..." (*Eureka Reporter*, March 23, 1928).

In 1935, Tintic's grain elevator, empty and still owned by the UG&E, was gutted by fire (letter to Mr. H.A. Crane, Delta, Ut, June 5, 1935, from Leon Newren of the UG&E, Knight, n.d.[a]).

The purchase, in 1928, of the Knight Farm by experienced dry farmers from Nephi appears to have initiated a wholesale buyout of Tintic's dry farms, in many cases through tax sales, by farmers from eastern Juab County (*Eureka Reporter*, July 20; September 27, 1928). Yet the fall of 1929 saw less than 1500 acres of Tintic Valley's dry farm land planted to wheat (*Eureka Reporter* June 12, 1930). In 1933, drought led once again to disastrous conditions for dryland wheat farmers in the

District (*Eureka Reporter*, June 29, 1933), and the first national set-aside program for wheat land was initiated (*Eureka Reporter*, August 17, 1933). Tintic's wheat farmers were paid to fallow 15% of their 1930-1932 land base (Smith 1933). The year 1934 saw "wholesale abandonment of wheat acreage" in Juab County, and a 60% reduction in yields due to drought (Smith 1935).

In March of 1935, at the request of U.S. Agriculture Secretary Henry A. Wallace, a conference of agricultural administrators from the eleven western states was held in Salt Lake City to develop procedures for producing an agricultural adjustment survey of the region. For purposes of the survey, Utah was divided into nine farming areas. Most of Juab County, including Tintic Valley, fell within area IV-B, characterized by seasonal grazing of range cattle and sheep. The survey noted livestock produced in this unit were "...fed during the winter, and as a result there is considerabl(e)... feed and forage produced (and) more supplementary winter feeding of concentrate foods" (than in other grazing units) (UAES 1935, p. 27).

Agricultural adjustments recommended by the survey report included "...elimination of sub-marginal dry land wheat acreages...." The report notes that "...wheat growing has been extended too far into lands which are sub-marginal with respect to soil or rainfall, and...[c]onsiderable abandonment of land in Juab (and other) Counties has already taken place" (UAES 1935, p.26). Between 1935 and 1939, nearly 30,000 acres of private land in Juab County were purchased by the Resettlement Administration under the Land Use Project of the Federal Bankhead Jones Act (Smith 1935, Knight, n.d.[b]). This included some 16,670 acres in Tintic

Valley, as estimated from a modern map of Bankhead Jones Lands (figure 5), but involved the resettlement of not more than five Tintic Valley families (Cannon 1986). In 1936, although the drought had begun to break, an additional 21,521 acres of dryland wheat were removed from production in Juab County, under a 1936-1939 federal contract (Smith 1936).

Fall drought in 1939 delayed wheat sowing and a late spring frost killed 50% of that wheat which had been planted in Juab County. Frost and drought destroyed the crops of over 100 families in the Levan and Nephi areas. Also in that year some 12,000 acres of marginal dry farm lands in Juab County were sown to crested wheatgrass. In 1940 the county agricultural extension agent recommended elimination of marginal lands from cropped areas for raising grain and the planting of these areas to grasses and other forage plants (Smith 1940). Also in 1940, under the Taylor Grazing Act of 1934, the public domain lands within the County were divided into three areas in order to administer regulations pertaining to grazing practices on public lands. The Tintic Unit contained 427,680 acres of public domain on which 245 applicants grazed 8,279 cattle, 221 horses, and 28,191 sheep from November 15 to May 1 (Smith 1940).

In 1942 the East Juab Soil Conservation District was established, encompassing "...all that area of land lying between the County East Boundary, along the Eastern line of Range 3 West to and including Range 5 West, Salt Lake Base Meridian, comprising some 800,000 acres" (Smith 1942, p. 22). Dry farms in the District varied from 40 to over 1000 acres (SCS 1942). After some 30 years of dry

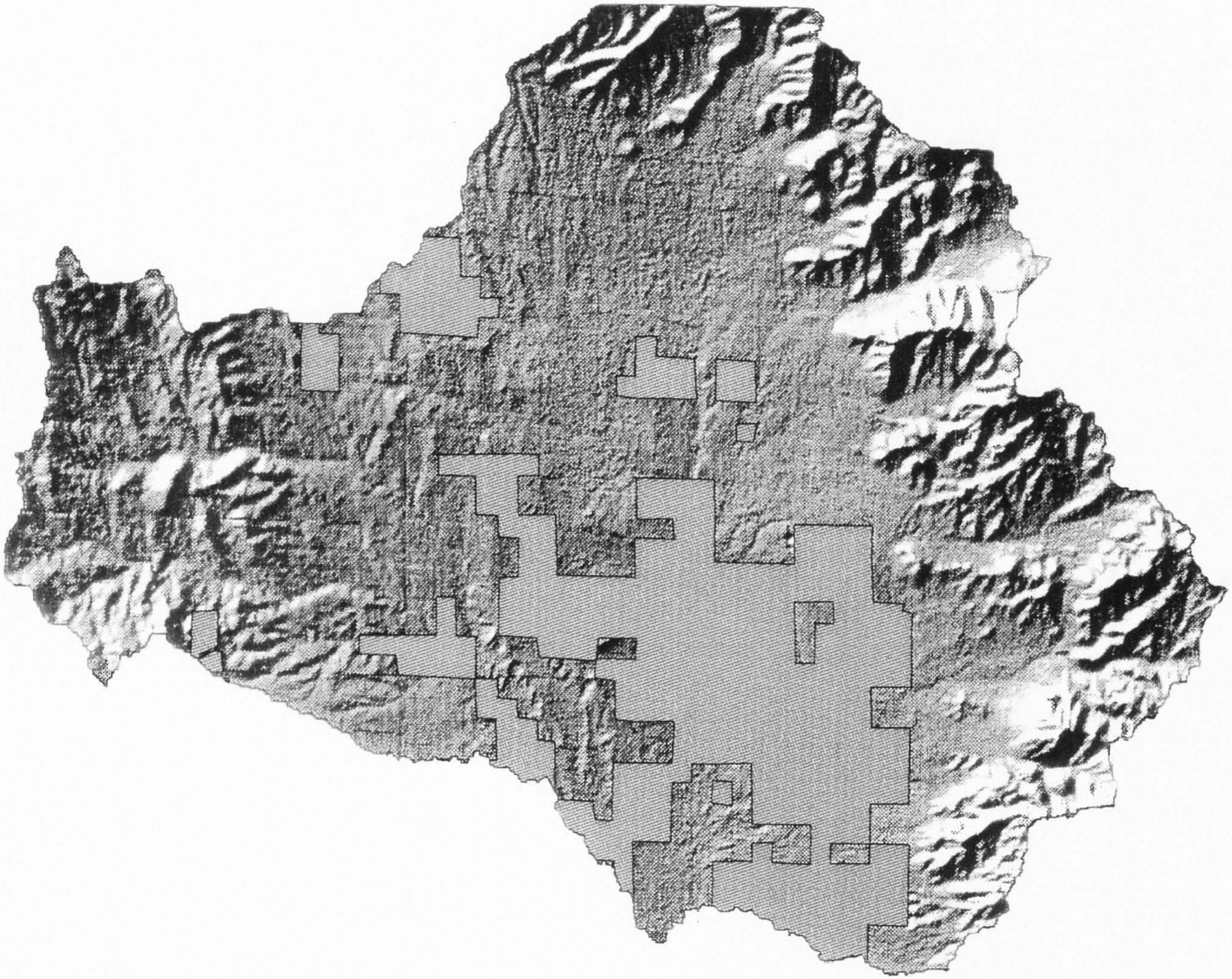


Fig. 5. Study area lands purchased by the Resettlement Administration under the Land Use Project of the Federal Bankhead Jones Act.

farming, the system of alternate years of cropping and fallow was still the most common practice, with few farms practicing any other system of rotation (SCS 1942). One of the most serious problems noted at this time was the presence of rye as a weed in stands of wheat, resulting in degradation of the harvested grain to feed-grade quality. Erosion, though "not conspicuous on dry farms," occurred primarily on fallowed lands. The SCS (1942) noted, "More soil is lost in this way than is generally realized," and recommended "fundamental changes in land use methods."

A 1942 map of the newly formed East Juab Soil Conservation District shows 19 dry farmed areas within the boundaries of this study and irrigated farmlands at the McIntyre Tintic Ranch at the confluence of Tanner and Death Creeks, the pourpoint of the study area drainage basin (figure 6). Considering the wholesale abandonment of dry farms in Tintic Valley in the 1930's, this apparent resurgence was almost certainly a response to the increased demands for wheat created by WW II.

By 1945 there was a growing interest among farmers and livestock producers in reseeding "abandoned farm lands, sagebrush, or similar areas to Crested Wheatgrass or other adapted grasses." This program was considered vital "...to help shift the range carrying load from the public lands to private lands in order to give the public ranges a better chance to rejuvenate and come back to a better carrying capacity..." (Parrish 1944, p. 14). Reports of the Juab County Extension agent in 1946 show fifteen dairy farms in the Tintic District, but these dairies milked a total of only forty-four cows. By 1949 Tintic District dairy cattle had plummeted to nineteen, representing 11 farms. This reflected the increasing availability of grade A milk off

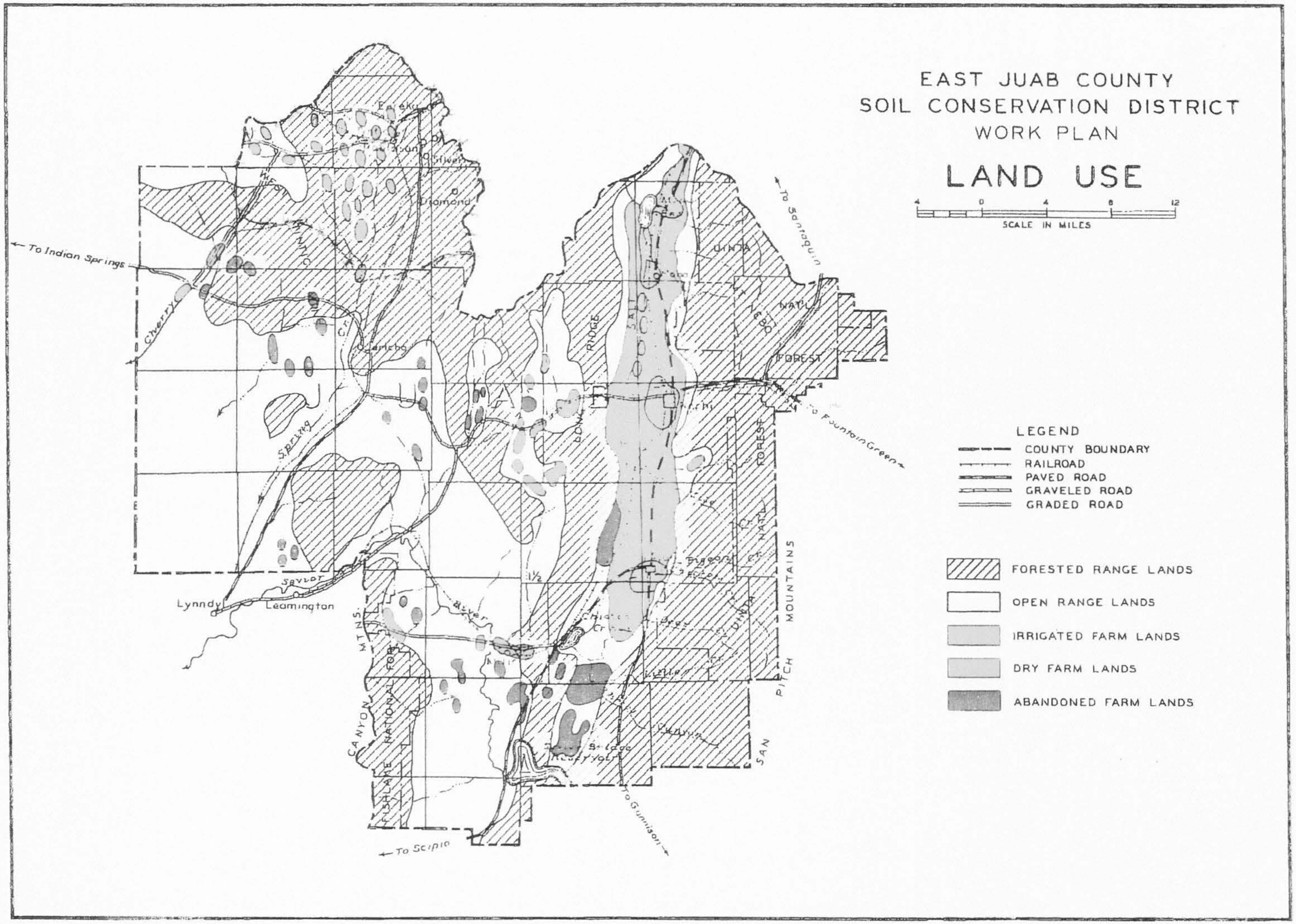


Fig. 6. East Juab County Soil Conservation District, 1942.

the farm, as well as a County-wide reduction in cattle numbers attributed to the unusually hard winter of that year (Parrish 1949). Losses of open range cattle in the winter of 1949 were 10-50%, even where attempts were made to feed stock by dropping hay from airplanes (Steele McIntyre, personal communication 8/95).

In 1946, Juab County farmers were "urged to adopt conservation practices to offset the loss of soil fertility used up in the tremendous production needed for war" (Parrish 1946, p. 12). A growing awareness of "the amount of soil losses ... taking place on Juab's dry land wheat farms from sheet and accelerated erosion" began to emerge with a concomitant call for reseeding of spring and fall ranges and marginal farmlands with perennial grasses (Parrish 1947, p. 20).

In 1949, Utah State Agricultural College began undertaking research on the 3360 acre experimental Tintic Pastures under the direction of C. Wayne Cook "to test methods of establishment and to derive grazing recommendations for the newly introduced wheatgrasses that were then coming into wide use on Intermountain rangelands" (USDI 1995 n.p.). By 1950, soil conservation had taken hold in the dry farm districts of Juab County. Contour plowing and range seeding were common practices, and stubble mulching was being advocated over the practice of burning wheat straw (Burtenshaw 1950).

During 1951 and 1952, under a May 18, 1950 Memorandum of Understanding between the Utah Agricultural Experiment Station and the Branch of Soil and Moisture Conservation Operations of the BLM, CO-UT Region IV, sagebrush on the Tintic Experimental Pastures was eradicated with a wheatland plow, followed by seeding to tall, intermediate, and crested wheatgrass. After 2 years, establishment rates were 6%, 6%, and 4%, respectively. By 1954, the Experimental Pastures were being sprayed with a variety of herbicides, sometimes from the air, to test the efficacy of these materials in brush control (USDI 1995). Some 150 acres of pinyon-juniper woodland on the Pastures were cleared by chaining, with a total of 1,150 acres thus cleared of shrubs and trees and reseeded to Eurasian perennial grasses (USDI 1995). Annual reports for 1959 and 1960 noted that the seedings were being rapidly reoccupied by sagebrush and rabbitbrush (USDI 1995 n.p.).

In 1965, the SCS assigned all of Tintic's dry farmed cropland to Capability Class IV, and recommended that lands in this class be converted to perennial grass cover (SCS 1966). Tintic's dry farming days were officially over. Today, less than 1,000 acres within the study area are dry farmed, and those intermittently (Ken Sevy, USDA NRCS, Nephi, Utah, personal communication, April, 1996). Irrigated alfalfa hay is produced on about 300 acres in the study area, while infestations of squarrous knapweed (*Centaurea virgata*) are becoming common on abandoned dry farm fields.

Agriculture Discussion

Data from dry farm areas of both the United States (Rasmussen et al. 1993) and Australia (Williams 1974) have suggested that the bare fallow, so vehemently advocated by the agricultural experts of the early dry farm era (Paxman 1914), inevitably resulted in declining soil fertility and declining yields (Bracken 1940). Recently published results from long-term studies of dryland wheat cropping systems have suggested that decades of dry farming, as traditionally practiced, have led to a linear decline in soil organic matter (Rasmussen et al. 1993). Further, because of the relatively high levels of microbial biomass in the top 5 cm of the soil, loss of this layer to erosion can be assumed to result in significant degradation of soil ecosystem processes (Bolton et al. 1993).

Paxman's (1920, p.12) description of the process by which sagebrush lands were converted to wheat fields is telling:

> A good plowing consists in having all the ground, to a depth, disturbed and moved in such a way as to change entirely its position and at the same time mix and pulverize it, so that each particle can be rejuvenated by the weathering elements.... Plow deep in the fall. Cultivate this well in the early spring and during the summer. On spring plowed lands follow the plow immediately with the harrow and cultivate frequently during summer....Keep the land free from weeds as these draw out the moisture and fertility.

In retrospect, the declining yields of Tintic's dry farms, from initiation of the practice in the decade of 1910-1920 to the period of farm abandonment in the drought years of the 1930's, can be viewed as an indication of not only the declining condition of Tintic's dry farmed soils, but also of the fundamental unsuitability of traditional dry farming practices for the soils in Tintic Valley upon which they were imposed.

Woodlands

Young and Budy (1979, 1986) and Lanner (1981) have chronicled the denudation of the hills surrounding the mining districts of Nevada, and Christensen and Hutchinson (1965) noted the extensive use of "cedar" in Tooele Valley for fuel, fenceposts, and charcoal, the latter fuel employed in the rendering of salt from the

Great Salt Lake. Bahre (1991) noted the general lack of recognition of the degree to which the woodlands of the semiarid west were impacted by the demand for biomass fuels in the mining districts of the region at the close of the nineteenth century. A review of historical records pertaining to mining activities in the Great Basin in general, and to the Tintic mining district in particular, revealed the following references to Tintic Valley woodlands:

"Of wood there is an almost unlimited supply, for the mountains and low foot-hills and large tracts of the valleys west of the district are heavily timbered" (Murphy 1872, p. 34).

"The only fuel used at present by the lead smelters of the Great Basin is charcoal, the price of which ranges from 15 to 34 cents per bushel of 1.59 cu. ft, according to locality. The lowest rates are paid at the American Fork and Tintic districts, Utah, where timber is abundant..." (Hahn et al. 1873, p. 111).

"The Mammoth copper claim is a remarkable deposit of ore in limestone, cropping out upon the western slope of a hill facing the broad and well-wooded valley of Tintic" (Raymond 1873b, p. 317).

"Both East and West Tintic districts are reached by Concord stage-coaches from the [Salt Lake] city, and they have the great advantages of accessibility, with plenty of wood and water" (Raymond 1873b, p. 316).

"This district is favored with an abundance of wood and water" (Packard 1873, p. 2).

S.F. Elton (n.d.), interviewed in the 1960's, recalled his first trip into Tintic

Valley and his disembarkation from the train at Ironton, sometime between 1878 and 1882: "I stepped off the train on to a little platform down in the cedars" (Elton, p. 14). This phrase, "down in the cedars," appears elsewhere in the memoirs of old-time Tintic Valley residents of Mammoth and Silver City (Toone n.d.).

Because an abundance of wood for fuel purposes was a desirable feature for any mining district in the era, a degree of boosterism undoubtedly colored some of the early descriptions of the Valley. Packard (1873), for example, a principal in the Eureka Mining Company, made his comments in a letter to stockholders. Raymond (1873a, 1873b), on the other hand, was the U.S. Commissioner of Mining Statistics, whose detailed reports on the mines of the district appear to be completely reliable. Overall, these descriptions convey an image of a Tintic Valley landscape in the early 1870's well covered with woodland.

Historical impacts on Tintic Valley woodlands

Intensive harvesting of trees within and around Tintic Valley began not later than 1870, and was associated with both early ranching activities and the first decade or so of mineral exploitation in the Tintic Mining District (Raymond 1873a, Gorlinski 1872-1874). The era of intensive woodland exploitation continued at least into the early 1880's. A second period of less intensive woodland exploitation occurred during the early 1930's, when high levels of mine unemployment led to organized removal of woodlands for their economic value as firewood, charcoal, and fenceposts (*Eureka Reporter* 1930-1931, Harris 1961).

Biomass fuels in the Tintic mining district.--Firewood and charcoal were the principal, and probably the only, fuels employed in Tintic Valley's mills and smelters beginning as early as 1870 and continuing at least through 1878 when the Utah Southern Railroad extended the first line into the Valley from Lehi, via Boulter Pass, to a terminus at Ironton (Heikes 1919). Gorlinski's (1872-1874) GLO survey notes contain several references to wood roads, charcoal makers cabins, and charcoal pits, while a Diamond City miner's journal from 1871 reveals the use of Tintic woodlands as a source of mine timbers for the smaller mines, as well as an important source of fuel for both domestic and ore processing needs (McKinney 1871).

Wood fuels were used not only for smelting, but also for driving the steam engines which drove the stamp mills (Raymond 1871), in the preprocessing of refractory ores and in the making of brick for furnace construction (Ward 1872). While biomass fuels may have been employed to power Tintic's narrow gauge railroads, no reference to the fuels employed by these engines was found. Raymond (1873a, p. 361) noted:

> Of the 311,996 bushels of charcoal used (in Utah in 1872)..., 85,000 to 90,000, (about 29%) made from nut pine or "pinon," was of good quality, though not equal to coal [sic] from hardwood such as maple, hickory, etc. The remainder was from red and white pine, cedar, and quaking asp, which, however well burned, cannot make a good or even fair fuel.... A pit of 100 cords of green wood...yields from 2500 to 3500 bushels of charcoal.

This illustrates not only the intensive harvesting of woodland for fuel at that time, but also suggests that pinyon was selectively harvested for charcoal making purposes.

The variety of both ores and processing techniques employed in this era of largely new and experimental ore reducing technology meant a wide range of fuel needs, depending upon the nature of the ores and the processing facilities involved. Quantities of fuel consumed per ton of ore processed were thus highly variable. Raymond (1873b) reported a range of 26-42 bushels of charcoal consumed per ton of ore processed, with an average ratio of 33 bushels of charcoal for each ton of ore.

Tintic's refractory, lower quality ores often required preprocessing via roasting or calcining, with approximately one cord of wood required for each 0.5-0.8 ton of ore so processed. The roasting and calcining processes themselves were highly variable in their fuel consumption, one cord serving to roast between 30 and 40 tons of ore, or for calcining three to four and a half tons of tailings (Raymond 1873).

Matte.--Early ore shipments from Tintic often consisted of matte, a high grade material produced through partial reduction of ores by the relatively crude facilities of the District (Raymond 1872, Heikes 1919). Under favorable conditions, roughly 12 cords of wood were consumed in reducing 8-10 tons of ore to one ton of matte, and this did not include fuel consumed in the roasting and calcining processes. Finished matte was shipped relatively cheaply as ballast to smelters as far away as Swansea, Wales (Raymond 1871).

To produce the matte, hand-broken ores were roasted in heaps, prior to crushing, to "expel a portion of the sulphur and partially oxidize the metals" (Raymond 1871, p. 369). The process of roasting is illustrated in figure 7 (Smith 1988b) and described in some detail in Raymond (1871, p. 369):

Fig. 7. Roasting ore at "Shawntie" (Smith 1988b).

> A single heap usually contains some thirty or forty tons of ore, and requires five or six weeks for the operation. A bed of cord wood, about sixteen feet square, is laid as the base, the first course, of thick billets, being laid directly on the ground, the billets parallel, but a little apart, to permit the passage of air, and the overlying courses being laid crosswise and more closely, forming a bed 5 or 6 inches in height and requiring altogether about a cord of wood for each heap. A wooden chimney, 9 or 10 inches square, is set vertically in the center, passing down through the bed of fuel and reaching above the top of the heap. A small quantity of charcoal is put at the bottom of this box-flue, and the heap is ignited, when ready, by setting fire to the coal. The ore is piled upon this foundation, around the chimney, the larger pieces being placed inside, and the whole covered on the outside with a layer of fine stuff, so disposed as to control the rate of combustion. If this is too slow in any part, the covering can be opened to give greater draught; if too rapid the covering is made closer. The only attention required during roasting is directed to the rate of combustion.

Ores, mills, and smelters, 1870-1882.--Harris (1961) reported over 30 mills and smelters were built in Tintic Valley between 1871 and 1908, and noted that smelters, mills and kilns could be seen all around the Valley. To derive an estimate of the ore processing capability, and thus the fuelwood consumption, of Tintic Valley's metallurgical industry during the biomass-fuel era, historical documents were reviewed for reference to Tintic ore processing facilities. Table 1 summarizes this information. Because most of these operations were short-lived and commonly changed ownership, name, and sometimes location, one or more times, opportunities for confusion are abundant (Smith 1988a). Every effort has been made to cross-reference names of facilities, locations, processing capacities, and dates of operation.

Early Tintic Valley mills and smelters ranged in ore processing capacity from 10 to 30 tons per day (table 1) (Raymond 1873a, Heikes 1919). This is consistent with the reported average daily reducing capacity of 16 tons of ore for all Utah

Table 1. Tintic Valley mills and smelters, 1870-1882.

Date	Location	Name	Capacity
1870	McIntyre Ranch?	Tintic Mills/Shoebridge	Mill
6/17/1871	Homansville	Clarkson (Wightman and Co.?)	Furnace
6/1871	Diamond City	Jones and Schofield	Furnace
1871	Diamond City?	Tintic Mills/McIntyre Bros.	15 Stamp Mill, furnace, smelter
1872	Tintic	Mammoth-Copperopolis	?
1872	Homansville	Lawrence, Richards & Co.	Steam mill, 14 tons/day
1872	Eureka	Abby, Drake & Co.	Steam mill, 12 tons/day
1872	Homansville	Homansville Mill?	12 stamp steam, 12-25 tons/day
1873	Tanner's Ranch	California?	stamp mill
1873	Eureka	Eureka Silver Mining Co. mill	12 stamp steam, 25-30 tons/day
1873	Homansville	Utah Smelting & Milling Co.	2 furnaces
1873	Diamond City	Tintic Smelting Co.	2 furnaces
1873	Tintic	Crismon-Mammoth	?
1873	Homansville	Wyoming Mill	10-24 stamp, steam, 10 tons/day
1873-1878	Homansville	Wyoming Silver Mining Co.	Stetefeldt Furnace, 30 tons/day
1873	Mammoth Gulch	Mammoth mill/Ferrell mill	?
1873	Tintic Mills	Shoebridge 15 stamp mill	Aiken furnace. mill:10 tons/day
1873	Homansville	Utah Silver Mining & Smelting Co.	2 furnaces?
1873	Diamond	Tintic Mining & Milling Co. Miller mill	wet crushing
1873	Roseville	Mammoth-Copperopolis Mill	steam,22.5 tons/day
1873	Roseville	Mammoth-Copperopolis Smelter	2, 12 ton/day furnaces
1874	Tintic Mills	Shoebridge 15 stamp mill?	Aiken roaster. mill, 10tons/day?
1874	Homansville	Wyoming Silver Mining Co.	Stetefeldt Furnace, 30 tons/day?
1874	Blk.Dragon Ho.	Germania Co.	independent furnace
1874	?	Jackson and Roslin	independent furnace
1874	Homansville	Utah Silver Mining & Smelting Co.	2 furnaces?
1874	?	Richmond, Buel & Bateman	independent furnace
1875	Homansville	Wyoming mill	10 stamp, steam
1875	Homansville	Wyoming smelter	Stetefeldt furnace
1875	Tintic Mills?	Shoebridge mill	15 stamp,Aiken furnace
1875	Diamond	Tintic Mining & Milling Co., or Miller's	10 stamp mill, wet process
1875	Roseville	Copperopolis mill	10 stamp
1876	Roseville	Copperopolis mill	10 + 12 stamp
1878	Tintic Mills?	Shoebridge/Ely mill	15 stamp,Aiken furnace?
1879	Roseville	Copperopolis mill	10+12+5+10= 27 stamp
1879	Roseville	Copperopolis smelter	White & Howell furnace
1880	Roseville	Copperopolis mill	wet crushing
1880	Roseville	Copperopolis smelter	chlorodizing furnace
1880	Homansville	Wyoming (reopened)	10 stamp?
1881	McIntyre Ranch	Mammoth Mining Co.	smelter
1882	Roseville?	Crismon-Mammoth	2 matting furnaces

smelters in the early mining era (Murphy 1872). Specified processing capacities of early mining era mills and smelters had little relationship to the actual quantity of ore processed, however. Few of these facilities were successful, few operated for more than a year, and few operated without at least intermittent shut-downs (Heikes 1919).

Early rates of ore production in the Tintic District were modest, but quickly increased (Butler et al. 1920). In the month of July 1870, Tintic produced approximately 30 tons of ore (Raymond 1871). A year later one of the first smelters in the District, the Clarkson at Homansville, produced several hundred tons of silver lead bullion (Heikes 1919). With lead averaging 13.5% in Tintic's ores (Butler et al.1920), this level of production reflects several thousand tons of ore processed by this smelter alone at a time when at least two other reducing facilities were operating in the District (table 1). Between April 29, 1876 and June 1877, the Wyoming Mill alone crushed 1,907 tons of ore from the Crismon-Mammoth mine (Butler et al. 1920) and at least four other mills and smelters were operating in the District at the same time (table 1). Even with a growing number of ore-reducing facilities, however, matte and higher quality ores continued to be shipped out of the District for final processing (Raymond 1873b), reflecting the inefficiency of Tintic's ore-processing facilities.

By 1884, the earliest year for which annual figures for Tintic District ore production are documented, production had "increased to 48,914 tons, of which 22,943 tons was shipped to smelters" out of the District (Heikes 1919). Assuming less than half of Tintic's ores were being shipped out of the district for processing prior to 1884, and that much of this was matte or ores that had already been processed to some degree in Tintic's mills and smelters, a conservative estimate of ores processed within the district in its early years is one half the total produced.

Using Butler et al.'s (1920) figures for total pounds of copper produced for the 1869-1880 period (3,179,628 pounds) and the average percentage of copper in the ore (0.6%), we can derive a minimum ore production of some 265,000 tons for the period 1869-1880 (3,179,628 x 100/0.6/2000 = 264,969). If we assume that somewhat less than half of this ore was shipped for processing out of the District, we derive a conservative estimate of 132,500 tons of ore processed by Tintic Valley mills and smelters for the 1869-1880 period (table 2).

This figure is almost certainly a conservative one, as it is derived from Butler et al.'s (1920) figures for copper only. The estimate of 265,000 tons of copper bearing ores for the 1869-1880 period yields an average annual production for the decade of 26,500 tons. That this estimate is a reasonable one is supported by the fact that in 1884, the first year for which ore tonnage figures are available (Butler et al. 1920), 49,000 tons of ore were produced in the Tintic district, with a reported average annual production of 45,490 tons for the 1886-1892 period (Butler et al. 1920).

At the rate of 16 tons per day (Murphy 1872), three smelters could have easily processed the 132,000 tons of ore estimated to have been handled within the Tintic District between 1870 and 1880 (132,000 tons/10 years/365 days per year/16 tons per day per smelter = 2.3 smelters). In fact, 20 or more mills and smelters operated in

Table 2. Estimated tons of ore processed in Tintic Valley, 1869-1880.

Item	Quantity
Copper produced	1590 tons*
% Copper in ore	0.6%*
Total copper ores	1590/0.006 = 265,000 tons
% of ores shipped	50%#
Total ores processed	132,500 tons (estimated)

* Butler et al. 1920.
# Heikes 1919.

Tintic Valley between 1870 and 1882 (Harris 1965, table 1). While some of these may have been the same mill or smelter operating under a different name or at a different location (Heikes 1919, Smith 1988) and probably none of them operated full time, it was clearly well within the combined capacity of Tintic Valley reduction works to have processed 132,500 tons of ore over the 1871-1880 decade. Indeed, the sheer number of these facilities suggests that the ore estimate used in this analysis may be excessively conservative. If, for example, we assume an average of only four plants operating full time for 10 years at a daily average capacity of 16 tons per day, 233,000 tons of ore could have been processed, nearly twice that estimated.

Industrial use of biomass fuels, 1870-1880.--The era of biomass fuels may have begun to come to an end with the extension of the Utah Southern Railroad into Tintic Valley to its terminus at Ironton in 1878 (Heikes 1919), potentially rendering coal an economically viable fuel for Tintic Valley ore processors. However, the transition to coal and coke as fuels probably occurred over a period of several years, as old reduction works were gradually abandoned (Emmons and Becker 1885). In order to derive an estimate of the total quantity of cordwood employed in the processing of Tintic Valley ores in the era of biomass fuels, it was assumed that wood or charcoal were the only fuels used in Tintic Valley mills and smelters between 1870 and 1880.

Roughly 12 cords of wood or 33 bushels of charcoal were required to process 10 tons of ore under favorable conditions (Raymond 1873a). Thus, one cord of wood or its charcoal equivalent was used as a minimum estimate of fuel consumed per ton of ore processed. Assuming 132,500 tons of ore processed within the District between 1870 and 1880 (table 2), an extremely conservative estimate of cordwood consumed in the processing of Tintic's ores, whether directly or after conversion to charcoal, is 132,500 cords. This figure is both conservative with respect to ore processing and ignores use of wood fuels for brick making, industrial purposes other than ore processing, consumption of biomass fuels for domestic purposes (discussed below), and the preprocessing of ores by small, independent operators. This latter component of the fuel consumption equation may have been significant, as charcoal production and roasting of ores may have been an integral part of general mining life for small Tintic operators (McKinney 1871). Murphy (1872, p. 35) noted that in addition to the bigger mines of the District, "...there are seven hundred other locations made within its limits." By 1880, this number had risen to 3000, and while not more than 500 of these locations were claimed, at least 100 had been developed to some extent (Emmons and Becker 1885).

Finally, a comparison of this estimate of Tintic Valley's industrial fuelwood consumption with that of another important mining district, Nevada's Comstock, helps to place it in context and further supports the view that the estimate is a conservative one. Young and Budy (1986) reported 120,000 cords of fuelwood used in that district in 1866 alone. In 1880, smelters and mills of Eureka, Nevada consumed 1.25 million bushels of charcoal, representing some 38,000 cords of wood (Young and Budy 1986). As Comstock area woodland resources were exhausted, more than 150,000 cords were transported into the district from the eastern Sierra Nevada via the Carson River every flood season (Young and Budy 1986). Charcoal for some Utah smelters was similarly transported from the eastern Sierra (Raymond 1871).

In light of the reported inefficiency of many early mining era reduction works, much more fuel may have been consumed than suggested by ore/fuel ratios specified in mining reports. Appalled by the ignorance of the region's smelter operators and by the low quality and waste involved in production of their product, Raymond (1873b, p. 302) noted, "For my part I am more and more thoroughly convinced that the men to whom the United States is virtually giving away its mineral lands are not the proper persons to regulate the tenure of their titles."

Domestic fuel use, 1871-1940.--In order to estimate the historic impact of domestic fuelwood harvest on Tintic's woodlands, a highly conservative fuelwood consumption rate of one cord per person per year was assumed (Bahre 1991, Hadley and Sheridan 1995). It was also assumed that wood was the principal domestic fuel from 1870 to 1940.

Human population figures were obtained from U.S. Census data (USDI 1880, 1890, 1900, USDC 1910, 1920, 1930, 1940, 1950, 1960, 1970, 1980, 1990), supplemented with data from other sources as noted. Table 3 summarizes population data for Tintic Valley from 1871 to 1990.

The earliest human population estimate found for Tintic Valley is that presented by Harris (1961) for 1871. In that year, the precincts of Eureka, Silver City, and Diamond were created. The tenth U.S. census of 1880, the first census to list population by precincts, shows a population of 550 for Tintic Precinct only. The apparent decline in the population of the Valley between 1871 and 1880 certainly reflects a lack of data rather than an actual decline in population for the period. By 1890, Tintic Precinct held 2,354 people, which included Eureka's population of 1733 and Mammoth's 286.

The Census of 1900 reports Diamond Precinct held 264 people, Eureka Precinct held 3325, Mammoth Precinct held 1585 and Silver City Precinct 918. "It is interesting to note that by this time the precincts in the Tintic District had become the most populous in Juab County as a result of the great mining activity there in the preceding decade. Eureka City had become the largest in the county, with a population of 3,085..." (McCune 1947, p. 43).

By 1910, Diamond City Precinct had been annexed by Silver City, which nevertheless showed a decline to almost half its 1900 population. Total Tintic area population for that year was 6,209 (USDC, 1910). By 1920, Eureka Precinct held 3,908, Mammoth 1125 and Silver City 689. Eureka City had 3,608, its highest recorded population, which has declined, along with that of the Tintic District

Table 3. Tintic Valley human population 1871-1990.

Year	Population
1871	900*
1880	550*
1890	2354
1900	6092
1910	6206
1920	7522
1930	4244
1940	2969
1950	1573
1960	879
1970	884
1980	670
1990	613

* incomplete data

generally, since that time. By 1930, the population of Eureka Precinct had declined to 3,216, Mammoth to 750 and Silver City to 278. Eureka City remained the largest city in the county, with 3,041 people. By 1940, Eureka City's population dropped to 2,292, and Nephi became the largest city in the County for the first time since 1890. Eureka precinct held 2,366, Mammoth 492, Silver City 111. After the 1940 census, Silver City Precinct was annexed to that of Mammoth (USDC 1950). In 1950, Eureka Precinct held 1389 people and Mammoth 184. By 1960, only Eureka appears in the U.S. census tables, with 879 people. The Eureka census division showed a slight increase in 1970 to 884 people, declining to 670 in 1980. The 1990 census reports 613 people for Eureka.

By assuming consumption of one cord of fuelwood per person per year (Bahre

1991, Hadley and Sheridan 1995), annual domestic fuelwood use for the years of each decade was estimated as the mean of adjacent decadal population values. These annual values were multiplied by 10 to derive decadal values for fuelwood consumption. Decadal values for the 1871-1940 period were then summed to derive an estimate of total domestic fuelwood use for that period of 281,025 cords (table 4). The 1880 census figure of 550 for Tintic Precinct was replaced for cordwood estimation purposes with 1550 with the view that this probably more accurately reflects the actual population of the Valley for that period.

Fences.--Young and Budy (1979, 1986) have suggested that harvest of Nevada's pinyon-juniper woodlands for domestic fuel, corrals, and other non-mine uses may have rivalled that for ore processing. Field observation in Tintic Valley revealed that juniper was the species of choice for posts in older fences and for ties for the narrow gauge mining railways of the District. Juniper was also used for timbers for the smaller mines (McKinney 1871). While wire fences alone demanded about 260 posts per mile (Young and Budy 1979, 1986), perhaps the most intensive use of woodlands for fencing purposes found expression in the impenetrable "bull fence," or "ripgut fence." Virtually a solid wall of juniper poles, bull fences

Table 4. Estimated Tintic Valley domestic cordwood consumption by decade, 1870-1930, inclusive.

Factor	Time period						
Decade	1870	1880	1890	1900	1910	1920	1930
Cords	12,250*	19,520*	42,230	61,490	59,640	49,830	36,060

* incomplete data

employed a free-standing tripodal design. Cut by hand and hauled into place by teams of men and horses, they were both labor and resource intensive (figure 8).

Field observation in the western section of the study area revealed that the use of bull fencing by the McIntyre Ranch alone was extensive. Steele McIntyre (personal communication August, 1995) stated that not only were all boundaries of the McIntyre ranch fenced in this manner, but cross fencing of the ranch was also done this way, by a crew of "100 men for a dollar a day." This was supported by field observations, although cross-fence remnants generally were found to consist of a few meters of fence only. Most of this fence remained intact into the 1960's, when firewood merchants were given permission to remove it (Steele McIntyre personal communication August 1995).

To derive an estimate of the number of trees cut for fencing purposes in Tintic Valley, perimeters of the Samuel McIntyre Investment Company's Summer Ranch (18 miles, 29 km) and Tintic Ranch (7.25 miles, 11.7 km) (USDI 1936) were measured on USGS 7.5 minute topographical maps. A total perimeter fence length of 25.25 miles (40.65 km) was thus derived.

Measurements of several sections of bull fence encountered in the field resulted in an estimate of 39 large stems per 10 m section, or 3900 stems per km. This produced an estimate of 158,500 stems used in fencing the perimeter of the McIntyre property alone. Given the multi-stemmed form common to *J. osteosperma*, this figure almost certainly does not reflect individual trees. On the other hand, an estimate derived from a photograph of a bull fence at the Homansville Mill (figure 8)

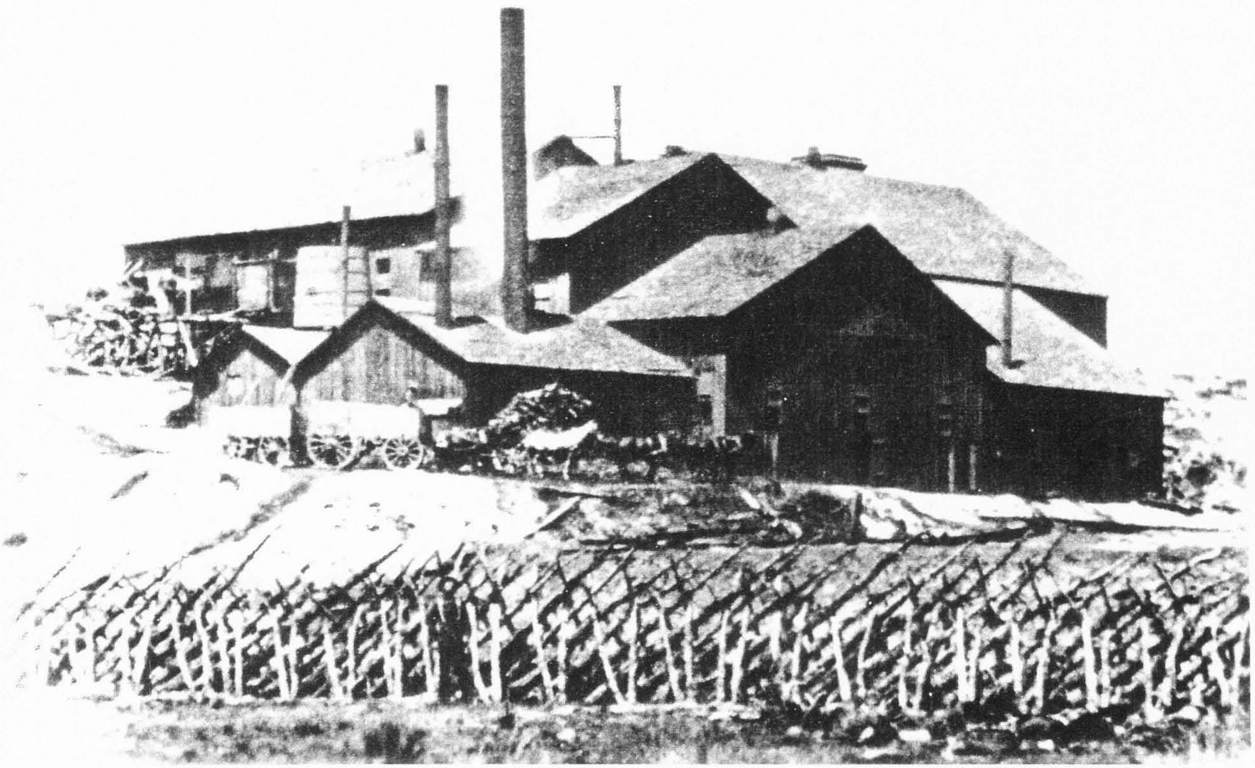


Fig. 8. Bull fence, Homansville Mill, 1870's (Seamons 1992).

yielded an estimate of 77 stems per 10 m section, twice the field estimate. Further, the figure of 158,500 stems does not include cross fencing with bull fence, use of posts for wire fences erected elsewhere in the Valley, or other uses, such as mine timbers or as ties for narrow gauge railways associated with the District's mines. Consequently, I have used 158,500 as a rough, if perhaps excessively conservative, estimate of the number of trees harvested for non-fuel uses in the Tintic area in the early ranching era.

Tintic Valley woodland harvest, 1870-1900

Two approaches were taken to derive a final estimate of woodland area harvested in and around Tintic Valley in the early settlement era. Area harvested for fuel was derived from domestic and industrial fuel use, as estimated above, and published figures for cordwood production from pinyon-juniper woodlands (Young and Budy 1979, 1986). To estimate the area of woodland harvested for non-fuel uses, the estimated number of trees harvested for bull fence construction on the perimeter of the McIntyre Tintic and Summer Ranches was compared with woodland tree densities estimated from witness tree data (Gorlinski 1874) using a modified point centered quarter (PCQ) approach (Cottam and Curtis 1956, Bonham 1989).

Fuelwood harvest, 1870-1900.--Young and Budy (1979) reported yields of cordwood from pinyon-juniper woodlands ranging from less than 1 cord per acre to 12 cords per acre and that 10 to 100 acres of woodland were cut to charge one charcoal pit. Smelting 1 ton of ore required 25-35 bushels of charcoal, representing about 1 cord of wood. With 132,500 tons of ore estimated to have been processed in Tintic Valley between 1870 and 1880, somewhere between 4,469 and 53,620 ha (11,042-132,500 acres) of woodland must have been harvested in and around Tintic Valley for milling and smelting purposes alone in the decade 1870-1880.

Similarly, domestic consumption of 74,000 cords of wood between 1870 and 1900 (table 4) suggests a harvest of between 2,496 ha and 29,947 ha (6,167-74,000 acres) of woodland.

Density methods.--Land Office surveyors commonly employed trees as markers of section and quarter-section corners, recording distances and compass bearings from the surveyed points to the "witness" trees. To derive an estimate of hectares of Tintic woodland harvested for non-fuel uses in the early settlement era, tree densities were estimated using witness tree data compiled from Gorlinski's (1872-1874) General Land Office survey notes (Cottam 1949, Bourdo 1956, Stearns 1974). A total of 82 section or quarter sections corners in the 1874 surveyors log included witness tree information. Twelve of these points involved 4 trees, 37 included 2 trees only, 30 noted 1 tree only and 3 entries included 3 trees. Because estimation of tree density using the PCQ method requires 4 trees at each sample point (Cottam and Curtis 1956), it could not be used without sacrificing most of the available data. Lamacraft et al. (1983) and Bonham (1989) present a generalized formula for density determination based on the PCQ method which allowed all of the data to be utilized:

$$m=\frac{n-1}{\pi\sum_{j=1}^{n} r_j^2}$$

where: m = mean density;
n = number of randomly located points;
and r = individual distances to the nearest plant from the random point.

Dispersion.--The correct application of distance measures requires a determination of the pattern of dispersion (spatial distribution) of the sampled population (Ludwig and Reynolds 1988). The PCQ method assumes a random dispersion of individuals and the generalized formula presented employed here is known to underestimate density where species distributions are clumped (Lamacraft et al. 1983). In order to determine the dispersion pattern of Tintic Valley witness trees noted in the original General Land Office Survey (Gorlinski 1872-1874), a single distance for each witness tree location was randomly selected. These distances were then used in the calculation of a distance index of dispersion (I), where the expected value of I is approximately 2 for a random pattern, less than 2 for a uniform pattern, and greater than 2 for clumped patterns (Ludwig and Reynolds 1988).

Ludwig and Reynolds (1988) note that where dispersion pattern is determined using only point-to-individual distances, as was the case in this analysis, no distinction between single scattered individuals and individuals on the edges of dense clumps can be made. However, in the case of witness tree data, the assumption that recorded distances reflect distances from the section corner to individual trees seems a reasonable one. This analysis revealed that witness trees selected by Gorlinski in the

Tintic Valley woodlands of 1874 exhibited a strongly clumped distribution (I = 5.08), $p < 0.0001$, suggesting that the density estimates presented below are low.

Results of PCQ density estimation.--On the assumption that the variation in number of witness trees noted was a function of available trees, rather than the whim of the surveyor, the witness tree data were first analyzed as four separate groups, based upon the number of distances recorded at each sample point (1-4). Four density estimates were thus derived. These were 13, 28, 32 and 149 trees, respectively, per ha. Pooling these values resulted in a mean tree density of 56 trees/ha. The four density values may represent the densities of distinct woodland and savanna (scattered trees within a grassland and/or shrubland matrix) communities. For the purposes of this analysis, however, what was wanted was a mean value for trees/ha. For this purpose, pooling of the data seems appropriate.

To check the density derived using Pollard's (Bonham 1989) generalized PCQ formula, the closest individual method, requiring only one point-to-individual distance, was used to derive a second estimate of density (Bonham 1989). This resulted in a density estimate of 48 trees/ha. As both approaches are known to under-estimate density when the distribution of the population of interest is clumped, the higher value (56 trees/ha) was assumed to more accurately represent actual mean tree densities in that area of Tintic Valley where trees were present in 1874.

Gorlinski's witness tree data included trees ranging in diameter from 5 to 36 inches. Where on the stem these measurements were taken is not reported. Consequently, the densities derived above, while representing a wide range of size classes of trees, do not include trees that would be considered seedlings or saplings. This suggests an additional degree of underestimation of total tree densities resulting from use of the witness tree data in the PCQ analysis. It is important to emphasize that the clumped dispersion pattern reported here reflects tree distribution across the landscape, rather than tree dispersion within stands. Thus these results do not necessarily contradict those of Welden et al. (1990), who found medium and large trees to exhibit a random or uniform distribution within pinyon-juniper woodland stands in Colorado.

With 158,500 trees estimated to have been cut for non-fuel uses in Tintic Valley between 1870 and 1900, and a mean woodland density of 56 trees per hectare, roughly 2,830 hectares of woodland were estimated to have been cleared for non-fuel purposes in the early settlement era. Given the biases of the density estimation method employed here, this estimate is probably high. On the other hand, the estimated number of trees cut is probably low, since it includes only those trees used for fencing the McIntyre Ranch. The figure of 2,830 hectares harvested for non-fuel uses is thus considered a reasonable one.

By combining woodland area harvested for industrial and domestic fuel uses with that harvested for non-fuel uses, total woodland harvest for the 1870-1900 period is estimated to have been between 9,795 and 86,397 hectares (table 5). These figures undoubtedly represent harvest of woodland area both within and beyond the study area. It is impossible, therefore, to conclude with any certainty how much of the study area was directly impacted by woodland harvest activities between 1870 and

Table 5. Total woodland harvest, Tintic Valley, 1870-1900.

Use	Area
Industrial fuels	4,469-53,620 ha
Domestic fuels	2,496-29,947 ha
Other uses	2,830 ha
Total	9,795-86,397 ha

1900. Barber and Josephson (1987), using historical records, estimated pinyon juniper woodland usage in East Central Nevada ranged from 7% to 40%, by area, between 1865 and 1890. Assuming the minimum estimated woodland harvest of 9,795 hectares was derived entirely from the 15,693 hectares of woodland and savanna occurring in the 29,061 hectare study area in 1874, as much as 63% of the study area's woodland may have been removed in the early historic era.

Woodland impacts discussion

Results of this analysis lend support to Young and Budy's (1986) observation that historic Great Basin pinyon-juniper woodland harvest for domestic fuel and timber needs, including corrals and fenceposts, may have exceeded that associated with mining activities. These results also suggest that Barber and Josephson's (1987) maximum estimate of 40% removal for Great Basin woodlands in the historic era may be low. This analysis also suggests that the degree of historic woodland removal in the study area may have exceeded by several times the 13% reduction between 1874 and 1943 suggested by the analysis presented in Chapter V (table 10). Recognizing the probability that the 1874 density of Tintic's woodlands has been underestimated here, it is possible that 63% of Tintic Valley's trees could have been removed while eliminating only 13% of its woodlands. Additionally, however, these results probably reflect recovery of the woodland component of the Tintic landscape in the 1874-1940 period.

Historical Fires

Clark (1989, p. 17) has noted that the assumption of "environmental stationarity .... implicit to calculations of disturbance frequency from observations of relative area disturbed..." is only valid when disturbance intervals and the probability of disturbance not change over time. Under the assumption of relative environmental stationarity in the pre-Euroamerican Tintic landscape, the frequency of fires in Tintic Valley's mixed steppe-woodland landscape prior to the historical period may be inferred from the vegetation patterns of the early historical period (Brown et al. 1994).

Fire is a natural agent of disturbance in shrub-steppe and estimates of natural return frequency for pre-Euroamerican fires in the type vary from 15 to 110 years, with longer frequencies generally associated with more xeric communities (Shinn 1980, Anderson and Inouye 1988, Whisenant 1989, Young 1989, Miller and Wigand 1994). Burkhardt and Tisdale (1976) suggested a fire interval of 30-40 would be sufficient to maintain a shrubsteppe free of incursion by woodland, and found actual fire intervals in the type to be closer to eleven years. Shorter fire intervals would be necessary in order to maintain grasslands free of shrubs (Arno and Gruell 1983).

Ungrazed, open pinyon-juniper woodlands commonly carry sufficient herbaceous vegetation to provide fuels to sustain a surface fire, while moderately dense woodland stands are unlikely to burn due to the reduction of surface fuels resulting from competition with trees for limited water and nutrients in these systems (Jameson 1987, Gottfried et al. 1995). This suggests that pre-livestock frequency of surface fires in open woodlands may have been similar to that of grassland or shrubsteppe systems. Tree establishment under such conditions would have been confined to "fire proof" sites, the density of which would have determined the degree of woodland closure. As understory production decreases with increasing woodland stand age (Tausch et al. 1981, West 1984, Jameson 1987, West and Van Pelt 1987), surface fire frequency within woodlands would also tend to decrease with time, permitting increased tree density and, ultimately, canopy closure. At this point a crown fire, leading to stand renewal, would become increasingly probable (Bradley et al. 1992). Gottfried et al. (1995) have reported stand-replacing fire intervals in pinyon-juniper woodlands of 200 to 300 years or more.

Using Tintic's 1874 vegetation mosaic (table 8, Chapter V) as an indicator of pre-Euroamerican fire frequency (Brown et al. 1994), and assuming a 10- to 20-year fire return interval for both steppe and savanna and a 200- to 400-year return interval for woodland and dense woodland, estimates of area burned in Tintic Valley on an annual basis in the pre-Euroamerican settlement era were derived.

Steppe and savanna vegetation represent a total of 49.5% of Tintic's 1874 landscape. Assuming a fire return interval of 10-20 years, on average, between 5%

and 10% of Tintic's shrub-steppe burned annually, representing between 718 and 1437 hectares. Woodland totaled 37.5% of the Valley in 1874. With a fire return interval of 200-400 years, somewhere between 0.5% and 0.25%, or 27 to 55 hectares of this component of the landscape burned, on average, each year. About 13% of the study area is not included in this estimate due to the lack of 1874 data for that component of the landscape.

Such estimates of average annual area burned are at best suggestive with respect to Tintic Valley's pre-Euroamerican fire regime. They offer, however, a basis of comparison with the limited historical record of fires in the Valley from 1912 to 1976, contained in the written fire reports of the Mammoth City and Juab County Volunteer Fire Departments, and the much more detailed Interagency Fire Center record of 1981-1994.

Tintic Valley fires, 1912-1976.--Although newspaper references to structural fires within the towns of Tintic Valley are numerous, few rangeland fires seem to have attracted the attention of the region's reporters. Excerpts from the limited newspaper accounts of Tintic rangeland fires are presented below in chronological order:

Bridge on Tintic Junction Road Was Destroyed by Fire.--The bridge on the wagon road leading to Tintic Junction was destroyed by fire on Thursday, the blaze having been started by sparks from a passing freight train (*Eureka Reporter*, July 30, 1915, p. 3).

Grass Fires Do Damage In The Hills of Tintic.--During the past week a number of grass fires have been burning in the Tintic hills, resulting in considerable damage. On Wednesday a fire swept over the hills to the east of the Tintic Standard mine, leaving that section entirely devoid of brush and other vegetation. Thursday afternoon a blaze performed like work in the vicinity of Silver City and destroyed the buildings of the Silver City Water Co., also damaging the three large water tanks. The tanks, being filled with water, were not destroyed, but they were badly damaged. This system supplies the people of Silver City with water, which comes from the large springs in the extreme south end of the district (*Eureka Reporter*, July 8, 1921, p. 2).

Big Brush Fire Sunday Damages Tintic Dry Farm.--Considerable damage was done in dry land farms in Tintic Valley last Sunday when a brush fire swept over several thousand acres of land and burned in its path a large portion of the Knight dry farm, west of Eureka, which this year is being operated by Vet Whiting. The fire started in the foothills in the north end of Valley and traveled toward Eureka for a distance of about five miles. The wind then changed and drove the flames west with the Knight farm houses and barns directly in their path. Mr. Whiting, sencing [sic] the danger, had plowed several furrows about a mile distant from the ranch in an effort to divert the blaze away from his place, but the fire jumped the plowed section and advanced steadily until about two hundred yards from the buildings when the wind again changed and the flames moved on toward the north. Mr. Whiting had turned out all his stock, which included more than two hundred pigs, and was himself leaving after gathering up a few household belongings when the wind turned the fire away from his place. Mr. Whiting states that his losses were not very great in view of the fact that most of the grain had been harvested, but it is understood that valuable farm machinery, which had been left standing out in the field, was destroyed. Several miles of fence was also burned (*Eureka Reporter* August 27, 1926, p. 3).

Of the 174 records of fires between 1912 and 1976 compiled from early newspaper accounts and the Fire Reports of the Mammoth City Fire Department (later the Juab County Fire Department), 115 were structural. The remaining 59 fires involved rangeland vegetation or, occasionally, dry farm stubble. All nonstructural fires were considered rangeland fires for purposes of this analysis.

Only four rangeland fires were reported prior to 1940, suggesting either that such fires were rare between 1912 and 1940 or, more probably, such fires were considered unworthy of either reporting or suppression. After 1940, with the rise of the era of fire suppression and the depression era decline of Tintic's urban population (table 3), rangeland fires appear to have become increasingly important. No records of fires were found for the period prior to 1912 (with the exception of a single mention of a structural fire in Diamond in the *Deseret Evening News* of March 28, 1900), and there are no Mammoth or Juab County fire reports for 1933, 1934, 1936, 1938, 1956, 1958-1962, 1964-1971, and 1973-1975. By 1950, recordkeeping by the Juab County Fire Department apparently had become a haphazard affair. Thus estimates of area of the Valley burned in the 64-year period derived from the historical record are necessarily conservative. It does seem likely, however, that for those years for which records were kept, larger rangeland fires particularly would have been noted in the Fire Record book. These appear to have been few. Only nine are reported to have been 40 acres or more, with an additional five estimated to have been at least this large based upon descriptive information included in the fire report.

The 59 rangeland fires reported for the 1912-1976 period represent a total of approximately 2900 hectares burned, averaging some 123 hectares per fire or 45 hectares per year. Only four of the reported rangeland fires involved trees, the rest burning in grass, brush, or grain stubble.

Tintic Valley fires, 1981-1994.--Fire records obtained from the National Interagency Fire Center (NIFC), Boise, Idaho, contain 149 records of rangeland fires within and near the study area from 1981 through 1994. This suggests that the 59 fires of record between 1912 and 1976 do indeed reflect gross under reporting of range fires for that period. Of the 149 fires 1981-1994, 109 had lightning as their ignition source. Of these, 78 burned 0.2 ha (0.5 acres) or less. If the 1981-1994 trend reflects that of the earlier period, lightning-initiated fires would have been the most common fire type, while at the same time probably the least likely to be reported. Because the 1981-1994 fires were subject to suppression efforts, it is not known how large these fires would have become without suppression. It thus cannot be assumed that the 52% of 1981-1994 fires that were both ignited by lightning and burned 0.2 ha or less reflects earlier fire dynamics in the area.

A total of 7736.75 ha (19,117.5 acres) burned in the 1981-1994 period. Mean fire size for the 1981-1994 period was 46.70 ha (128 acres), with a range of 0-2832.86 ha (0-7000 acres). Thirty-one fires occurred in woodland vegetation, with 118 occurring in non-woodland vegetation. Total woodland area burned was 6168.35 ha (15,242 acres). In other words, although only about 21% of the fires involved woodland area, these fires represented nearly 80% of the total area burned, including the largest fire (1986 Hose Lay Fire). Mean woodland fire size was 198.98 ha (491.68 acres), roughly four times that of the overall mean. Total non-woodland area burned was 1568.39 ha (3875.5 acres). Mean non-woodland fire size was 13.29 ha (32.84 acres), with a range of 0-471.47 ha (0-1165 acres).

Discussion: Fire dynamics over time

Given the incomplete record, it is not possible to compare figures for the period 1912-1976 with estimates of average fire size derived from the 1874 vegetation mosaic or the 1981-1994 record with a known degree of confidence. It is interesting to note, however, that the reported average annual fire size (45 ha) for steppe vegetation in the 1912-1976 period appears to fall within the range of average annual fire size for woodland vegetation derived from the 1874 vegetation mosaic. Assuming edaphic obstacles to woodland establishment to be minimal (Gottfried et al. 1995, Sherel Goodrich, Ashley National Forest, Vernal, Utah, personal communication, October, 1995), this suggests a fire regime which would, if maintained over time, permit the establishment of woodland vegetation across the entire Tintic landscape. Table 6 summarizes apparent trends in fire size in the two vegetation types in the study area over time.

Mean annual fire size for steppe vegetation in the 1981-1994 period (13 ha) is nearly two orders of magnitude lower than the estimated range of 1874 steppe fire size, and is about half the size of the estimated minimum 1874 woodland fire. Mean woodland fire size for the 1981-1994 period, however, is four times or more greater than that estimated for 1874. This apparent trend toward increasing fire size in woodland vegetation over time is consistent with results suggesting increasing canopy closure in Tintic's woodlands (Chapter V) and with trends reported for east central Nevada by Barber and Josephson (1987).

Overall, results appear to reflect effective fire suppression efforts in steppe vegetation leading to decreased fire size in this vegetation type, with gradually increasing fire size in woodland vegetation as more difficult to suppress crown fires become increasingly probable with increasing canopy closure. These data suggest that fire dynamics in Tintic Valley have changed over time and that such change is ongoing.

Table 6. Mean annual area burned (ha).

Location	1874	1912-76	1981-94
Steppe	1077	45	13
Woodland	41	ND	199

The assumption of environmental stationarity (Clark 1989) is clearly inappropriate across a threshold of cultural change in which effective fire suppression has become increasingly the norm, and in the face of change in the landscape vegetation mosaic and concomitant changes in fire behavior. Thus, the mean annual fire sizes derived here, and their associated implicit fire intervals must be understood as reflecting conditions at points in time only. The 1874 data, for example, are suggestive of possible fire return intervals in the pre-Euroamerican settlement era, but the assumptions inherent in the derivation of those intervals must be clearly recognized.

The fire reports consulted for this analysis constitute both a partial record of fire occurrence in Tintic Valley from 1912 to 1994 and, more completely, a record of fire suppression efforts during that period. Given the high percentage of lightning ignitions involved in Tintic's recent (1981-1994) fires and the large range in size of suppressed lightning fires, it is reasonable to conclude that suppression activities have led to a significant change in the fire dynamics, and thus the vegetation mosaic, of Tintic Valley (Baker 1993). This change in Tintic's vegetation mosaic in turn can be seen as acting as a positive feedback in the changing fire dynamics of the study area.

Conclusion

From the record of historical impacts compiled here, it is evident that significant change in the Tintic landscape has occurred in the historical period as a direct function of human use of that landscape. Through intensive anthropogenic manipulation, patterns of the Tintic landscape have been altered. Evidence of changing patterns of fire behavior suggest that landscape processes too have changed and will continue to do so via a process of positive feedbacks between fire behavior and vegetation dynamics. The number and magnitude of disturbances reflected in this analysis, in aggregate, suggest catastrophic disturbance of the Tintic landscape in the historic era.

CHAPTER V

CHANGE IN THE TINTIC VALLEY VEGETATION MOSAIC

1874-1995

Introduction

Implicit in the preparation of an ecological history is the understanding that landscapes are dynamic in structure, function, and spatial pattern over time (Dunn et al. 1991, Tausch et al. 1993). Change in the configuration of landscape elements (in both space and time) can be attributed to a combination of environmental and anthropogenic factors. Landscape dynamics may be dominated by natural disturbance processes, such as hurricanes, wildfire or flood, or by land use practices, which in turn may be governed by social, political and economic forces. Where non-anthropogenic and anthropogenic forces interact, complex patterns of change result (Hamburg and Sanford 1986, Bull 1991).

A large body of ecological and historical literature suggests that significant vegetation change has occurred across landscapes throughout the Great Basin since Euroamerican settlement (Christensen 1963, Christensen and Hutchinson 1965, Cottam 1976, Eddleman 1987, Longland and Young 1995). Invasion of large areas of bunchgrass vegetation by shrubs and trees, for example, has been widely documented (Blackburn and Tueller 1970, Tausch et al. 1981, Young and Evans 1981, West 1984, Miller and Wigand 1994). This chapter explores vegetation change for the upper Tintic Valley from 1874 to 1995.

Vegetation Change

Change in the landscape vegetation mosaic

Methods.--A problem inherent in the analysis of long-term ecological change is the different spatial and informational resolution of data derived through varying techniques over time. Characterization of landscape change demands a classification system that can be applied over the entire period of interest. In order to facilitate comparison of vegetation data compiled from descriptive language in the 1874 General Land Office (GLO) surveyor's log with data derived from historical (1943) and recent (1993) aerial photography, vegetation data from these three sources were subjected to similar analyses. Vegetation cover and physiognomic data of comparable informational and spatial resolution were thus derived for three points in time, spanning a total of 119 years.

1874 GLO Field Notes.--The field notes of the original GLO survey of the study area (Gorlinski 1872-1874) were reviewed for information pertaining to vegetation. Mylar overlays were placed over the cadastral survey grid on modern (1976) orthophotoquads of the study area, and each section line was divided into quarter-mile increments. Each point resulting from this division was assigned a vegetation physiognomic type, based on the 1874 GLO surveyors log (figure 9). Examples of descriptive language in the log include: "dense cedars;" " good bunchgrass;" "shrubs with scattered cedars;" etc.

In order to develop a two-dimensional representation of the Tintic Valley

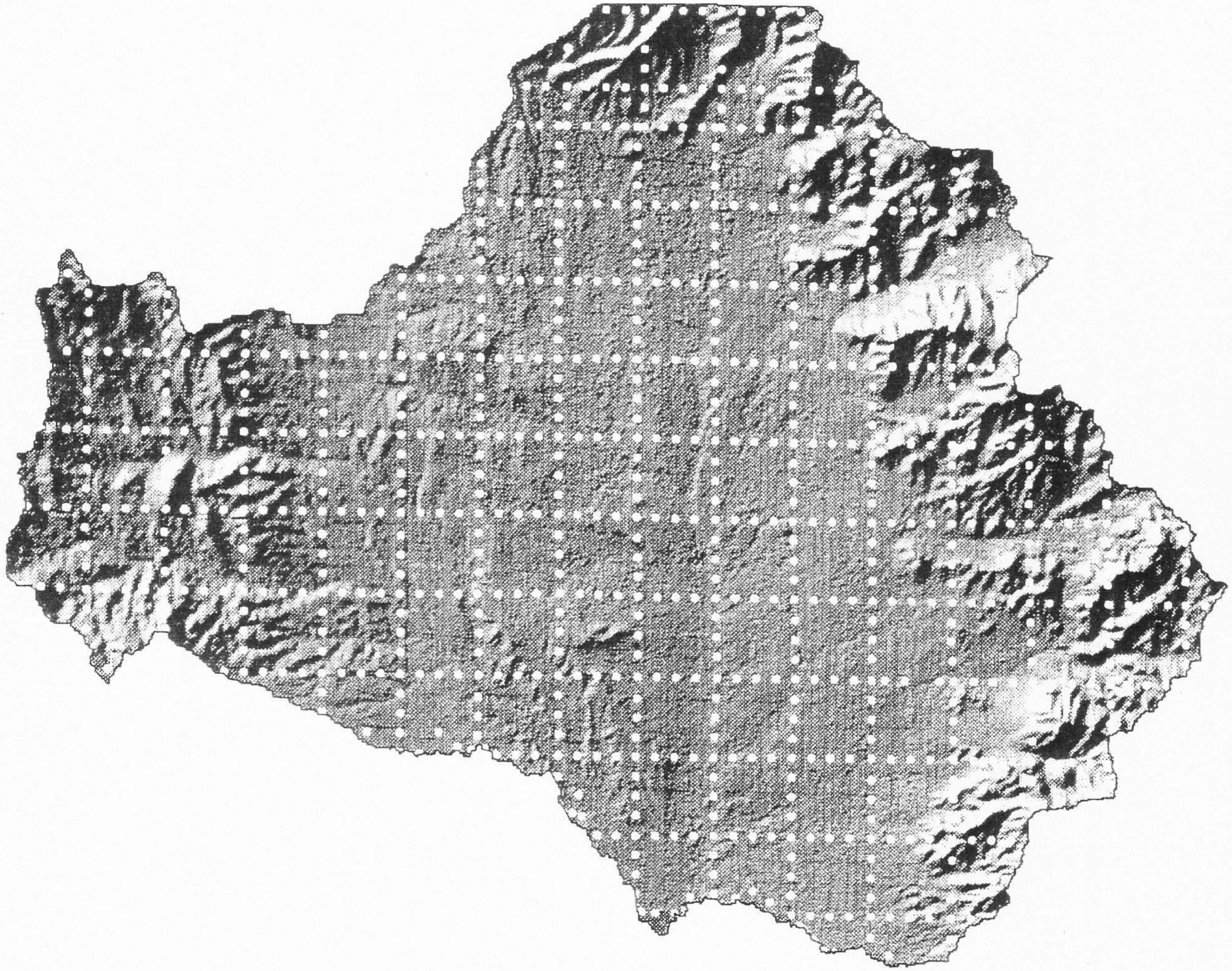


Fig. 9. Vegetation sample grid.

landscape vegetation mosaic, the vegetation value at each sample point was treated as the center point of a quarter-mile segment of section line, with the vegetation value of the point assumed to represent the dominant vegetation physiognomic type in both directions along the entire quarter-mile segment (table 7).

Aerial photography interpretation.--The cadastral survey grid was manually transferred to mylar overlays on 1943 aerial photography (1:24,000 nominal scale) and 1993 aerial photography (1:40:000 nominal scale) of the study area. A Bausch and Lomb Zoom Transfer Stereoscope facilitated the accurate placement of section corners on the aerial photos (Bahre 1991). As with the 1874 GLO survey data, vegetation physiognomic data from the aerial photographs were transferred to mylar overlays of the cadastral survey grid on modern orthophotoquads of the study area. Vegetation data for all three periods were subsequently assigned to points and their associated quarter-mile segments on acadastral survey coverage of the study area within an ARC/INFO GIS database (ESRI 1991). The completed coverage constituted the cadastral survey grid, with approximately 800 associated data points, each point

Table 7. Key to vegetation classes.

Class	Physiognomic Type
1)	Herbaceous vegetation.
2)	Shrubby vegetation, with or without herbaceous understory.
3)	Open savanna; herbaceous and/or shrubby vegetation with scattered trees.
4)	Open woodland, with herbaceous and/or shrubby vegetation.
5)	Woodland or closed woodland.
6)	Mines, urban or other non-vegetated.
nd)	No data.

attributed with vegetation physiognomic values for each of the three temporal periods (figure 9).

Examination of the aerial photographs and GLO survey notes resulted in the subjective derivation of 27 and 35 vegetation classes, respectively. Prior to data analysis, classes were reduced to six by grouping vegetation by the largest physiognomic class present on a sample site (table 7).

Landscape analysis of vegetation change.--The vegetation coverages for the three temporal periods within the ARC/INFO GIS data base were converted from point to polygon coverages using the "THIESSEN" command within ARC/INFO (ESRI 1991). Each polygon was defined by that region of the coverage closer to each single point than to any other point. Each polygon was thus assigned the vegetation class value of the data point from which it was formed. Adjacent polygons with the same vegetation type label were merged into a single, larger polygon. This resulted in fewer, larger polygons of each vegetation class (figure 10).

The three thiessen polygon coverages were then compared, by vegetation class, for total number of polygons and total polygon area. Results were tabulated. Points assigned a "no data" value included 106 points in 1874 and 13 points in 1943 and 1993. All comparisons between years involved the same number of no data values. Thus, for comparisons with 1874, the 106 "no data" points were similarly assigned a "no data" value for 1943 and 1993 (table 8), while the comparison between 1943 and 1993 data involved only 13 "no data" values (table 9). Table 10 shows the relative proportions of the five physiognomic types for the three temporal periods.

Fig. 10. Thiessen polygon figures showing Tintic Valley landscape mosaic for three temporal periods.

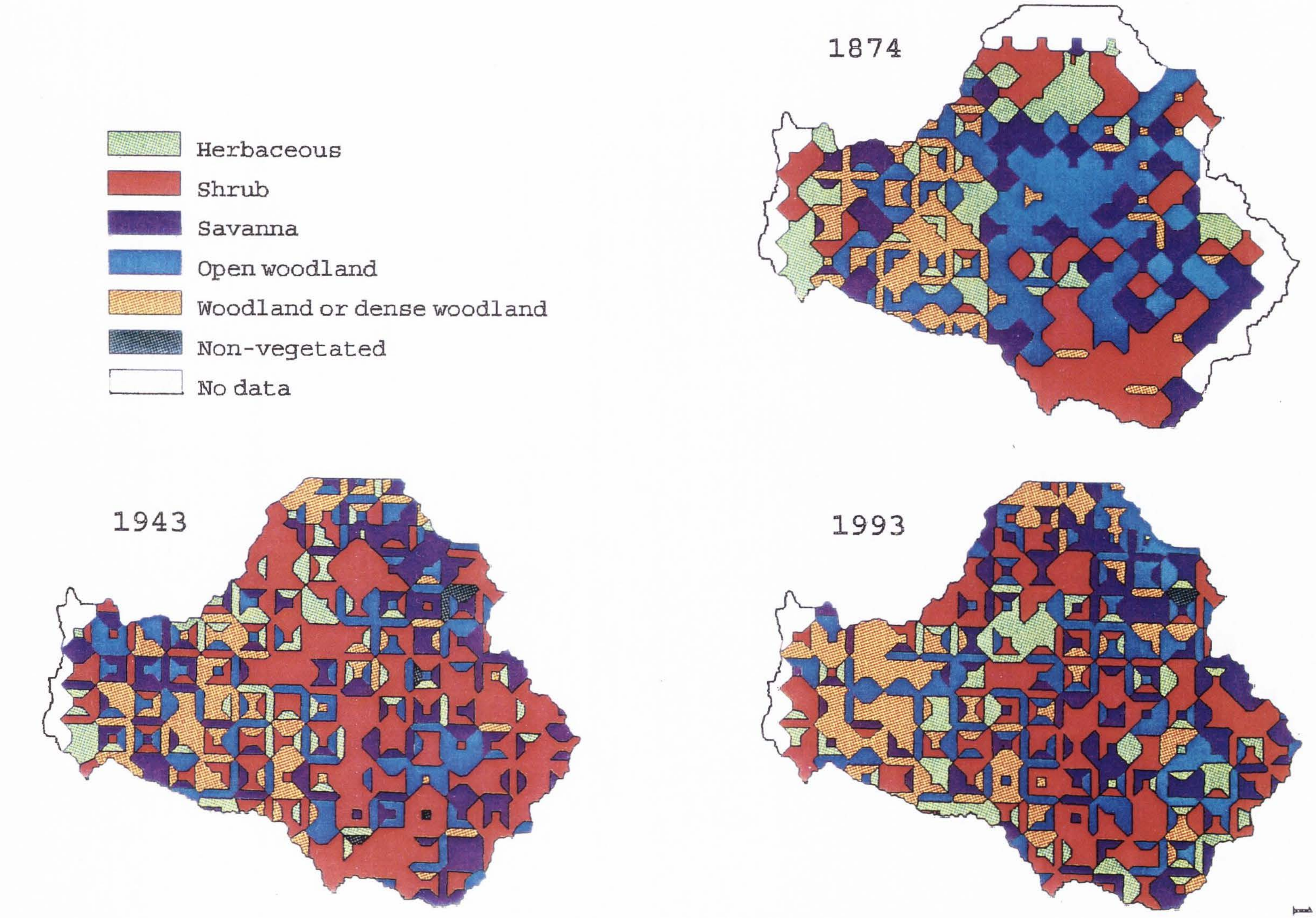

Herbaceous
Shrub
Savanna
Open woodland
Woodland or dense woodland
Non-vegetated
No data
1874
1943
1993

Table 8. Number of polygons and total polygon area for each of six vegetation classes, 1874, 1943, and 1993 (nd = 106/807).

Veg Class	1993			1943			1874		
	#	Area (ha)	Area (%)	#	Area (ha)	Area (%)	#	Area (ha)	Area (%)
1	36	2902	10.0	40	2211	7.6	24	3396	11.7
2	41	8347	28.7	43	10770	37.1	18	6179	21.3
3	64	4476	15.4	55	4601	15.8	31	4790	16.5
4	50	5153	17.7	51	4347	15.0	30	7468	25.7
5	31	4307	14.8	32	3051	10.5	24	3441	11.8
6	1	89	0.3	6	294	1.0	0	0	0
nd	4	3787	13.0	4	3787	13.0	4	3787	13.0
Total	227	29061	99.9	231	29061	100	131	29061	100

Table 9. Number of polygons and total polygon area for each of six vegetation classes, 1943 and 1993 (nd = 13/784).

	1993			1943		
Veg Class	#	Area (ha)	Area (%)	#	Area (ha)	Area (%)
1	38	3180	10.9	44	2423	8.3
2	36	9062	31.2	42	12092	41.6
3	65	5388	18.5	57	5464	18.8
4	55	5884	20.2	57	4619	15.9
5	30	4842	16.7	35	3619	12.5
6	1	89	0.3	4	229	0.8
nd	2	617	2.1	2	617	2.1
Total	227	29062	99.9	241	29062	100

Table 10. Proportions of the five vegetation classes for three temporal periods.

Year	Herbaceous	Shrub	Savanna	Woodland	Dense Woodland	Total
1874	.135	.256	.196	.275	.137	0.999
1943	.094	.433	.191	.155	.127	1.000
1993	.116	.323	.199	.188	.174	1.000

Landscape vegetation mosaic results

Change in landscape vegetation mosaic, 1874-1943.--Tabulated data (table 8) reveal that between 1874 and 1943 herbaceous-dominated landscape area of Tintic Valley declined by about 4%, shrub-dominated area increased by about 16% and savanna declined by less than 1%. Open woodland area declined by almost 11%, and closed woodland decreased by slightly more than 1%, for a total decline in woodland area of about 12% from 1874 to 1943. Between 1874 and 1943, total polygon numbers increased 76% (table 11). That is, fewer, larger polygons were replaced over time by an increased number of smaller polygons. This in turn suggests significant fragmentation of the Tintic Valley landscape mosaic across this temporal interval.

Change in landscape vegetation mosaic, 1943-1993.--From 1943 to 1993, herbaceous-dominated landscape area increased by 2.6%, while shrub-dominated area decreased by over 10% (table 9). Savanna declined, although by only 0.3%, while open and closed woodland each increased by over 4%, for an overall increase in

Table 11. Change in polygon frequency over time (nd = 106/807).

Year	Frequency	% Change
1874	131	--
1943	231	+76%
1993	227	-5.8%

woodland area of 8.5%. Nonvegetated areas declined, apparently as a function of the depopulation and abandonment of Tintic Valley towns during the sample interval. Vegetation polygon numbers decreased 5.8% from 1943 to 1993 (table 11), suggesting stabilization, and incipient reversal, of the fragmentation of the Tintic Valley landscape vegetation mosaic observed in the previous interval.

Change in landscape vegetation mosaic, 1874-1993.--From 1874 to 1993, herbaceous-dominated landscape area declined by less than 2%, shrub-dominated area increased by 7.5%, and savanna declined by just under 1% (table 8). In stark contrast to findings reported throughout the Intermountain region (Blackburn and Tueller 1970, West 1984, Barber and Josephson 1987, Miller and Wigand 1994), open woodland area in Tintic Valley was found to have declined by 8% over the study period. While closed woodland increased by 3%, there was a net decline in woodland area of 5% over the 119-year period. This decrease is consistent with historical trends reported by Christensen and Brotherson (1979) for Salt Lake and Utah Valleys. At the same time, vegetation polygon numbers increased 73% from 1874 to 1993, suggesting significant fragmentation of the Tintic Valley landscape mosaic has occurred over the study period (table 11).

Vegetation change within stands

Methods.--The above analysis permitted an assessment of change in the Tintic Valley landscape vegetation mosaic and a rough mapping of landscape vegetation patterns for the three temporal periods of the study. In order to quantify vegetation change within stands, a vegetation transition matrix was constructed (Callaway and Davis 1993) (table 12). Figures 11-13 summarize the data of table 12 and indicate the direction and magnitude of vegetation transitions within stands for the three temporal periods. Nonvegetated areas (vegetation class 6) and areas of no data were excluded from this analysis.

Stand transition results.--Stand transitions, 1874-1943.--Of the five vegetation classes examined, stands dominated by shrubby vegetation were the most stable (14.5% of stands began and ended the 1874-1943 period as shrublands), followed by woodland (6.5%), closed woodland (4.9%), savanna (4.5%), and herbaceous stands (2.2%). Further, a shift to shrubland was the most common transition for the period, with 9% of 1874 stands shifting from savanna to shrub, 9.5% from woodland to shrub and 8.2% from herbaceous-dominated to shrub-dominated between 1874 and 1943 (figure 11). This trend is consistent with the clearing of woodland-dominated stands on the one hand and the invasion of herbaceous-dominated areas by shrubs in response to livestock herbivory and/or fire suppression on the other. Given the length of this time period (69 years), within this shift toward shrub dominance may be embedded at least one intermediate phase of stand domination by herbaceous vegetation, at least for some stands.

The second most common directional change for the 1874-1943 period was toward increased tree dominance. Thus, nearly 5% of stands shifted from shrubland

Table 12. Vegetation physiognomic type transitions for three temporal periods (%).

Transition	1874-1943	1943-1993	1874-1993
1-1	2.2	2.7	2.2
1-2	8.2	4.8	6.6
1-3	1.6	1.4	2.1
1-4	0.7	0.3	1.4
1-5	0.7	0.0	0.9
2-1	2.2	5.9	1.9
2-2	14.5	23.4	11.7
2-3	4.9	10.0	6.9
2-4	2.3	3.5	2.6
2-5	2.5	0.0	2.1
3-1	1.7	1.3	3.3
3-2	9.0	1.8	5.9
3-3	4.5	6.5	3.6
3-4	3.5	7.3	3.9
3-5	1.3	3.0	3.4
4-1	2.0	0.5	3.1
4-2	9.5	1.2	7.6
4-3	5.9	1.4	4.7
4-4	6.5	6.5	7.0
4-5	4.2	6.0	5.4
5-1	1.0	1.0	1.1
5-2	2.6	0.7	2.0
5-3	1.9	0.4	1.6
5-4	3.2	2.0	3.4
5-5	4.9	8.5	5.4
N	692	769	699

to savanna and 4.2% of woodland moved toward increased closure, even as nearly 6% of woodlands and about 3% of closed woodlands moved in the direction of lower stand density (figure 11) This suggests that had significant woodland harvest not

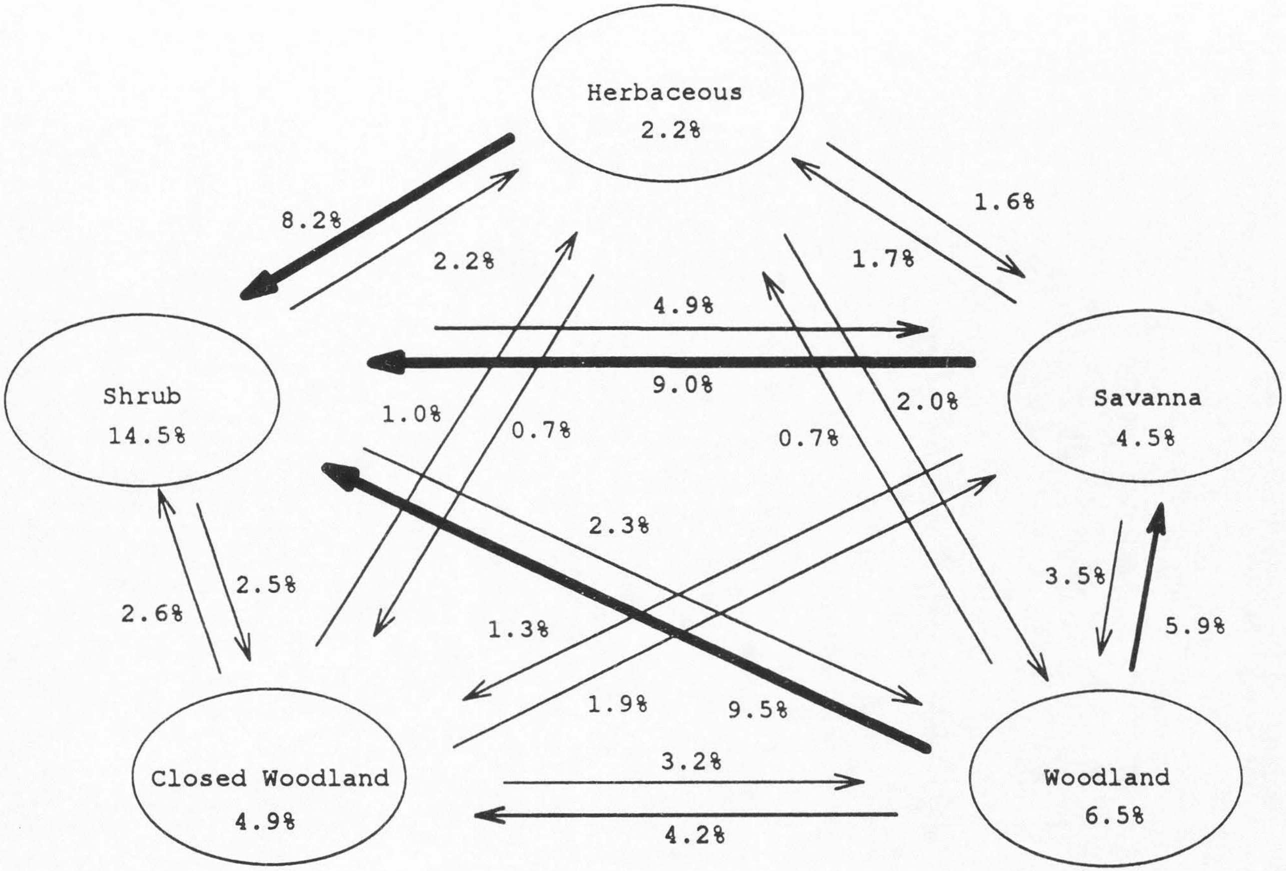


Fig. 11. Stand vegetation transitions, Tintic Valley, 1874-1943 (n = 62).

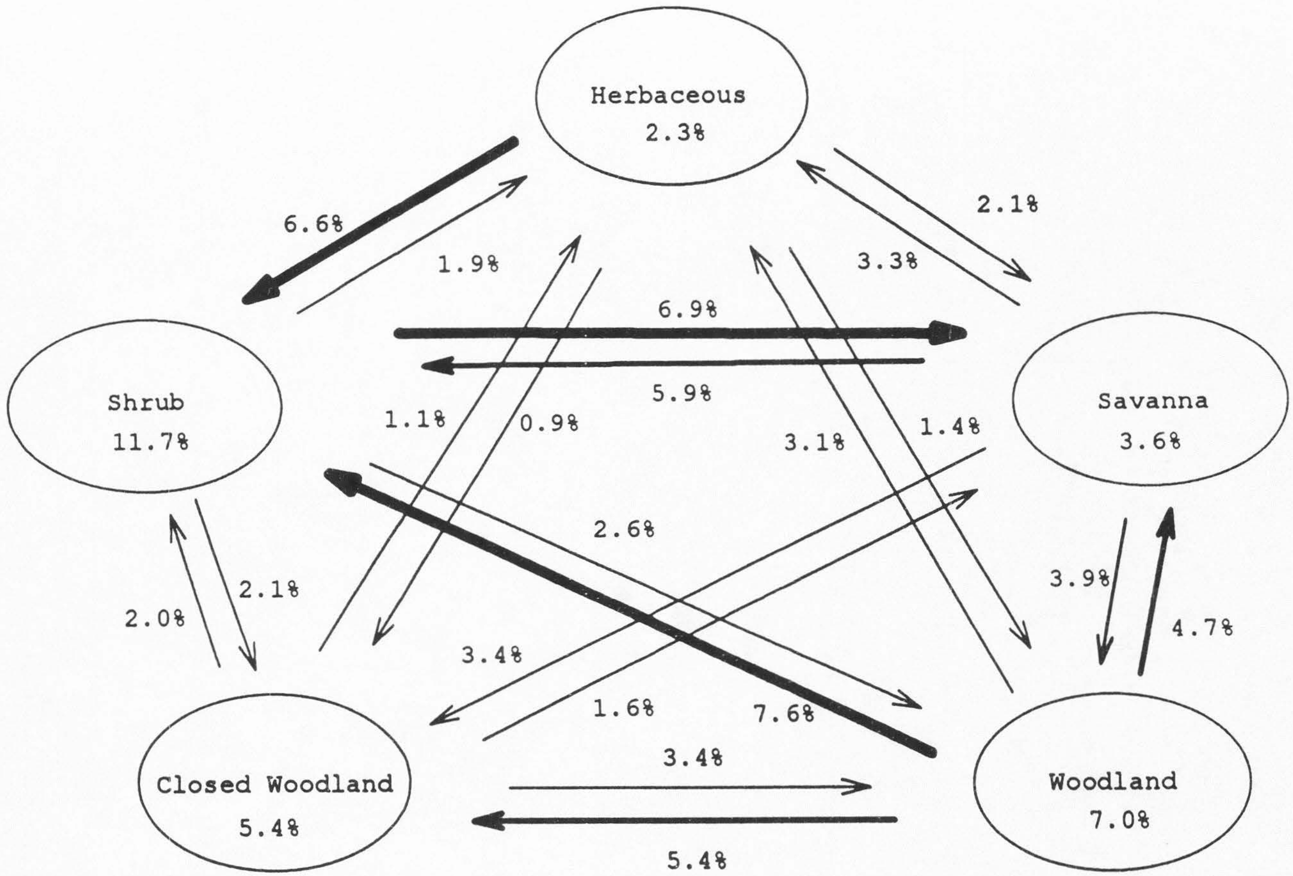


Fig. 13. Stand vegetation transitions, Tintic Valley, 1874-1993 (n = 699).

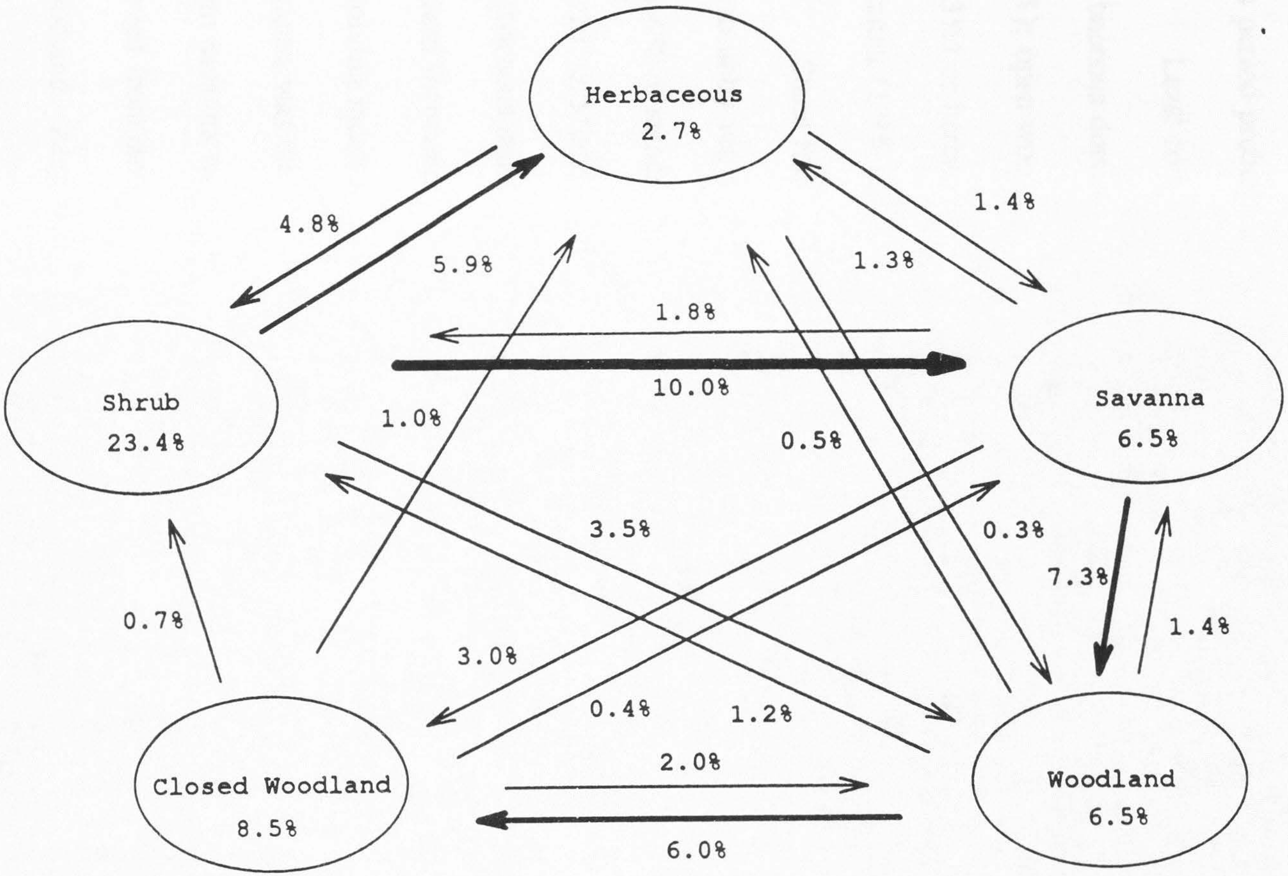


Fig. 12. Stand vegetation transitions, Tintic Valley, 1943-1993 (n = 799).

occurred in this temporal interval, a general trend toward increased tree domination in this period probably would have been observed.

Least common transitions for the 1874-1943 period included: a shift from herbaceous domination to closed woodland (0.7%) and closed woodland to herbaceous (1%); open woodland to herbaceous dominance (0.7%); savanna to closed woodland (1.3%) or herbaceous domination (1.7%); and closed woodland or herbaceous to savanna (1.9% and 1.6%, respectively).

Stand transitions, 1943-1993.--As for the 1874-1943 period, stands dominated by shrubby vegetation in 1943 were the most stable during this 50-year interval (23.4% of stands began and ended the 1943-1993 period as shrublands), followed by closed woodland (8.5%) and both woodland and savanna (each at 6.5%, figure 12). Herbaceous stands were the least stable (2.7%) across this period. A general shift toward increased tree cover characterized the interval, with almost 30% of transitions involving increased stand domination by trees. The transition from shrubland to savanna was the single most common transition (10%), while 7.3% of stands shifted from savanna to woodland, 6% moved from woodland to closed woodland, 3% moved from savanna to closed woodland, and 3.5% moved from shrubland to woodland. Almost 6% of stands shifted from shrub to herbaceous dominance, but this was balanced by a near 5% shift in the opposite direction. Least common transitions for the 1943-1993 period included closed woodland to savanna (0.4%), closed woodland to shrub (0.7%), closed woodland to herbaceous (1%), woodland to herbaceous (0.5%), and herbaceous to woodland vegetation (0.3%).

Transitions from tree domination toward herbaceous and shrub dominance, and from woodland to savanna vegetation, presumably reflect clearing of trees by wild or anthropogenic fire, chaining, or other management intervention. This includes over 8% of the study area for the 1943-1993 period (table 13).

Stand transitions, 1874-1993.--As for the intermediate sampling intervals, shrub-dominated stands were the most stable across the 119-year study interval (11.7%), with herbaceous stands least stable (2.3%). Unlike the previous intervals, however, combined values of stable woodland and dense, or closed, woodland stands exceeded that of stable shrubland areas from 1874 to 1993 (12.4%). This suggests that woodland expansion in the 1943-1993 interval included areas that were dominated by woodlands in the settlement period, but had been cleared in the 1874-1943 interval.

The single most common transition for the 1874-1993 period was from woodland to shrubland (7.6%). Overall, 22.1% of stands shifted to shrub domination, with a net increase in shrub-dominated area of 7.5%. While 24.7% of Tintic Valley stands shifted in the direction of increased tree domination across the 119-year interval, net tree-dominated area declined by 5% (table 13).

Table 13. Change in vegetation cover by area, patch frequency and as a percentage of total study area for three temporal periods (nd = 106/807).

Veg class	1874-1943 ha	%	fq	1943-1993 ha	%	fq	1874-1993 ha	%	fq
1	-1185	-4.1	+16	+691	+2.4	-4	-494	-1.7	+12
2	+4591	+15.8	+25	-2423	-8.3	-2	+2168	+7.5	+23
3	-189	-0.7	+24	-125	-0.4	+9	-314	-1.1	+33
4	-3121	-10.7	+21	+806	+2.8	-1	-2315	-8.0	+20
5	-390	-1.3	+8	+1256	+4.3	-1	+866	+3.0	+7
6	+294	+1.0	+6	-205	-0.7	-5	+89	+0.3	+1

Fire and Ecological Site Factors

Methods

Aro (1965, p. 35) argued, "The most consistent indicator of an original (pre-livestock) pinyon-juniper site is the stoniness or coarseness of the soil...Rapid infiltration, deep penetration and low soil moisture tension at these sites favor dominance of woodland over grassland." He identifies narrow ecotones between woodlands and grasslands at topographic breaks from stony upper slopes to non-stony, gently-sloping lower sites. Mean woodland slope was found to be 25%. Grasslands showed a mean slope of 15%, which was considered high due to failure to extend sampling transects further into the grassland zone (Aro 1965). Sauerwein (1981), drawing on Aro's work, offered stoniness and slope as the two primary considerations in juniper to grass conversion projects. He argued surface coverage by stone or bedrock is the "simplest and best" site indicator, with <15% stone cover offered as a requirement of sites to be considered for conversion to grass.

While this approach to site classification is ultimately based on effective precipitation (Stevens et al. 1974), both Aro (1965) and Sauerwein (1981) were explicit that a change in fire regime was responsible for observed expansion of pinyon-juniper woodland into grassland areas. Both argued that slope and soil texture together offer reasonable criteria for identifying "true" woodland, or "fireproof," sites, i.e., sites that would be woodland even in the absence of fire suppression, livestock or other post-Euroamerican settlement factors (Sauerwein 1981).

To explore the role of fire in the determination of pre- and post-Euroamerican landscape vegetation pattern in Tintic Valley, Aro's (1965) and Sauerwein's (1981) model of "fire prone" and "fireproof" ecological sites was used to derive expected landscape pattern under the following hypotheses:

H01: fire was not a major factor in the determination of pre-Euroamerican landscape vegetation pattern in Tintic Valley.

P1: There is no correlation between "woodland" patches at the time of settlement and "fireproof" ecological sites.

P2: There is no correlation between "non-woodland" patches at the time of settlement and "fire prone" ecological sites.

H02: Tintic Valley landscape fire dynamics have not changed since Euroamerican settlement.

P1: Woodland area has not increased on "fire prone" sites since Euroamerican settlement.

P2: Non-woodland area has not increased on "fireproof" sites since Euroamerican settlement.

To test the above hypotheses, and to test Aro and Sauerwein's model against observed settlement era vegetation patterns in Tintic Valley, the GIS database was used to develop an ecological site map of the Valley. Aro and Sauerwein's slope and soil surface texture criteria were applied to published soil survey information for the study area (Trickler and Hall 1984) to classify the study area into four ecological sites, based upon susceptibility to fire (figure 14). Slope and soils information was derived from a Digital Elevation Model (30 m resolution, USGS 1994) of the Valley and digital soils attribute data (SCS 1994) respectively. In decreasing order of fire susceptibility, sites were classified as follows:

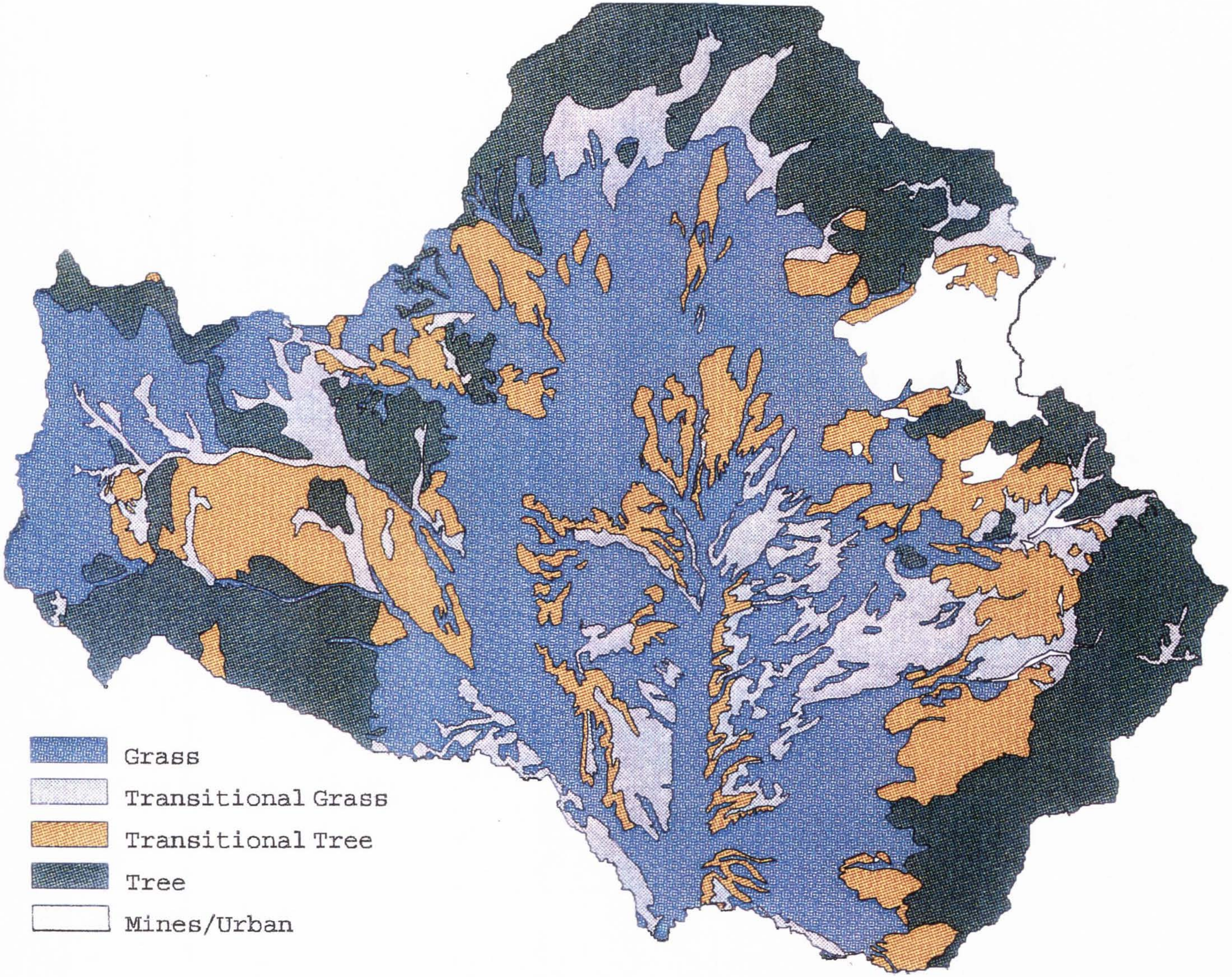
1) grass (slope < 15% and soil surface texture < 15% cobble, stone or gravel);
2) transitional grass (gr-, slope > 15%, surface texture < 15% cobble stone or gravel);
3) transitional tree (tr-, slope < 15%, surface texture > 15% cobble, stone or gravel) and;
4) tree (slope > 15% and surface texture > 15% cobble, stone or gravel).

For this analysis, in order to avoid confounding due to the potential for quarter-mile sample segments to overlay more than one ecological site, the vegetation data presented above were treated as point data. Each sample point (figure 9) was queried as to its ecological site and vegetation value over time.

Fire and ecological site factor results

Figure 15 shows relative frequencies for all five vegetation classes on each of four ecological sites in 1874. Figures 16 and 17 show the equivalent patterns for 1943 and 1993, respectively. From these histograms it is evident that while all four ecological sites defined under Aro (1965) and Sauerwein's (1981) criteria have experienced some degree of vegetation change over time, sites classified as "tree" or "transitional tree" were relatively stable when compared with sites classified as

Fig. 14. Ecological site map of Tintic Valley (after Aro 1965).


Grass
Transitional Grass
Transitional Tree
Tree
Mines/Urban

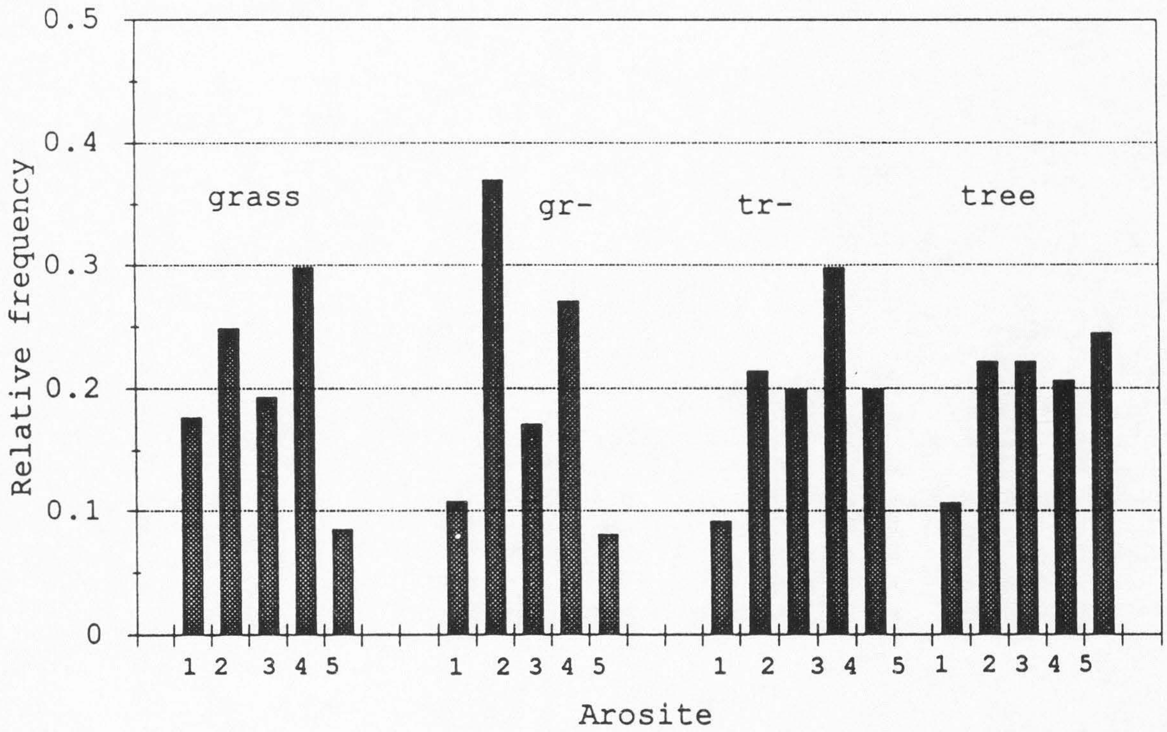


Fig. 15. Relative frequencies for five vegetation classes on four ecological sites, 1874.

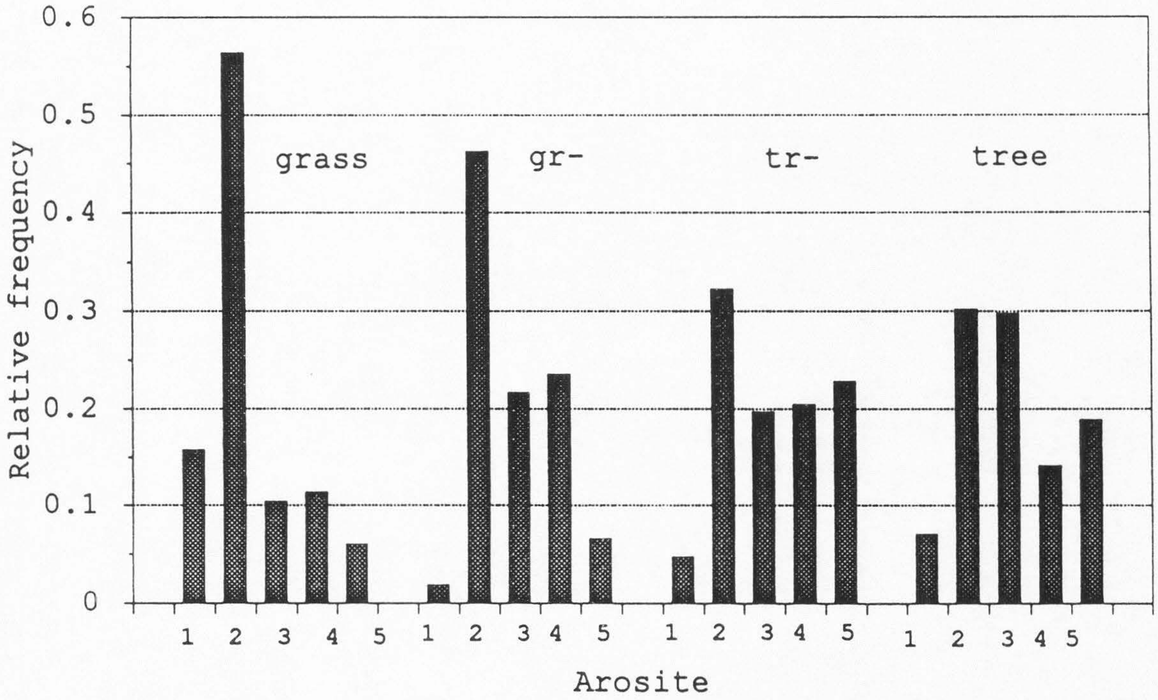


Fig. 16. Relative frequencies for five vegetation classes on four ecological sites, 1943.

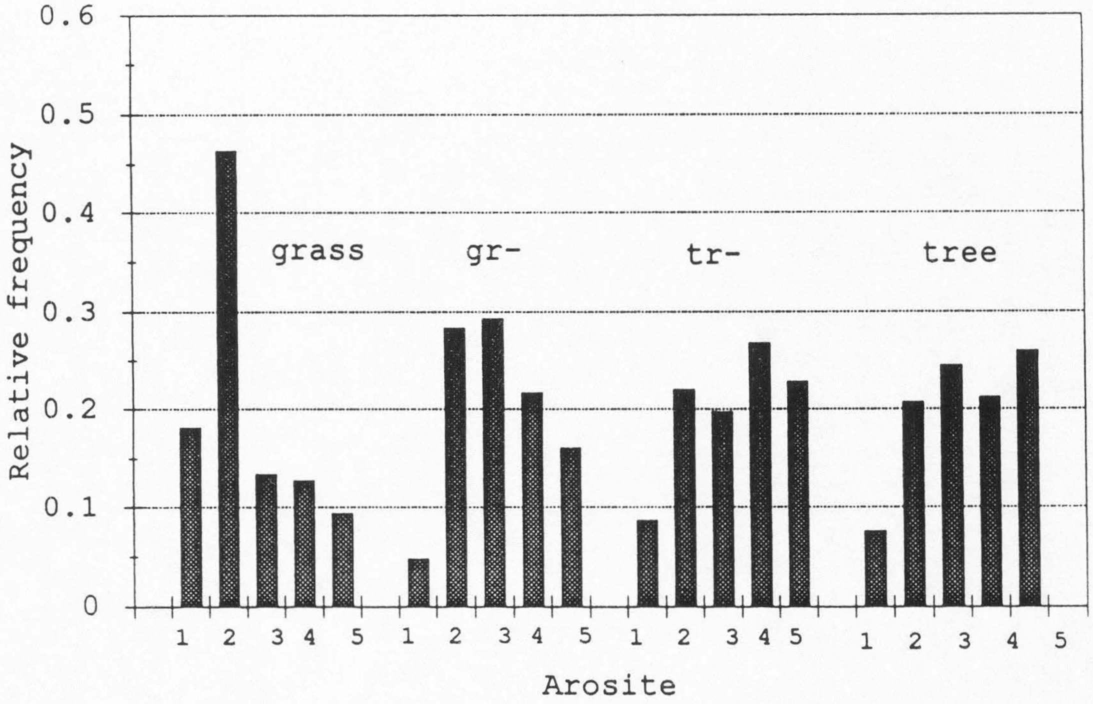


Fig. 17. Relative frequencies for five vegetation classes on four ecological sites, 1993.

"grass" or "transitional grass."

While vegetation change on all four types of site reflected the general trend of decreasing tree cover between 1874 and 1943, this trend was less dramatic on "tree" and "tr-" sites. Further, while overall trends showed a 5% decline in site domination by woodland vegetation between 1874 and 1993, these histograms are interpreted as suggesting that vegetation patterns on "tree" and "tr-" sites in 1993 were very similar to vegetation patterns on those sites in 1874. Thus, the bulk of the changes which actually occurred in Tintic Valley over the 119 year study period occurred on sites classified as "grass" or "gr-."

Because, by definition, these sites would be most likely to lend themselves to clearing or other management practices, these results are perhaps not surprising. While there is a general trend on "tree" and "tr-" sites toward reestablishment of 1874 vegetation patterns, modern management practices appear to be retaining a relativelylow percentage of both woodland and dense woodland patches on "grass" and "gr-" sites, although the woodland trend is upward on these sites when compared with 1943 patterns.

This analysis also reveals that the rather dramatic reduction of woodland-dominated patches (classes 3-5) on "grass" sites between 1874 and 1943 (figures 16 and 17) accompanied an increase in shrub-dominated patches on "grass" sites. The long interval between these two sampling periods allows the possibility that this shift from woodland to shrub dominance may have included at least one herbaceous-dominated phase. Declining herbaceous domination on "gr-" sites between 1874 and

1943 also appears to be a function of increasing shrub domination on these sites.

A general decline in shrub cover on all four types of sites between 1943 and 1993 (figures 16 and 17) appears to have occurred through a slight increase in all other vegetation cover classes, with the exception of herbaceous-dominated tree sites. These remained unchanged from 1943 to 1993. Herbaceous domination increased slightly on all other site types in this interval.

Figures 18-20 permit the testing of the above hypotheses pertaining to fire dynamics in Tintic Valley. Specifically, these figures show the relative frequency of vegetation patches, pooled into two classes as a function of hypothesized fire frequency, on two types of ecological site, i.e., "fireproof" and "fire prone," based upon Aro's and Sauerwein's slope and soil texture criteria.

Figure 19 reveals that "non-woodland" vegetation (herbaceous, shrub and savanna classes) does indeed occur with greater relative frequency on fire prone sites than on fireproof sites in 1874, and that the opposite scenario (woodland vegetation occurring with greater relative frequency on fireproof sites than on fire prone sites) is also true for the early Euroamerican settlement era. These results are the opposite of those predicted under H01 and therefore fail to support the null hypothesis that fire was not a major factor in the determination of pre-Euroamerican landscape vegetation pattern in Tintic Valley.

The prediction under H02, that woodland area has not increased on fire prone sites since Euroamerican settlement is consistent with the observed results. However, the prediction that non-woodland area has not increased on fireproof sites since

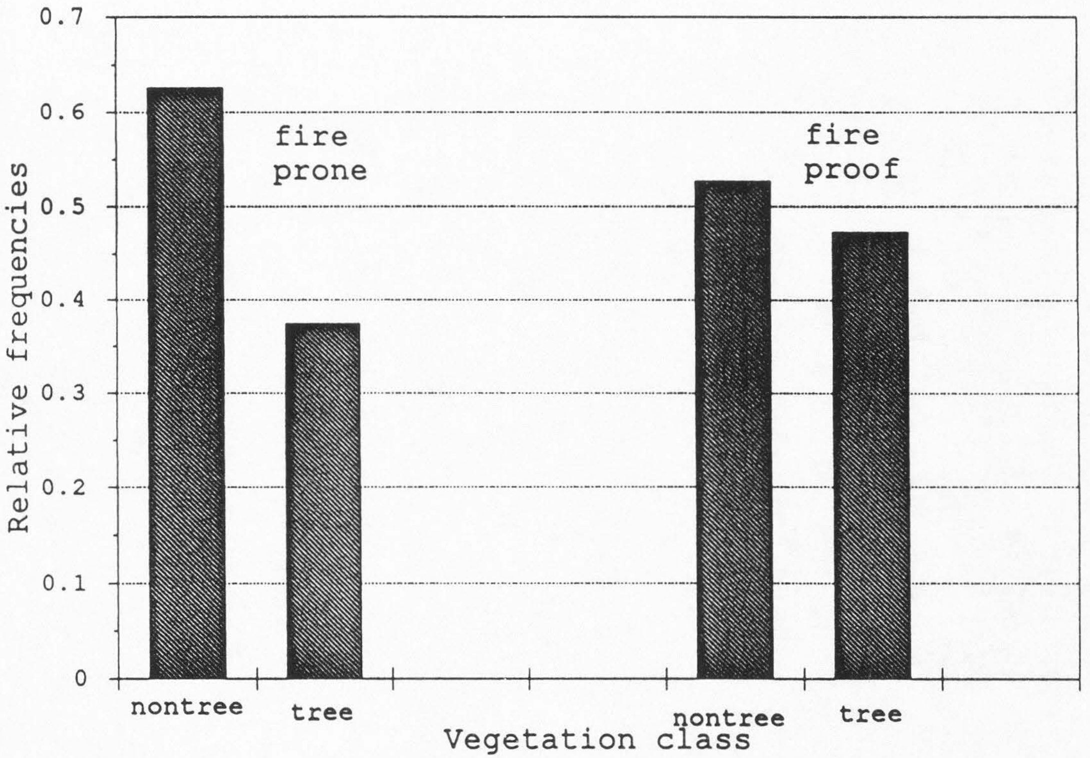


Fig. 18. Relative frequency of woodland and non-woodland vegetation on two ecological sites, 1874.

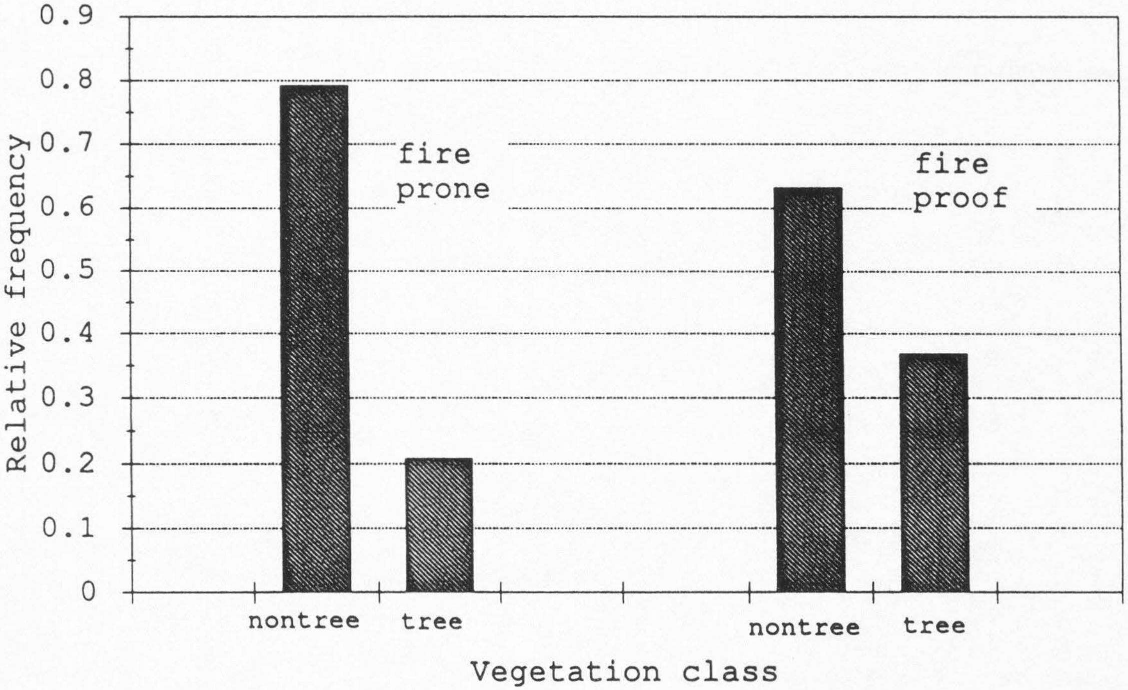


Fig. 19. Relative frequency of woodland and non-woodland vegetation on two ecological sites, 1943.

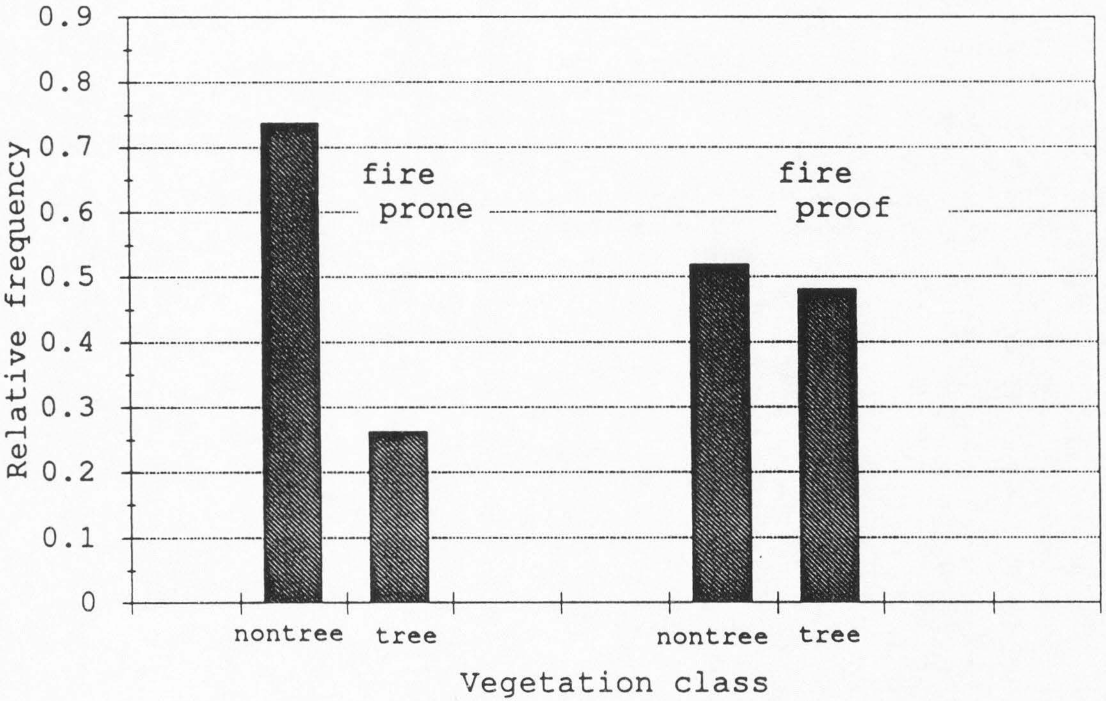


Fig. 20. Relative frequency of woodland and non-woodland vegetation on two ecological sites, 1993.

Euroamerican settlement is not consistent with the observed results, which show an increase in non-woodland vegetation on fireproof sites between 1874 and 1943, with a return to 1874 levels by 1993. Thus, while the data appear to broadly support the hypothesis that Tintic Valley fire dynamics have not changed since Euroamerican settlement, the results also suggest that factors other than fire may have played an important role in structuring the post-Euroamerican settlement era vegetation mosaic of Tintic Valley. This is consistent with the findings of Chapter IV.

Repeat Photography

Methods

Repeat ground photography has been widely used to document vegetation change. For example, Hastings and Turner (1965) and Bahre (1991) employed repeat ground photography to document vegetation change in southeastern Arizona. Humphrey (1987) used repeat photography to illustrate change across ninety years along the US-Mexican border. Rogers (1982) used repeated photographs to illustrate nearly a century of ecological change within the Great Basin.

Limitations to the use of repeat photography in characterizing vegetation change include the fact that historical photos were often taken near settlements and well-traveled routes, limiting their spatial coverage and resulting in an emphasis on landscape conditions under relatively intense human impact. University of Arizona botanist H.L. Shantz, for example, developed an extensive collection of photographs of Southwestern U.S. landscapes in the 1920's, but often photographed disturbed vegetation because this was his area of interest (Rogers 1982).

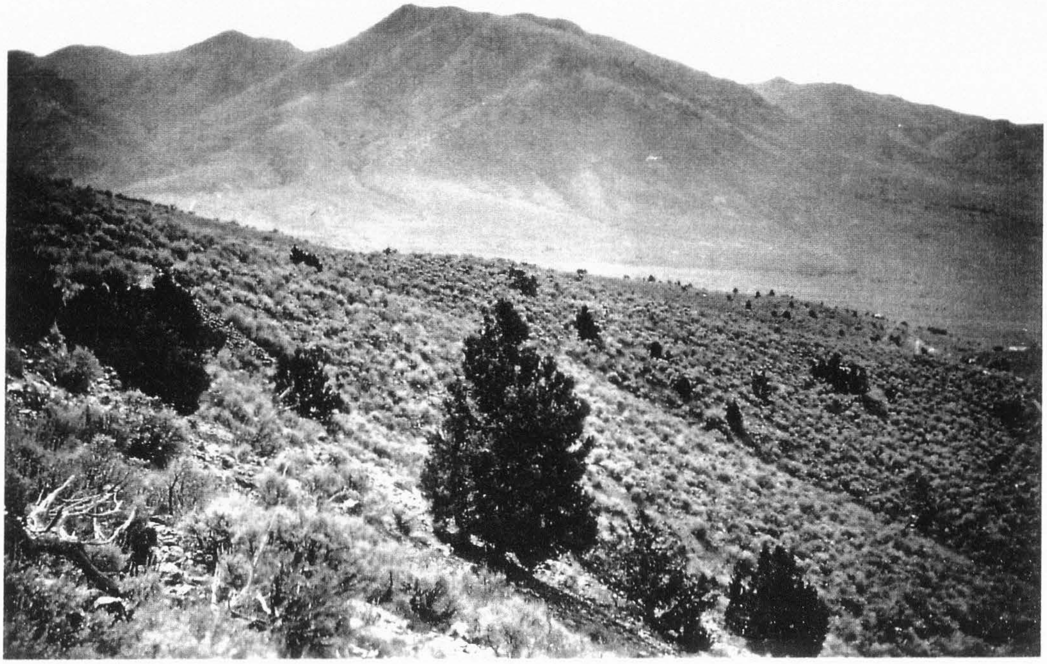
Ideally, studies employing repeat photography should employ the work of as many early photographers as possible to minimize the personal bias of individual photographers in characterizing the historical landscape. For this work, a number of potential sources of early photographs of Tintic Valley were explored, including the Still Pictures Branch of the National Archives, USGS reports, the photographic collection of the Utah State Historical Society, Special Collections of the University of Utah and Utah State University, G.K. Gilbert's "Photos of the Great Basin," and the Shantz photographic collection of the University of Arizona herbarium. While this search did turn up several photographs of general interest, most were of Tintic mines, towns and citizens, with little if any landscape content. Possibly the single best general collection of photographs of the Tintic Valley area was found in Notariani (1992).

A small but excellent group of early Tintic Valley landscape photographs are those taken by G.F. Loughlin in 1911 (Lindgren and Loughlin 1919). Prints of these photographs were obtained from USGS Archives, and the photographs retaken in summer 1995, using methods outlined in Rogers (1982) and Rogers et al. (1984).

Figures 21-32 are paired photographs showing vegetation change in the East Tintic Mountains across a period of eighty-four years. Captions are based upon those of Lindgren and Loughlin (1919), while the number following Loughlin's name is the USGS archive number associated with each photograph.

Fig. 21. Eureka Peak from west slope of Godiva Mountain. Above: 1911 (Loughlin 3-a). Below: 1995.

Fig. 22. Sunrise Peak, looking south from Treasure Hill. Above: 1911 (Loughlin 9). Below: 1995.



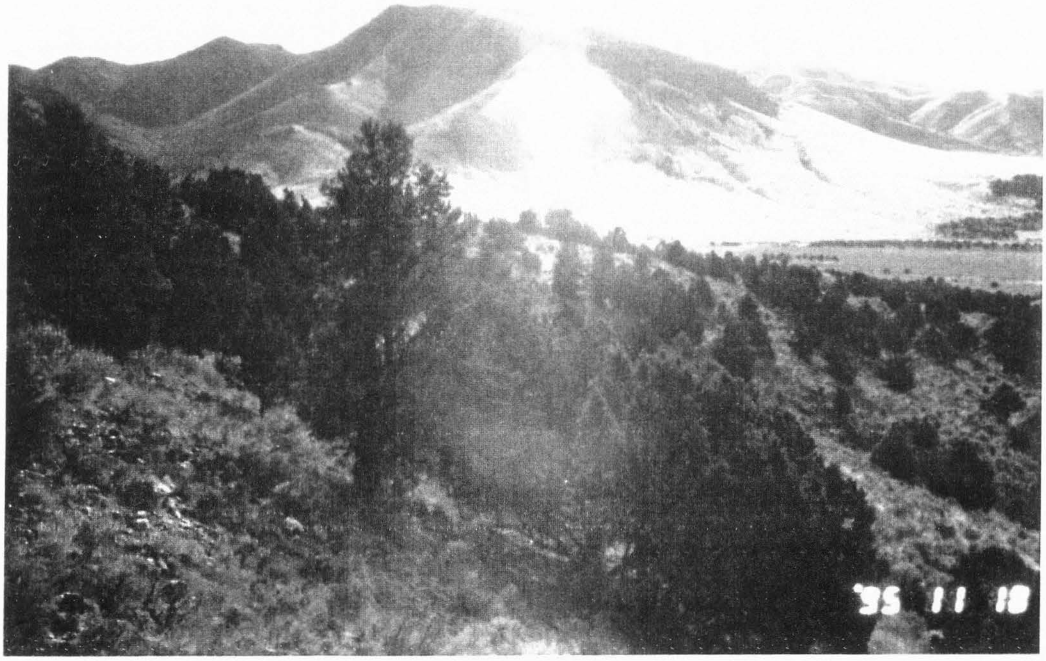

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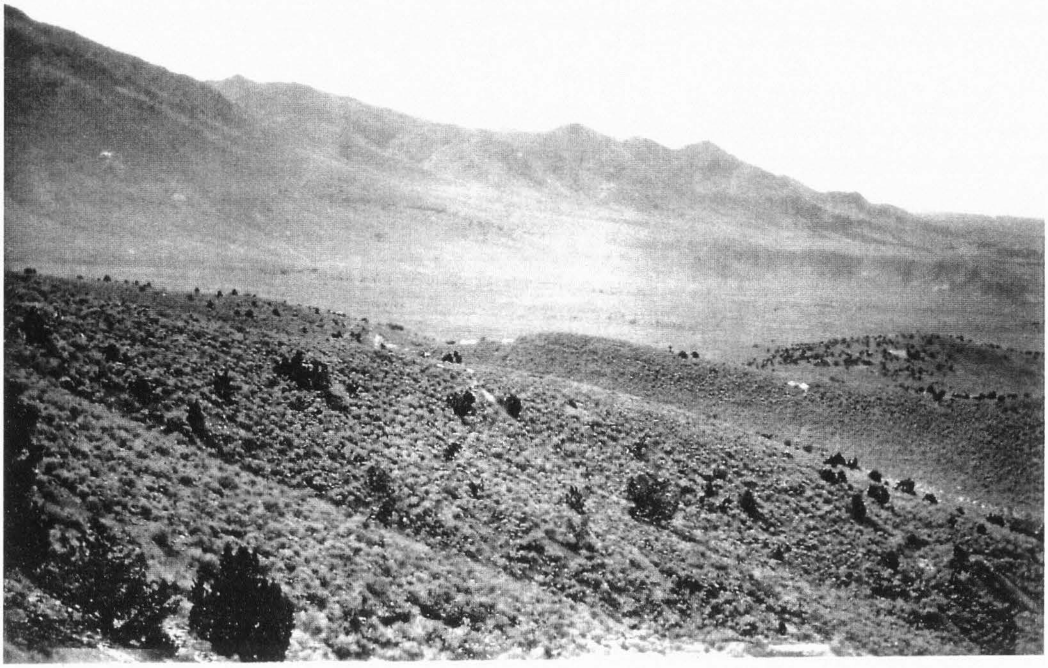
Fig. 23. Volcano Ridge, looking south from Treasure Hill. Above: 1911 (Loughlin 10). Below: 1995.



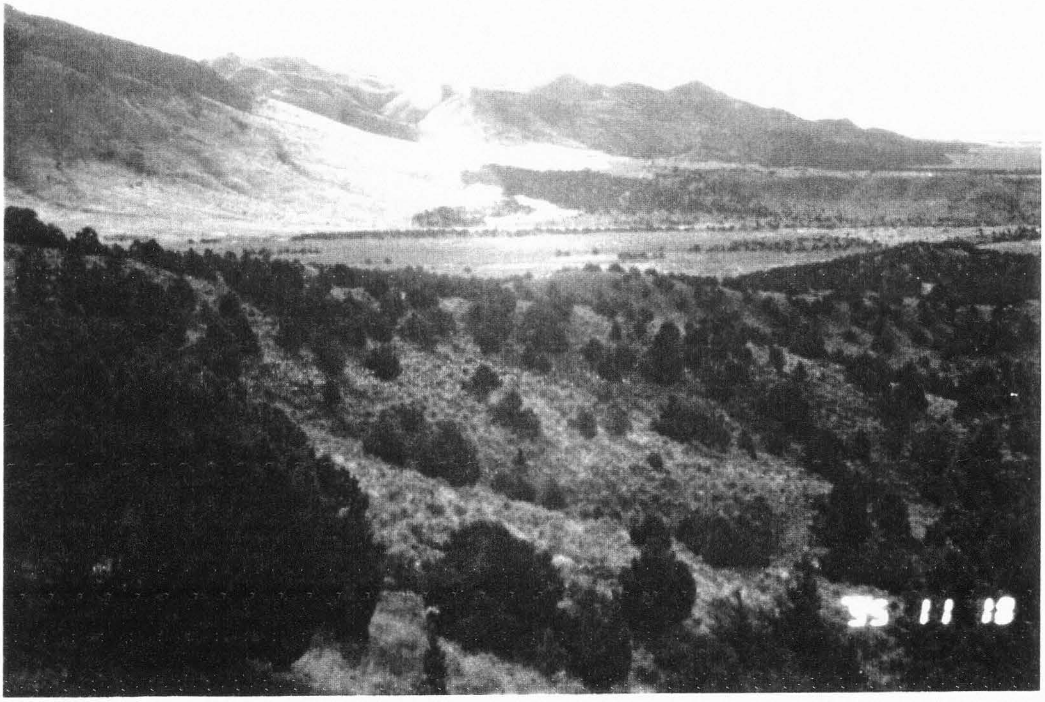

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Fig. 24. East Tintic Mountains, looking north-northwest from Treasure Hill across Ruby Hollow. Above: 1911 (Louglin 6). Below: 1995.

Fig. 25. East Tintic Mountains, looking north from Treasure Hill across Ruby Hollow. Above: 1911 (Loughlin 5). Below: 1995.

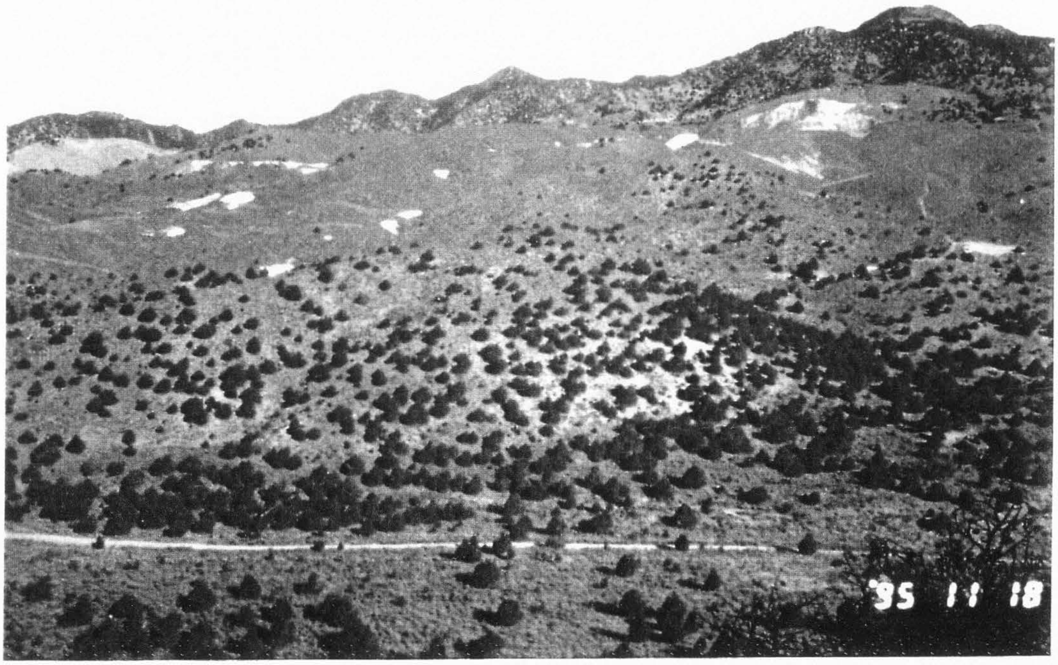
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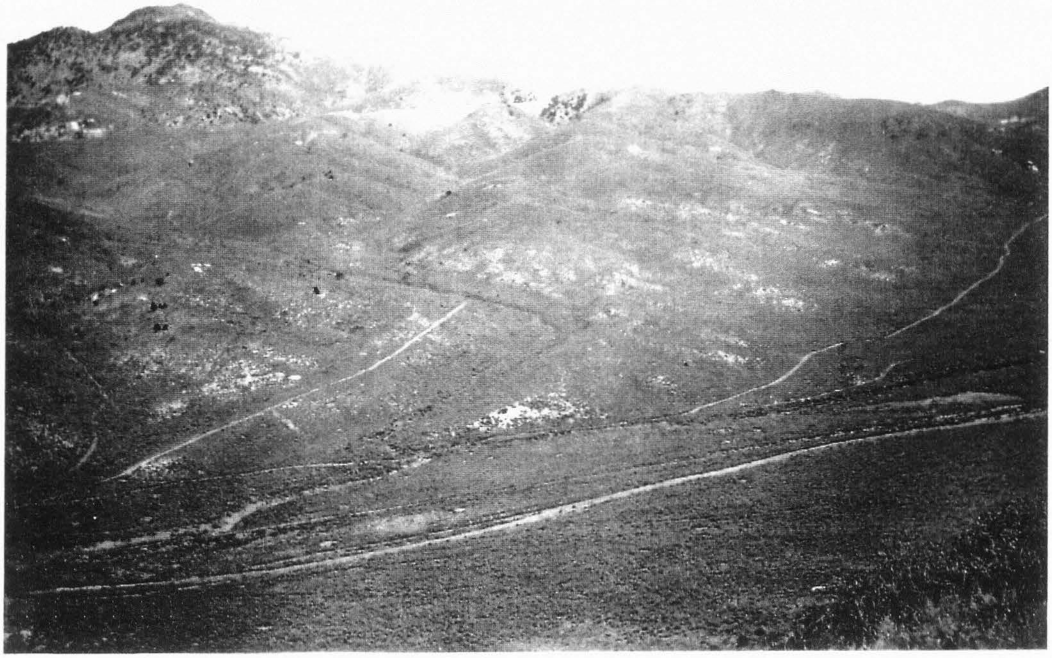
Fig. 26. East Tintic Mountains, looking north-northeast from Treasure Hill across Ruby Hollow. Above: 1911 (Loughlin 4). Below: 1995.



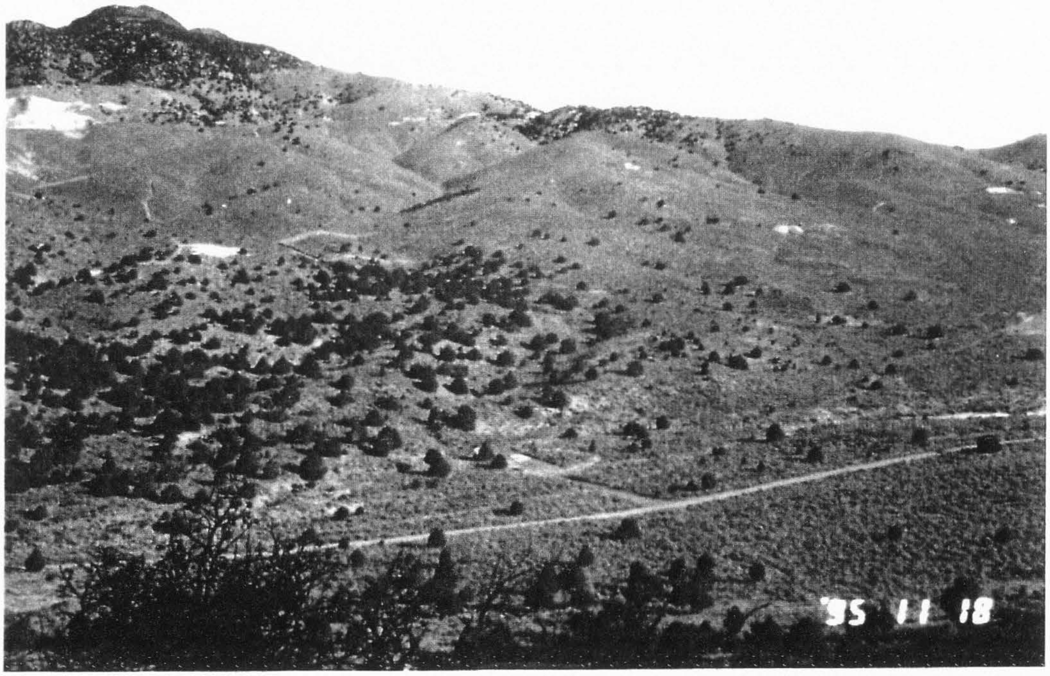
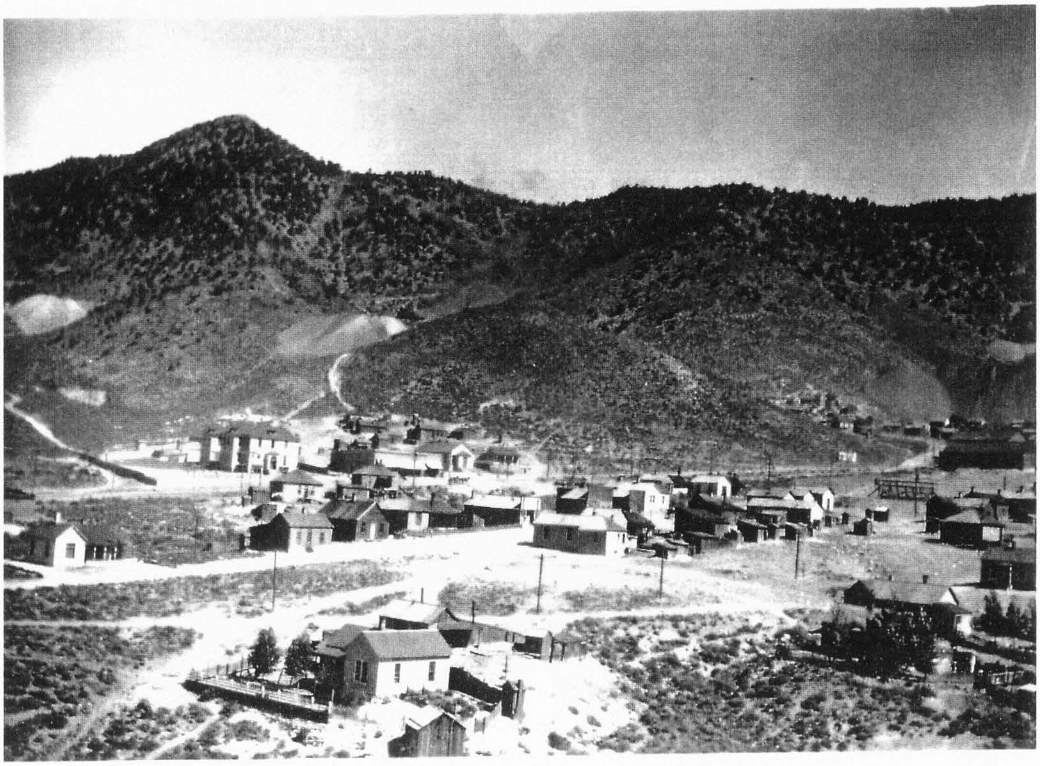

95 11 18

Fig. 27. View east-northeast to Mammoth and surrounding mountains. Above: 1911 (Loughlin 22). Below: 1995.



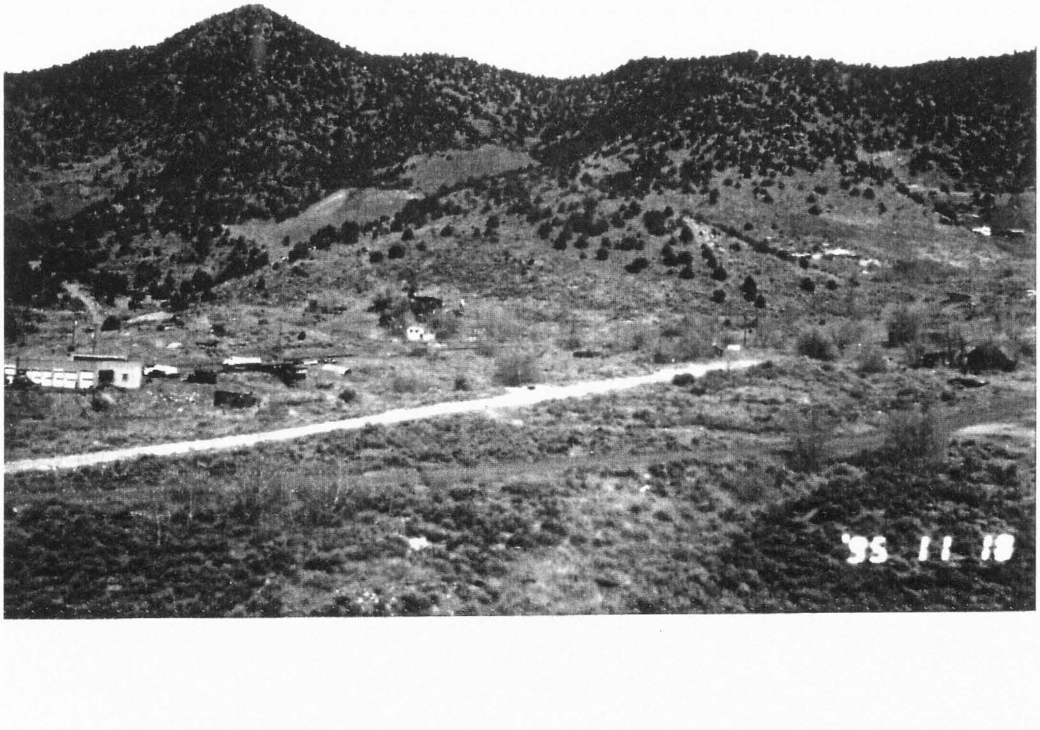
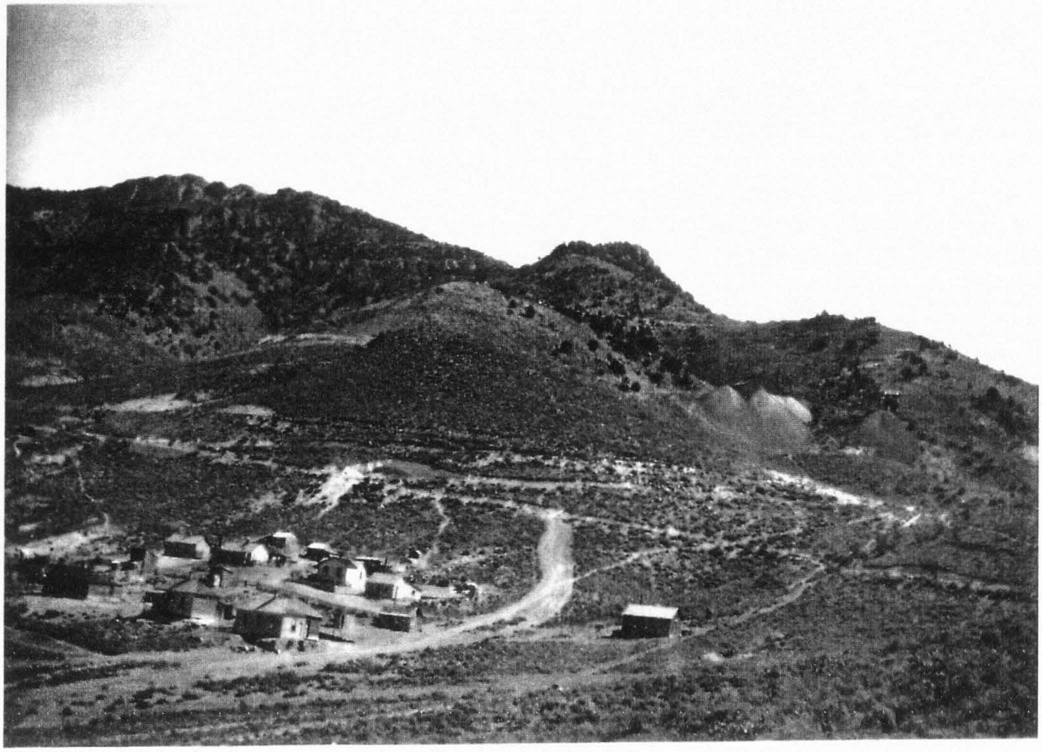

'95 11 18

Fig. 28. View east to Mammoth and surrounding mountains. Above: 1911 (Loughlin 23). Below: 1995.

Fig. 29. View east-southeast to Mammoth and surrounding mountains. Above: 1911 (Loughlin 24). Below: 1995.



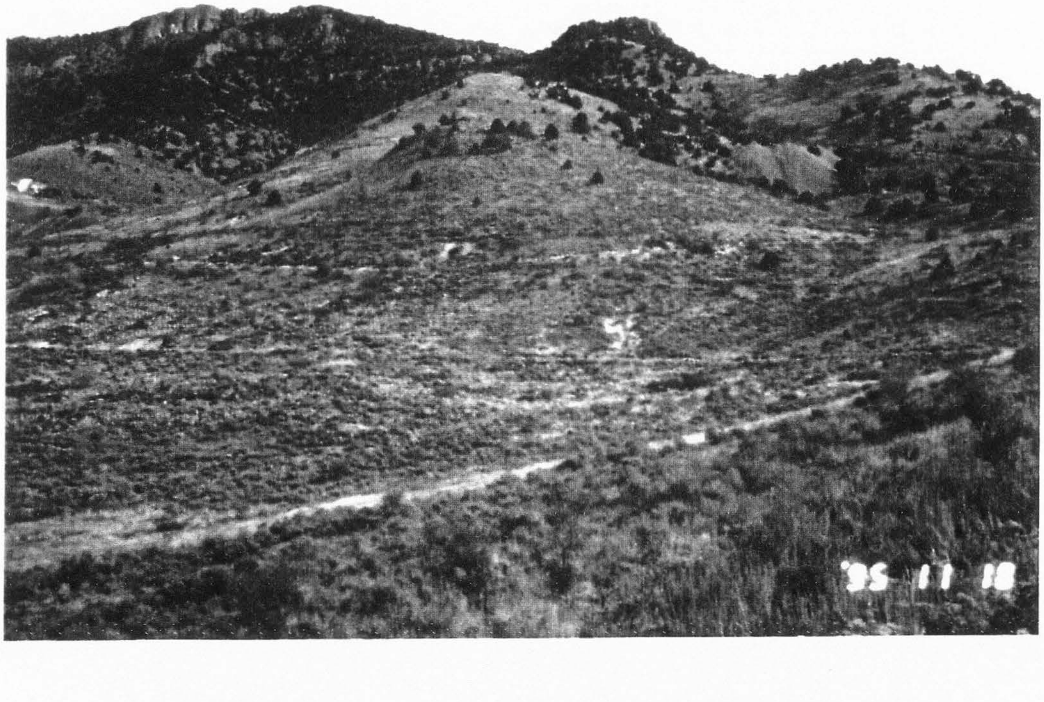

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Fig. 30. Outcrop of Bluebird Dolomite east of Herkimer shaft. Above: 1911 (Loughlin 20). Below: 1995.

Fig. 31. East-west fault south of the saddle east of Quartzite Ridge. Above: 1911 (Loughlin 19). Below: 1995.

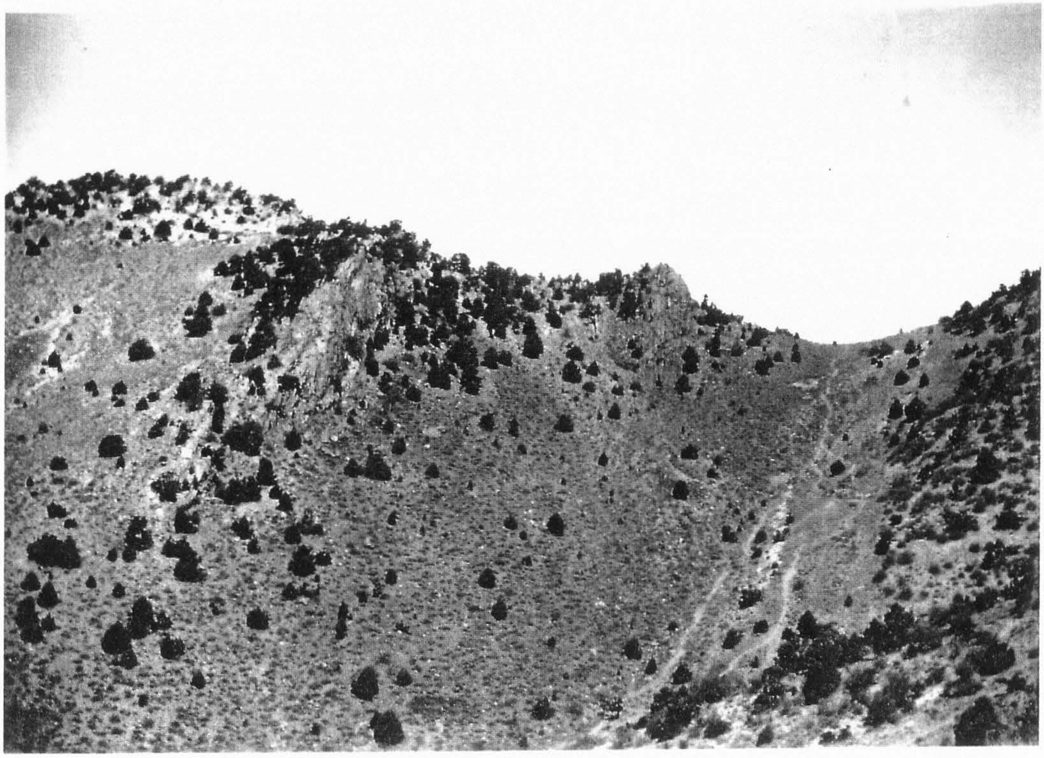
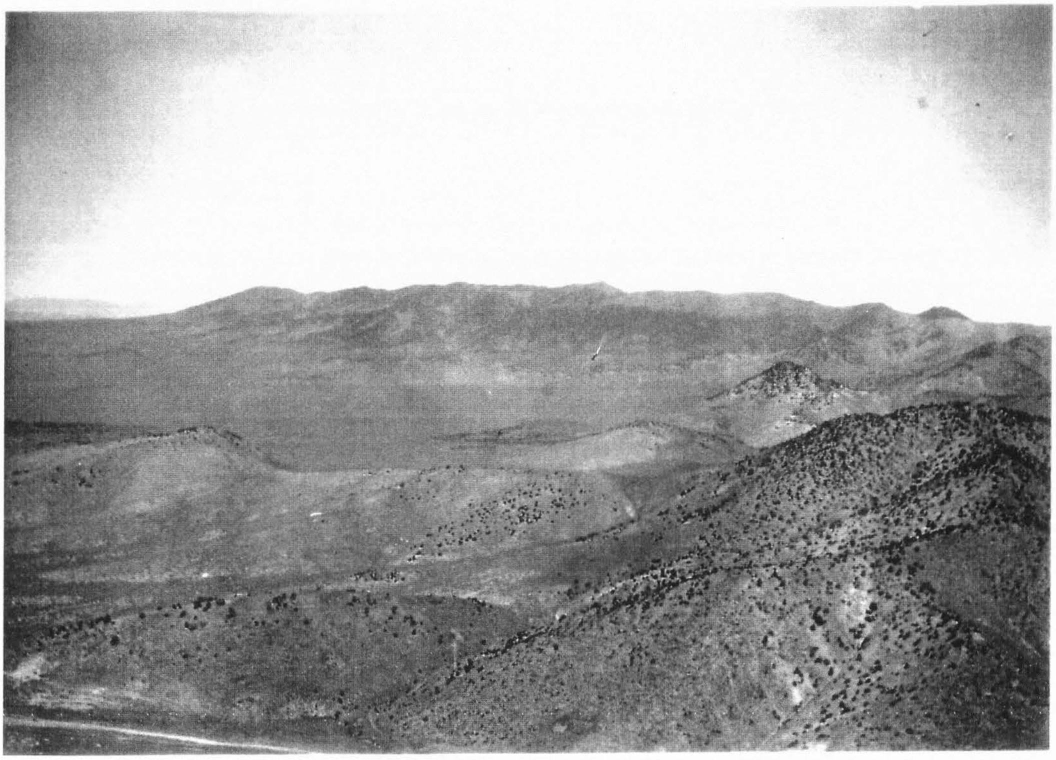


Fig. 32. Foothills northwest of Eureka and head of Tintic Valley. Above: 1911 (Loughlin 18). Below: 1995.



Repeat photography results

Without exception, these photographs show an increase in the areal extent and/or density of woodland vegetation across the 84-year interval. Particularly dramatic is the increase in woodland cover in the north end of the Valley as seen in figure 32 and in the saddle of Quartzite Ridge, figure 31. Significant increase in woodland cover is also apparent on the south facing slopes north of Ruby Hollow, above the site of Silver City (figures 24-26).

The dynamic nature of Tintic Valley's vegetation across the 1911-1995 interval can be seen in figures 22 and 23. In both the 1911 and 1995 photos, the west slope of Sunrise Peak is dominated by non-woodland vegetation. In 1911, however, a young woodland stand can be seen on the lower slopes of the mountain. By 1995, this area had been chained and seeded to crested wheatgrass following an August 1992 crown fire in the dense woodland that covered the slope in that year. Standing dead trees are visible on the steeper upper slopes above the chaining. Thus, a complete cycle of woodland establishment and elimination by crown fire is evident in this group of photographs.

These photographs cover that part of the study area in which towns and mines were concentrated and where several early smelters and mills were also located (Chapter IV). Vegetation patterns visible in the distance in figures 21, 24, and 32, suggest, however, that the increase in woodland extent and density from approximately 1911 to 1995 has been generally the case across the Valley.

Discussion

Descriptors used to define vegetation along section lines in the 1874 GLO survey undoubtedly masked finer scale variability in the landscape vegetation mosaic. This dictated the decision to limit the informational and spatial resolution of this analysis to largest physiognomic type and one quarter mile, respectively. The Bureau of Land Management, the Natural Resources Conservation Service, and the Utah Department of Fish and Game monitor a limited number of plots within the study area, and these data were reviewed. While these may be of value as elements in a regional data set, permitting interpretation of trends at the regional scale, limited spatial and temporal scales of these data render them inapplicable to this study.

Results of this analysis reveal that the Tintic Valley vegetation mosaic has been dynamic throughout the 119-year study interval. Yet, when viewed across the entire period, vegetation cover across the landscape, as reflected in vegetation physiognomy, appears remarkably stable. The observed 12% decline in woodland area from 1874 to 1943 is consistent with historic woodland harvest activities in Tintic Valley (Chapter IV) and with results reported by Christensen and Brotherson (1979), who found decreases in juniper woodland cover in Salt Lake and Utah Valleys in the historic era. The increase in woodland cover in the 1911-1995 period is consistent with more commonly reported trends in the region (Blackburn and Tueller 1970, Young and Evans 1981, Tausch et al. 1981, West 1984, Miller and Wigand 1994).

Despite the general overall stability of vegetation cover types, however, the concomitant degree of landscape fragmentation over the 119-year study period suggests a significant reconfiguration of vegetation patch size and patch location within the spatial and temporal bounds of the study. Relatively large patches of open woodland and shrubland and, to a lesser degree, savanna and herbaceous-dominated patches in 1874 had, by 1943, been highly fragmented. Most conspicuous is the dramatic reduction and fragmentation of the open woodland-dominated landscape area and its replacement by 1943 with a relatively continuous shrub matrix (figure 10).

Indeed, it is interesting to note that the Tintic Valley landscape mosaic of 1874 was not dominated by any one vegetation type to the degree that would permit identification of that type as the landscape matrix, although, consistent with early descriptions of the Valley (Chapter IV), the open woodland class was found to extend nearly across the entire landscape in 1874. By 1943, shrubland had so come to dominate the landscape that, even though much more highly fragmented than the landscape of 1874, the 1943 landscape matrix was a highly fragmented shrubland. By 1993, although total patch number had declined slightly from 1943 levels (table 11), this shrub matrix had in turn begun to be fragmented by an increasing number of open woodland patches. This suggests that the woodland expansion evident in the repeated photographs has occurred primarily in the post-WW II period.

With respect to hypotheses pertaining to Tintic Valley's fire dynamics, the overall study period trend toward increased dominance by shrubby vegetation at the expense of herbaceous vegetation, as well as the 1943-1993 increase in tree cover at a time when field observation reveals that chaining was an important management tool in Tintic Valley, is consistent with the hypothesized decrease in fire frequency. The notable decrease in woodland cover in the 1874-1943 period at the same time that shrub-dominated area increased supports the view that management activities other than fire were responsible for the decline in woodland area for this period (Chapter IV). Results for the 1943-1993 period appear to support the hypothesis of an altered fire regime following Euroamerican settlement of the Valley, while results for the 1874-1943 period suggest factors other than fire played a more important role in changes in the vegetation mosaic, masking any changes in fire dynamics which may have occurred. Both the continuing and changing role of fire in Tintic Valley is suggested in the vegetation dynamics revealed in figures 10 and 11.

Noss (1996) noted that fragmentation is one of the most common trends in modern landscapes. Holt et al. (1995) argued that this global trend renders an understanding of the implications of fragmentation essential to ecological restoration. Habitat fragmentation has been associated with reductions in species diversity (EPA 1994). However, because organisms' perception of their environment is scale-dependent, interpretation of the meaning of habitat fragmentation is also scale-dependent (Holt et al. 1995, West 1996). Critical thresholds of habitat fragmentation are not a landscape property, but a property of species' relationships to the landscape (With and Crist 1995, West 1996); whether a patch appears isolated from or embedded within the landscape matrix is a function of the species of interest (Holt et al. 1995, West 1996). Thus, spatial dynamics may or may not play a major role in determining, for example, the direction of early secondary succession on disturbed sites (Holt et al. 1995).

Disturbance and change are inherent properties of landscape dynamics, however, and ecologists have consistently recognized the existence and importance of landscape patch mosaics, landscape pattern, patch size, and configuration (Pickett and White 1985, Turner et al. 1993). Pickett et al. (1992) have suggested that a landscape which exhibits a changing patch distribution in time cannot be considered at equilibrium. Landscape fragmentation may result in driving landscape connectivity, and thus landscape dynamics, across some critical threshold to a new domain of behavior (With and Crist 1995, Milne et al. 1996), constituting a change in system state (Bull 1991).

From the point of view of landscape dynamics, as opposed to population dynamics, therefore, fragmentation is important insofar as it both reflects and affects landscape processes. The capacity of a system-organizing process such as fire, for example, to move through a landscape is, among other factors, a direct function of the degree of contiguity of flammable community types (Forman 1987, Turner and Romme 1994). Change in landscape pattern is thus important both for the information it conveys regarding pattern-generating processes and for its effects on those processes and the landscape dynamics they embody.

Baker (1995) emphasized that the meaning of landscape structure, as reflected in patch number and degree of fragmentation for example, remains both poorly understood and variable, depending on whether the subject of interest is nutrient cycling, habitat, energy flows, etc. He defines landscape density as a function of patch number, and suggests that higher density landscapes require more time to adjust to new disturbance regimes, and to recover from disturbance, than do the same landscapes at a lower patch density. This is because the disturbance will require a greater number of repeated occurrences to affect all similar patches on the more dense landscape. If we assume that fire was the primary landscape-structuring disturbance of pre-Euroamerican Tintic Valley, the observed fragmentation can be presumed to imply a lengthening of the response time of the landscape to that disturbance. That is, more time and more fires would be required to reestablish the pre-Euroamerican pattern than would have been required to maintain that pattern in the absence of fragmentation (Baker 1995). Alternatively, larger fires could accelerate the restoration of the pre-Euroamerican vegetation mosaic by moving across patch boundaries, effectively reintegrating the fragmented landscape.

Finally, in interpreting the above results, it is critical that the distinction between a state transition at the landscape level, that is, a change in the behavior of the landscape system, be clearly distinguished from transitions in vegetation cover of the individual stand (Bull 1991, Allen and Hoekstra 1992). The stand transitions reported above may represent fluctuations within some normal range of vegetation change for individual stands in Tintic Valley. Such change would not, by definition, constitute the change in stand behavior requisite for the recognition of a state transition (Bull 1991). A shift from bunchgrass to sagebrush domination, followed by a return to bunchgrass domination following fire, can be seen as an example of a stand transition that does not necessarily constitute a change in system behavior when viewed over the entire temporal period of such change. On the other hand, if shrub cover is replaced following fire by cheatgrass, resulting in a change in the behavior of the system due to a change in fire dynamics, then a state transition may indeed be considered to have taken place. Thus, while the above results appear to support the hypothesis of a change in landscape system behavior, i.e., a state transition at the level of the study area landscape, individual stands may or may not have experienced state transitions, even where vegetation transitions were found to have occurred.

Conclusion

The general trend toward increased fragmentation of the Tintic Valley landscape mosaic is consistent with historic era trends globally (Holt et al. 1995). The fact that it is Tintic's woodlands, rather than its herbaceous-dominated landscape areas, which have been most subject to historic era fragmentation, reflects the intensive historic era exploitation of those woodlands (Chapter IV). A century after the era of intensive exploitation of woodland biomass, total Tintic woodland area is beginning to approach 1874 levels. However, the configuration of those woodlands across the landscape appears highly fragmented relative to 1874.

Turner et al. (1993) noted that landscape equilibrium is a scale-dependent concept, and echoed Naveh's (1987a) observation that different spatial and temporal scales of disturbance result in fundamentally different landscape dynamics. However, both Turner et al. (1993) and Naveh (1987a) addressed disturbance-mediated landscape dynamics in the context of repeated disturbance over time, even where the spatial and temporal scales of that disturbance may change.

The case of woodland reduction and fragmentation in Tintic Valley does not fit this view of disturbance as a recurring, system-organizing process. Rather, it appears to fit a catastrophe model of change (Waddington 1975), in which a single event, extensive in space but essentially instantaneous in time, resulted in dramatic reconfiguration of Tintic Valley landscape patterns. This catastrophic change in pattern precipitated a change in system behavior, driving the landscape system across a transition threshold to a new state (Bull 1991).

Intensive agro-industrial exploitation of Tintic's woodlands in the early settlement era (Chapter IV), while spatially extensive, appears to have a low probability of recurrence. This disturbance thus fits Turner et al.'s (1993) model of nonequilibrium system disturbance dynamics. However, current trends in the Tintic landscape toward increasing tree density on tree-dominated sites, as revealed in this analysis, raise the possibility of future analogous events in the form of landscape-scale crown fire. Indeed, the occurrence of four such fires in the study area between 1992 and 1996 suggests that such change in the landscape dynamics of Tintic Valley may already be taking place.

Taken together, results reported here appear to support the working hypothesis of a state transition in the landscape dynamics of Tintic Valley in the historical period. Ambiguity in the interpretation of these results may be as much a function of a failure to clearly define *a priori* the expected indicators of such a transition as it is of the results themselves. The observed fragmentation, change in patch size and number, and reconfiguration of the vegetation mosaic of Tintic Valley are unequivocal indications of landscape change (Pickett and White 1985, Turner et al. 1993). These results are consistent with both perceived threats to biodiversity in global landscapes and state transitions from equilibrial to nonequilibrial landscape dynamics (Pickett et al. 1992, Turner et al. 1993, Baker 1995, Noss 1996, West 1996). That this change has been accompanied by a change in landscape processes is supported by the ecological site analysis, by observed changes in historical fire dynamics, and by historical trends in vegetation dynamics revealed in repeated photographs. Together, the observed changes in both pattern and process suggest a change in behavior of the landscape system. Bull (1991) has argued that it is change in system behavior, rather than a change in system structure, which constitutes a valid criterion for recognition of the crossing of a threshold to a new system state.

CHAPTER VI

GEOMORPHOLOGICAL CHANGE

1874-1995

Introduction

Instability in geomorphic systems results from a combination of thresholds, positive feedbacks, and deterministic chaos. Establishing causality in the face of changes in such systems is thus difficult, if not impossible (Schumm 1991, Phillips 1995). Newly formed gullies, however, are commonly recognized as evidence of recent landscape change (Renwick 1992). This chapter explores the question of historic era gully formation as an important component of the recent ecological history of Tintic Valley. It is the thesis of this chapter that a change in system geomorphology is an indicator of system change predicted under the hypothesis of a state transition in the dynamics of the Tintic Valley landscape (Peterson 1950, Chorley 1962, Leopold and Langbein 1962, Bull 1991, Renwick 1992) accompanying the cessation of indigenous land-use practices.

The linked phenomena of arroyo formation and entrenchment in valleys of the American West have attracted the research interest of numerous geographers, geologists and resource managers for most of this century (Rich 1911, Bryan 1928, Cottam and Stewart 1940, Antevs 1952, Denevan 1966, Cooke and Reeves 1976, Graf 1979a). Bailey (1937, p. 997) declared, "A new epicycle of erosion" unlike anything since the "glacial epoch of the Pleistocene" was initiated with European settlement of the United States, and provides numerous examples of arroyo formation within ten to fifteen years of Euroamerican settlement at various sites in Utah.

Historic era changes in Western landscapes were both cause and effect of changes in regional spatial and temporal disturbance patterns. These included changes in patterns of anthropogenic fire and patterns of herbivory, the latter exemplified by the introduction of domestic livestock into the region. This led to increased and novel impacts on the soil/litter/vegetation complex (Pieper 1994). The virtual extinction of the hydrogeomorphic keystone species *Castor canadensis* (beaver) throughout the region due to overexploitation by fur trappers resulted in an increase in the spatial scale of soil and water movement, culminating in increased intrasystem transport and extrasystemic losses via extended gully networks (Leopold 1951, Cooke and Reeves 1976). This in turn can be hypothesized to have resulted in a decline in landscape productivity due to soil loss and a generalized lowering of water table levels leading to ephemeralization of perennial streams and springs (Cottam and Stewart 1940, Pieper 1994).

The forces mediating geomorphological change in the American West are generally recognized as being limited to four classes: climate, tectonics, land use and inherent hydrogeomorphological instability. Whether arroyo cutting and filling are primarily the result of climatic fluctuation to a more humid, or more arid climate (Bryan 1940, Schumm and Hadley 1957), change in the relative frequency and magnitude of rainfall events (Leopold 1951, Schumm 1973), land use practices (Rich 1911, Bailey 1937, Antevs 1952), or inherent geomorphic processes (Schumm and

Hadley 1957, Graf 1979a) remains a subject of debate (Patton and Schumm 1981, Bull 1991, Prosser et al. 1994). Certainly all of these factors have played, and continue to play, some role in historic geomorphologic change in Western landscapes, with the relative importance of each dependent primarily upon the fundamental geomorphic properties of the individual drainage basin. Ultimately, degree of arroyo entrenchment is a function of time, available tractive force (volume and velocity of flow), nature of the eroded materials, and resistance, the latter provided primarily by vegetation (Graf 1979a, Spaeth et al. 1996).

Similarly, increases in the rate of erosion in valley bottoms are the result of change in one or more of three critical system variables: increased slope, increased hydraulic radius of flow, and/or reduction in surface roughness (Cooke and Reeves 1976). Schumm and Hadley (1957) noted that an increase in slope of fluvial deposits over time is common in ephemeral, semiarid fluvial systems. This is a function of loss of water to infiltration and evaporation downstream, leading to sediment accumulation in particular reaches. This in turn leads to local oversteepening of the valley floor and, eventually, to initiation of head cutting.

Increases in hydraulic radius, result from increased discharge, increased concentration of flow, or both (Cooke and Reeves 1976). Because surface roughness is primarily a function of biomass on the valley floor (Graf 1979b, Thornes 1987), reduction of vegetation cover and/or inundation of vegetation by sediment during flood conditions are the most probable precursors to decreased resistance to erosive forces (Cooke and Reeves 1976). Tractive force within the channel is mediated both by biomass upstream of the channel, which affects runoff and thus stream discharge, and by the resistance of vegetation within the channel and near channel banks. Impact on vegetation may be the single most important factor governing the effects of human activities on geomorphological systems (Graf 1979b).

Increase in erosivity of flow potentially is a function of a number of primary variables, with each variable itself a function of multiple factors. There is potential for significant change in rates of erosion without an increase in volume of flow, while flow alone nevertheless has the potential to cause increases in those rates. The complexity of these relationships needs to be considered in any discussion of causality in arroyo development.

There is a notable absence of evidence of tectonically mediated alterations of relief or base levels in most Western valleys subject to significant arroyo formation or incision in the historic period (Cooke and Reeves 1976). Thus, attempts to ascribe cause to observed channel changes throughout the region have focused on the temporal and spatial association of climatic fluctuations and land uses with gully formation. While Bryan (1940) focused on climatic change and fluctuation as initiating factors in cycles of erosion, Leopold (1951) and Balling and Wells (1990) looked at changes in the intra-annual distribution of rainfall and the intensity of rainfall events as explanatory of gully initiation and entrenchment. Others, including Rich (1911), Bryan (1928), Bailey (1937), and Cottam and Stewart (1940) have focused on historic livestock impacts in the region, noting the central role of vegetation in determining the resistive force of hydrogeomorphological systems. Most researchers have acknowledged the potential role of both climate and anthropogenic factors in the initiation of gullying in the region, while the inherent instability of semiarid hydrogeomorphological systems has also been widely, if more recently, appreciated (Schumm and Hadley 1957, Graf 1979a, Graf 1988, Bull 1991).

A Systems View of Gully Dynamics

While the search for a universal cause for these ubiquitous features of the western landscape has occupied researchers for nearly a century (Rich 1911), more recent work (Schumm and Hadley 1957, Graf 1979b, Schumm 1991, Renwick 1992, Spaeth et al. 1996) has recognized both the multifactorial nature of geomorphic processes and the relationship between force and resistance as the "heart of explanation in geomorphology" (Graf 1979b). Recognizing landscape dynamics as the interplay of tractive and resistive forces leading to behavior typical of chaotic non-linear dynamical systems, mediated by the temporal and spatial scales of reference of the observer, has helped free historical geomorphological studies from the frustrating search for ultimate cause (Phillips 1995).

In the simplest sense, arroyo formation results when tractive forces exceed the threshold of resistance offered by the land surface (Graf 1979a). The process would thus appear to lend itself to prediction within the theoretical framework of thermodynamics. Schumm (1973) noted that the predictive power of Newtonian physics is limited when applied to the complexity of natural geomorphologic systems. Consequently, the field of geomorphology early adopted an open-system thermodynamic explanatory framework and has provided much of the language and many real-world examples of thresholds, stable and metastable states, and dissipative structures (Schumm and Hadley 1957, Chorley 1962, Graf 1979a, Renwick 1992). Phillips (1995) argued that "Declining relief over time implies non-chaotic evolution" while "the presence or absence of deterministic chaos is directly linked to the degree of entropy production and self-organization in an evolving landscape..." Increasing relief implies chaotic (negentropic) and decreasing relief nonchaotic (entropic) evolution (Naveh 1987a, Renwick 1992, Phillips 1995).

Any event leading to erosion within a drainage basin results in increased sediment production which in turn results in increased deposition and increased incision as the sediment load decreases (Schumm 1973). Heede (1975, p. 407) noted a positive feedback cycle is initiated by channelization, as "watershed area outside the stream decreases, lag times for flow concentrations decrease, and direct rainfall into the channels increases," resulting in higher peak flows and larger magnitude of flows, leading to increased erosion. He thus describes a process of "negative" homeorhesis (Waddington 1975), typical of processes of degradation (Chapter II).

Gravel bars, beaver dams, and log dams, "dynamic agents for slope adjustment" (Heede 1975, p. 410), can be viewed as energy-dissipating structures (Naveh 1987a) within the landscape system, slowing degradational processes and, potentially, reversing them. Thus, despite a high stream gradient, actual flow velocities may be remarkably low. For example, Graf (1979a) found the steeper of two streams, with a greater number of gravel bars and log dams, carried only half the sediment of the less steep stream. By reducing energy available for transport of material out of the system, such dissipative structures within the channel resulted in increased conservation within the system. Similarly, a knickpoint (or channel scarp) can be viewed as a dissipative structure, with energy being used to extend the gradient of the lower channel reach up slope (Schumm 1973, Graf 1979a). This illustrates the capacity of the hydrogeomorphological system to generate self-stabilizing structure through what may appear, within a limited spatio-temporal framework, to be degradational processes.

The case of Tintic Valley

Tintic Valley is topographically open (Snyder 1962), draining via Tanner Creek to the closed, now-dry basin of Sevier Lake. High energy runoff events in the Sevier Lake basin are primarily the result of cloudburst floods caused by local convectional storms in the summer months. Rainfall intensity within any given convectional storm tends to be concentrated near the storm center, such that even storms of less than one mile square in extent will tend to concentrate rainfall impact within a smaller area (Woodward and Craddock 1945).

The earliest known flash flood in the study area in the historic era is that which took the life of the oldest son of William H. McIntyre, William L., in 1888 and from which Death Creek derives its name (Steele McIntyre, personal communication, April, 1996). Damage in subsequent years included at least six human deaths, destruction of railroad bridges and track, damage to mines, and considerable damage to places of business in the town of Eureka (Woolley 1946, Butler and Marsell 1972). Woolley (1946) reported 42 cloudburst floods in Tintic Valley between 1895 and 1938, including the following:

August 25, 1904, a dam west of the town of Tintic was destroyed during heavy rain, causing considerable flooding;

July 23, 1910, a cloudburst flood at the McIntyre's West Tintic Ranch filled a reservoir with mud, cutting off the water supply to Mammoth City;

July 23, 1917, an 8-foot wall of water washed out the Homansville Canyon road, an event repeated on August 20, 1925;

A 10-foot wall of water washed through Dragon Canyon, near Silver City on August 15, 1931;

July 23, 1936, a flash flood in the canyon above Death Creek Spring washed out a pipeline and nearly took a crew of men with it (Steele McIntyre, personal communication).

Butler and Marsell (1972) reported, but did not describe, an additional 14 cloudburst floods in Tintic Valley between 1939 and 1969. Of the 56 floods reported in Tintic Valley between 1895 and 1969, 47, or 84%, occurred in July and August (Woolley 1946, Butler and Marsell 1972).

Average storm duration in the Sevier Basin is approximately 90 minutes, with maximum rates of rainfall sustained for less than 10 minutes. Storm intensity tends to increase with storm volume. While all areas of the Basin are expected to receive up to 0.8 inches of rain in single storm events each year, storms of 2.5 inches or more have an expected return interval of 50 years (Woodward and Craddock 1945). Fifty-year floods in Tintic Valley are expected to yield between 6 and 12 cubic feet per second per square mile, with runoff volume increasing from the southwest to the northeast (Jeppson et al. 1968). Woodward and Craddock (1945) reported an increase in runoff, as a percentage of total precipitation, from June to August. This was attributed to a change in soil conditions from loose and friable following freeze and thaw cycles of winter and spring and development of seepage channels due to the percolation of melted snow, to conditions of surface sealing and compaction due to thunderstorm raindrop impact and livestock trampling (Woodward and Craddock 1945).

While infiltration rates are a function of different variables across specific rangeland communities (Spaeth et al. 1996), storm and infiltration characteristics together determine the amount and frequency of surface runoff. Because summer storms in the Sevier Basin are inevitable, any factor inhibiting the infiltration capacity of a site must result in increased volume and frequency of surface runoff, while factors increasing that capacity will have the opposite effect. On all soil complexes in the Sevier basin, an increased amount of rainfall is required to induce runoff as plant cover increases. Woodward and Craddock (1945) found all flood source areas within the Sevier Basin showed signs of over grazing by livestock and big game, as reflected in deterioration of plant-cover and soil disturbance, to the point where further degradation of the infiltration capacity was judged impossible at that time. Seasonal average runoff and mean annual stream flow from the study area are so low as to fail to appear in published mapped representations of these variables (Jeppson et al. 1968).

As throughout much of the Intermountain West, incised stream channels are a significant feature of the Tintic landscape. Tintic Valley has been identified as a "problem area" in the Sevier Lake Watershed, and Eureka Creek, draining southwest from the East Tintic Mountains through the town of Eureka, has been a source of significant flood hazard for the community, aggravated by depletion of watershed vegetation (USDA 1950).

Deforestation, mine excavation, road, railroad and town construction, grazing, and agriculture have all impacted pattern, structure, and function of the Tintic landscape (Chapter IV). Historic geomorphic response of the Tintic basin can be assumed to have included both accelerated hillslope erosion and entrenchment of both ephemeral and perennial stream channels. Graf (1979b), for example, found tractive force within stream channels increased as much as eight times in response to disturbance attributed to mining and related settlement activities in the Central City District of Colorado and concluded that "the spatial distribution of energy and force has been substantially altered by human activities" (Graf 1979b, p. 262).

In reviewing the original General Land Office survey notes for the study area (Gorlinski 1872-1874), an apparent spatial association between locations of historic roads and modern gullies became evident. Subsequent field observations suggested a similar association between railroad grades and gullies. Previous work has explored this relationship in parts of the Southwest and California (Leopold 1921, Swift 1926, Cooke and Reeves 1976). Cooke and Reeves (1976) have suggested that human action, including construction of bridges, canals, trails, and roads, may be the most effective means of increasing concentration of flow and thereby the hydraulic radius factor of the erosivity equation.

In order to both test the hypothesis of a state transition resulting in relaxation of the Tintic landscape toward a new quasi-equilibrium state (Renwick 1992), and explore the spatial and temporal association between historic roads and modern gullies, a multitemporal analysis of the Valley gully network was undertaken.

H0: There has been no change in rates of soil erosion since Euroamerican settlement of Tintic Valley.

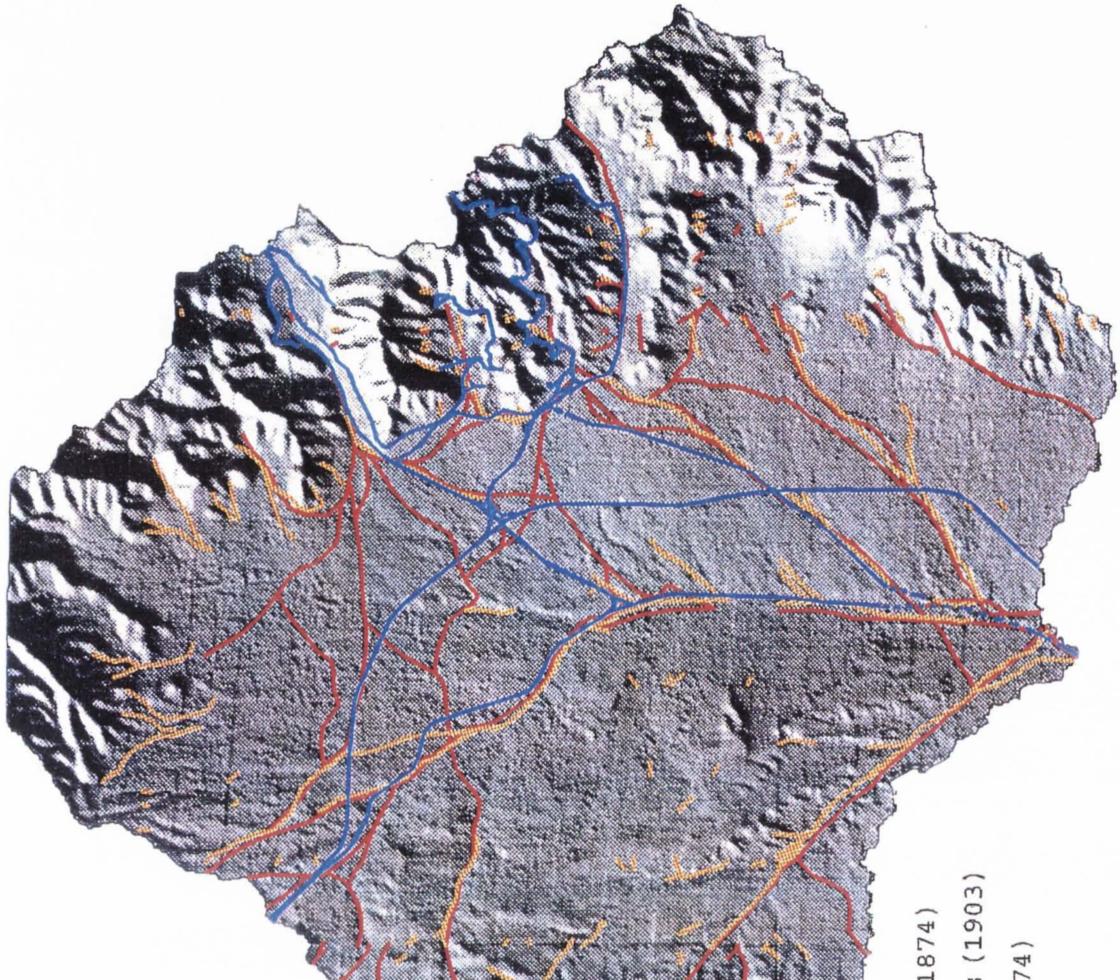
Prediction: the Tintic Valley gully network did not change following Euroamerican settlement.

This hypothesis was tested via multi-temporal analysis of the Valley gully network.

Methods

GIS and aerial photography interpretation.--The original General Land Office Survey notes and associated maps (Gorlinski 1872-1874) were thoroughly reviewed. All information pertaining to roads, fences, springs, and gullies or other fluvial features was transferred to mylar overlays on appropriate modern orthophotoquads (figure 33). Information that generally corresponded with current geomorphology of the study area was assumed to be correct, while features inconsistent with existing

Fig. 33. Study area road and gully network, 1874, with 1903 railroad network.


Gullies (1874)
Railroads (1903)
Roads (1874)

geomorphology were considered to reflect inaccuracies or outright falsification in the original survey. Examples of the latter included streams or gullies shown to divide in a down slope direction, to flow uphill, or to occur in other improbable geomorphological configurations.

Similarly, the Tintic Valley railroad network was transferred to mylar overlays of the modern orthophotoquads, using early and recent topographical maps, the orthophotoquads themselves, historical aerial photography (1943, 1:24,000), and field observations. Field observations were particularly important in distinguishing roads from railroad grades and identifying several narrow gauge railroad grades associated with historic mine and mill sites. The Tintic Valley gully network was similarly delineated for both 1943 (figure 34) and 1993 (figure 35) via aerial photography interpretation, and this information was also transferred to mylar overlays on the appropriate orthophotoquads.

The above overlays were then digitized as coverages within the Tintic Valley ARC/INFO GIS database. This permitted exploration of spatial associations among the following features:

Gullies and roads of 1874 and railroad grades of 1903 (figure 33);

Gullies of 1943, roads of 1874 and railroad grades of 1903 (figure 34);

Gullies of 1993, roads of 1874 and railroad grades of 1903 (figure 35);

Gullies of 1874 and 1943 (figure 36);

Gullies of 1874 and 1993 (figure 37).

Fig. 34. Study area road and gully network, 1943, with 1874 road and 1903 railroad networks.

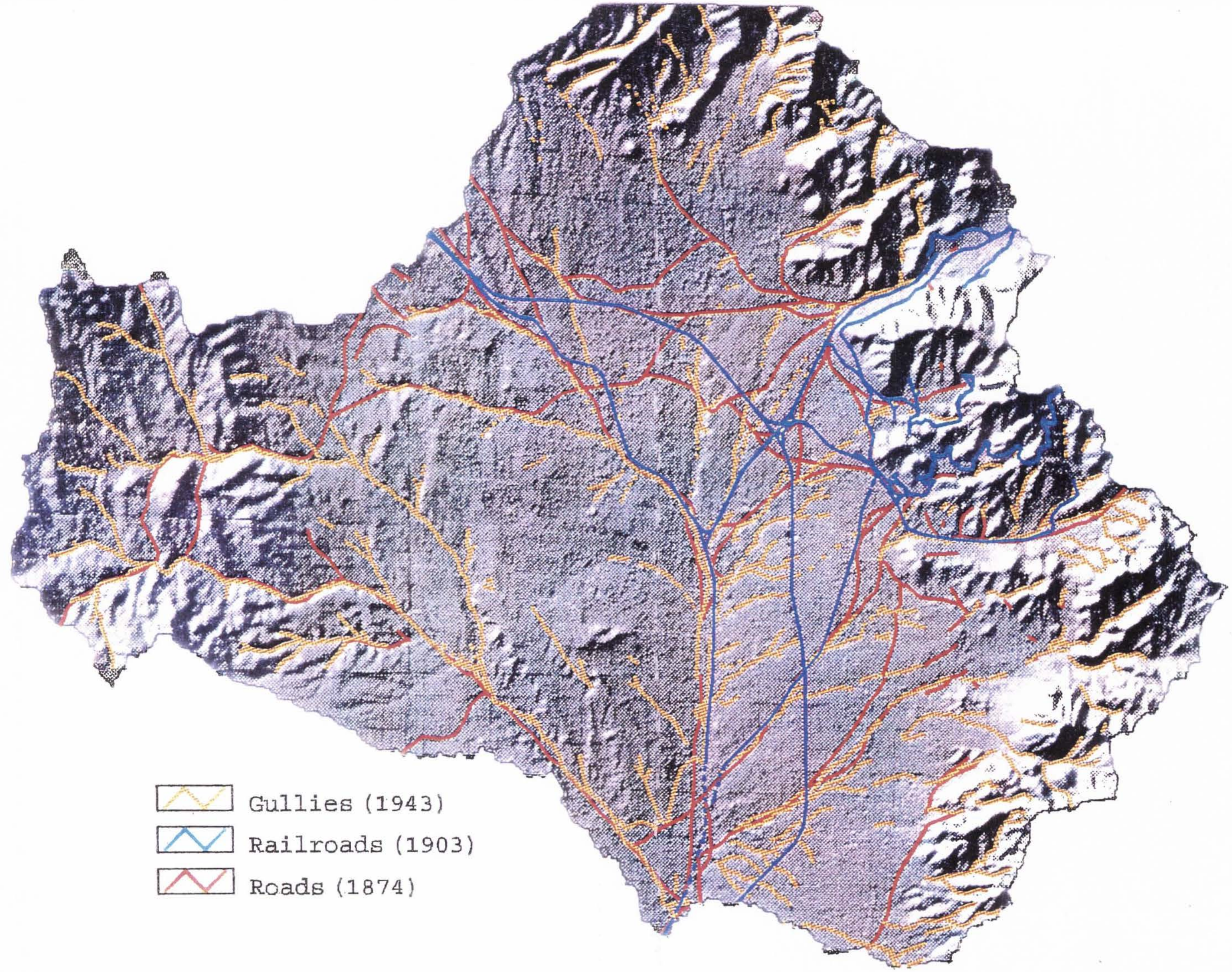

Gullies (1943)
Railroads (1903)
Roads (1874)

Fig. 35. Study area gully network, 1993, with 1874 road and 1903 railroad networks.

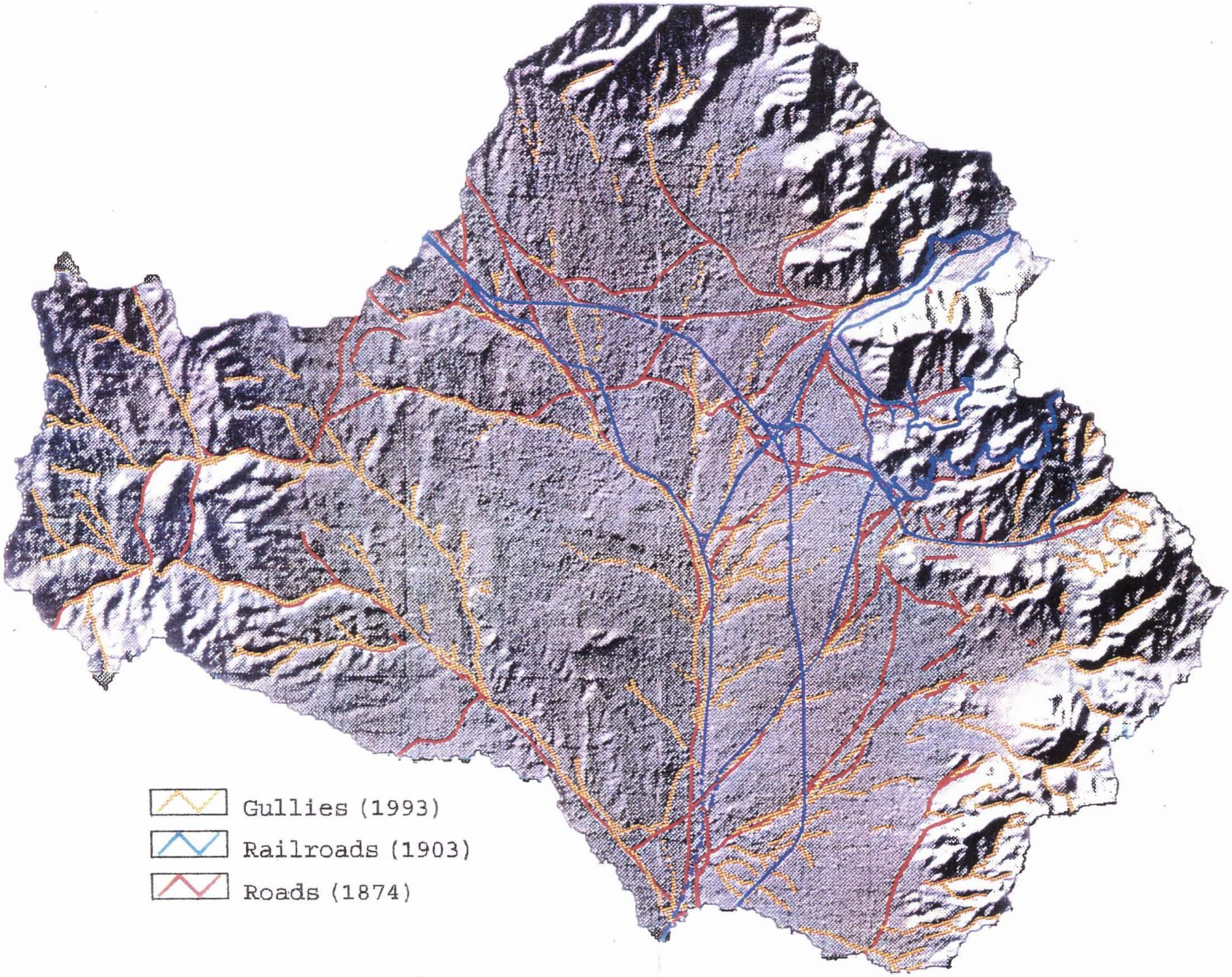

Gullies (1993)
Railroads (1903)
Roads (1874)

Fig. 36. Study area gully networks, 1874 and 1943.

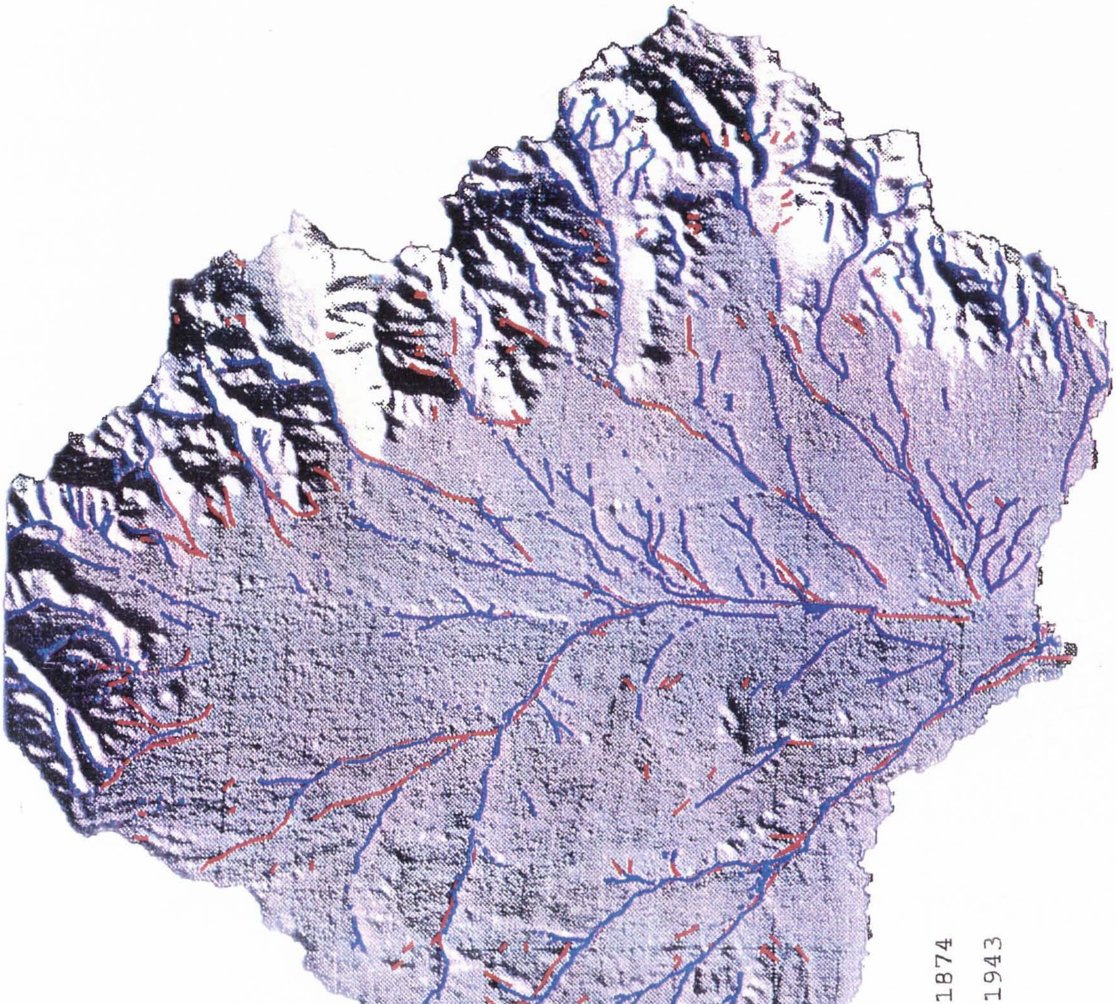
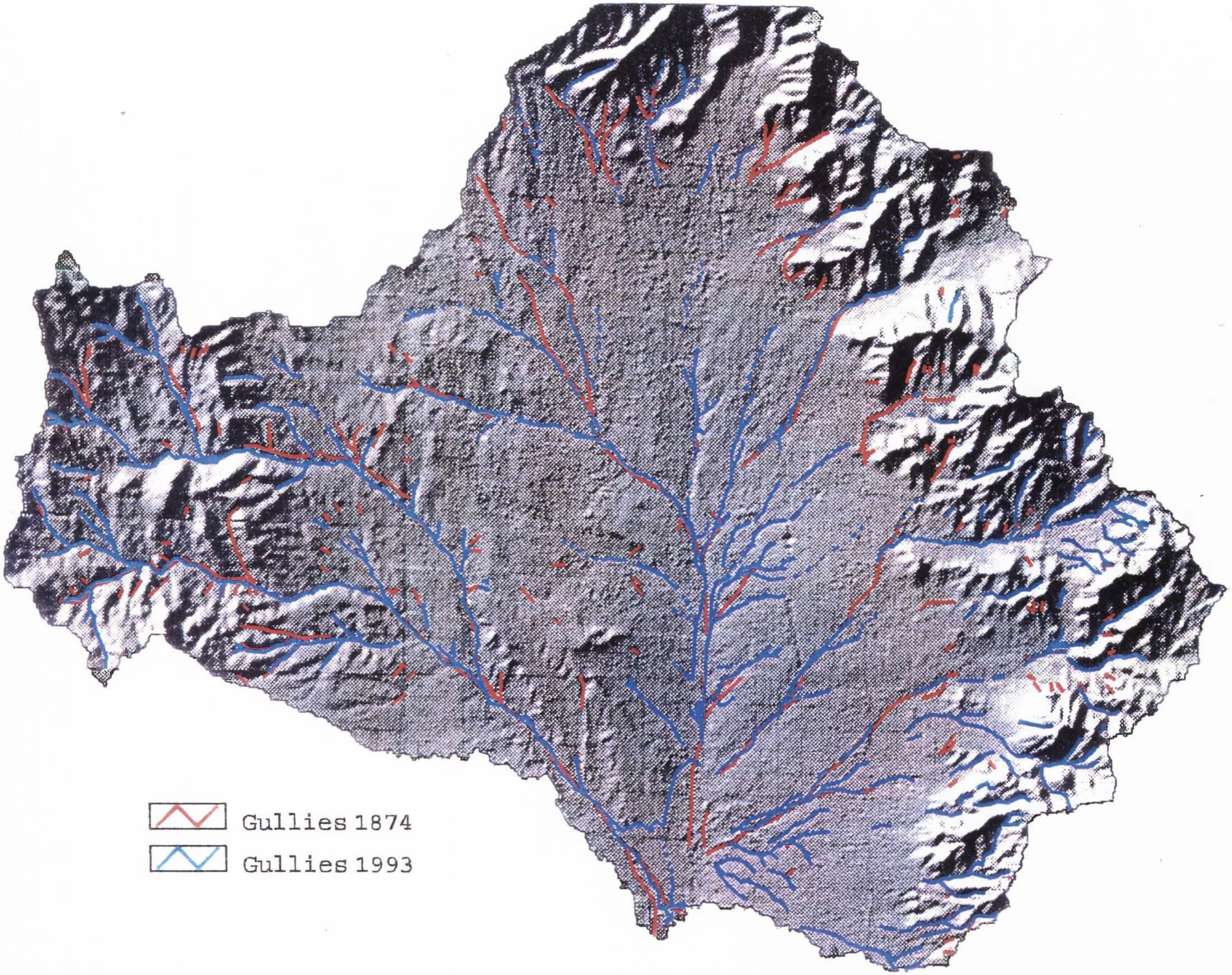

Gullies 1874
Gullies 1943

Fig. 37. Study area gully networks, 1874 and 1993.


Gullies 1874
Gullies 1993

Channel characteristics for the periods 1874-1943, 1943-1993, and 1874-1993 were evaluated qualitatively by comparing verbal descriptions from the 1874 General Land Office Survey with interpretation of 1943 and 1993 aerial photography. Results were tabulated categorically, with improvement in channel condition assigned a (+), degradation a (-), and no change a (=). A sign test (Zar 1984) was employed to statistically evaluate qualitative change in channel condition over the study period.

Field Study.--In order to further explore relationships among the modern gully network and historic roads, railroads and gullies, a field survey was conducted. Gully and road locations and descriptive information contained in the 1874 GLO survey were transferred to maps and a field notebook, respectively, and field checked during summer, 1995. Modern gully width and depth were measured.

Maximum and minimum widths were recorded to compensate for uncertainty associated with the exact location of the 1874 cross section. Photographs of each site were taken, and descriptive characteristics were recorded, including apparent channel stability, vegetation, and evidence of historic disturbance, if any. Spatial association between gully features and the Tintic Valley road and railroad network discovered in the field was recorded using photographs.

A total of 36 gullies yielded paired values for statistical analysis. Channel widths (in links and chains) recorded in 1874 were converted to meters and compared with the 1995 field data using a paired sample t-test (Zar 1984) to evaluate the statistical significance of observed changes in gully width across the 121-year (1874-1995) sampling interval. When a gully was found in 1995 where none had been recorded in 1874, the gully was assumed to have formed in the intervening period and assigned an 1874 width of 0 m. Both maximum and minimum differences between 1874 and 1995 gully widths were evaluated for statistical significance.

Results

GIS analysis.--By overlaying road locations in 1874, railroad grades in 1903, and gullies in 1943 and 1993, a clear spatial association among these linear landscape features is revealed (figures 34 and 35). The extent of the study area gully network has apparently increased since 1874 (figure 34). Further, that the bulk of this increase had occurred prior to 1943 is revealed by the fact that the gully network appears to have changed only superficially between 1943 and 1993 (figures 36 and 37).

Changes in gully condition, 1874-1995.--A confidence interval approach was taken to evaluate the statistical significance of the differences between observed and expected proportions of positive (+) and negative (-) changes in gully qualitative characteristics. An exact binomial test was equally appropriate, however the confidence interval approach offered an evaluation of statistical significance while additionally providing a measure of the degree of variability actually existing in the sampled population. In this case, the population consists of those gullies contained within the area of the 1872-1874 General Land Office survey. Table 14 summarizes the sign test results (see appendix 1 for statistical hypotheses and calculations of these values).

Change in gully width, 1874-1995.--The paired t-test results reveal a significant increase in gully width over the 121-year study interval. Three of the 36 gullies showed a decrease in width over the study interval. Figure 38 shows the mean minimum and maximum differences in gully widths between 1874 and 1995. Figure 39 shows mean gully width for 1874 and mean minimum and mean maximum widths for 1995.

Field observations.--Evidence of multiple cycles of deposition and entrenchment was noted in the field, most dramatically at gully points #72-76 (figure 40), where the channel network was so completely reconfigured from the 1874 description as to render three of the five cross sections unrepeatable. The deepest and straightest channels encountered in the field were consistently spatially contiguous with abandoned railroad grades.

Similarly, the most dramatic head cuts encountered in the field were those associated with Union Pacific Railroad grade culverts and the diversion of flows from natural channels. Eureka Creek (gully points 80b-80c, figure 40) was found to have

Table 14. Confidence intervals and exact probabilities associated with changes in the gullies of Tintic Valley, 1874-1993.

Parameter	1874-1943	1943-1993	1874-1993
Lower	1.7%	5.8%	5.9%
Upper	8.7%	22.9%	14.3%
Observed	6.25%	14.0%	13.3%
P value	0.0001	0.0001	0.0001

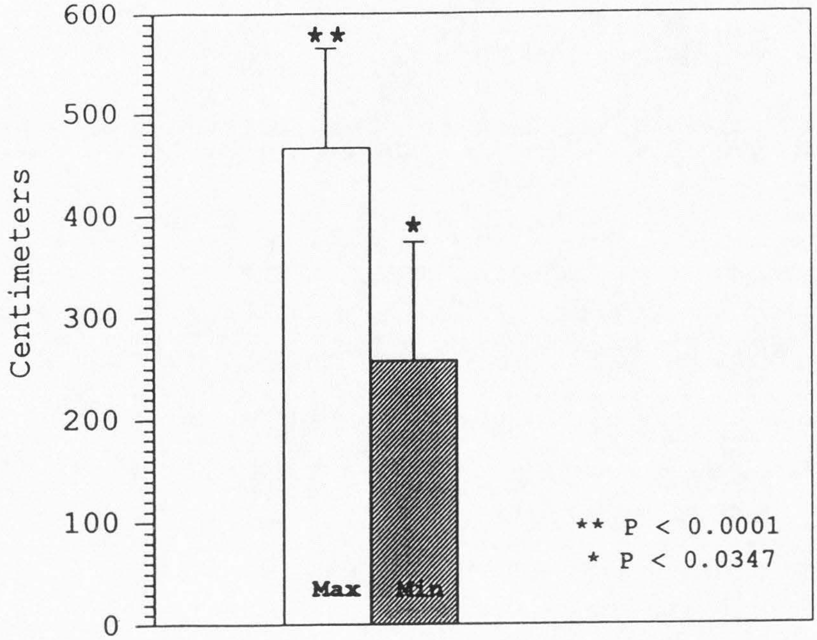


Fig. 38. Mean width change, Tintic Valley gullies, 1874-1995.

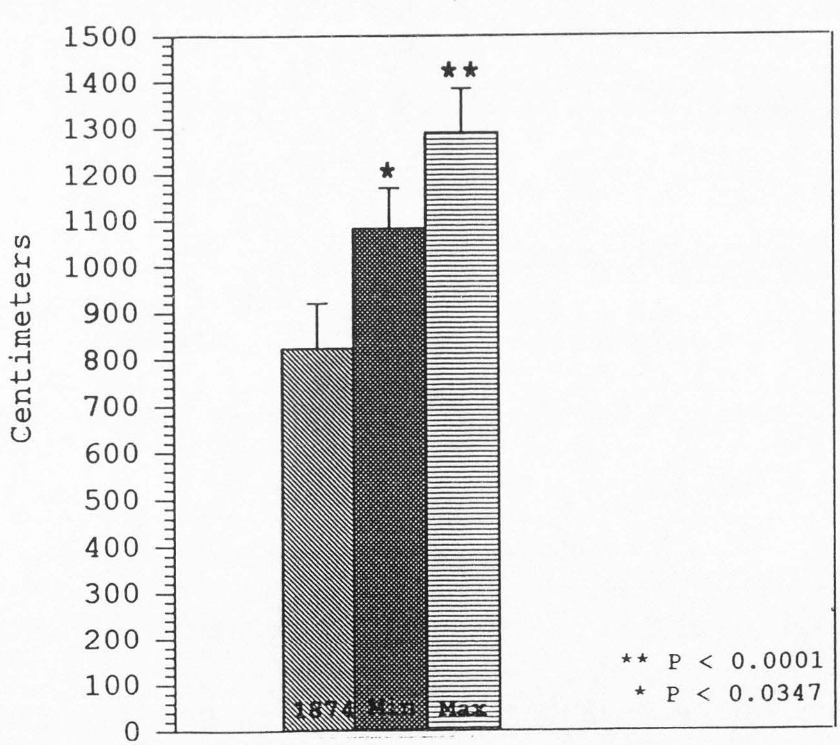


Fig. 39. Gully width, Tintic Valley, 1874-1995.

Fig. 40. Gully sample points.


1
2
48
86
46
85
84
57
83
58
80b
45
50b
50c
50
50a
49
53b
53d
53a
53c
79
81
92
82
80
80a
88b
88
93
95
90
89
101
100
91
44
43b
43
47
47b
42
41
78
77
51
52
75
74
4
40
41b
34
35
36
37
12
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20
24

been diverted from its original channel by railroad grades at Tintic Junction, constructed in 1883 (Alter 1932). This observation is supported by the fact that the geological substrate of the abandoned channel of Eureka Creek consists of Holocene alluvial deposits, while the modern day bed of Eureka Creek lies on fan deposits dating from the Pleistocene (Pampeyan 1989).

Post-settlement efforts to divert and maximize on-site retention of water include abandoned canals at Death Creek Spring (gully point #18), and two canals diverting flow from Death Creek to north and south ends of the meadow at the McIntyre Tintic Ranch (gully points #91 and 100). These diversions appear to be associated with smelter sites, possibly the Shoebridge and Tintic smelters, respectively (Chapter IV, table 1). The large dike or berm (gully point #100) associated with the historic Tintic Ranch headquarters may have been constructed to divert water from Death Creek to a smelter and/or mill at this site. This dike appears to have aggravated, if not actually caused, channelization of Death Creek.

Failure of this dike, located at the pour point of the study area drainage basin, appears to be linked to the entrenchment of Tanner Creek and the diversion of its channel to a point west, and, most suggestively, upslope, of its natural flood plain. This anomalous configuration can be explained by the following hypothesized series of events: At some point water accumulated behind the dike, to an elevation approaching that of the dike's high (west) end. Continued, or subsequent, flow from Death and/or Tanner Creeks, probably due to one or more convectional storms in the upper reaches of the watershed, lead to breaching of the dike at that end. As water the dike, and finally into the original grade of the valley floor. Cutting continued, incising the new gully below the elevation of the natural Death/Tanner flood plain and defining the new bed of Tanner Creek.

Death Creek apparently surfaced in McIntyre meadow in 1874 (Gorlinski 1874). The dike lies over the bed of the Central Utah Railroad grade, constructed in between 1874 and 1878 (Alter 1932), dating entrenchment of Tanner Creek at this location to some time after that period. Perhaps the dike was breached in the flash flood of July 1888, the year the creek was named. Field observation suggests the base level of the study area drainage basin has been lowered by 4.5 m in the historic era (gully point #100, figure 40).

Discussion

These results are interpreted to suggest that the extent of the gully network in the study area has increased in the historical period. The spatial and temporal coincidence of historic transportation corridors and water diversions with modern gullies revealed in this analysis suggest that roads and railroads played, and may continue to play, a role in gully dynamics in Tintic Valley. Results appear to support Cooke and Reeves' (1976) insight into the role of roads and railroads in arroyo formation, entrenchment, and location. It is important to recognize, however, that the complex response dynamics of high-energy drainage basins preclude the strict attribution of cause in geomorphic change (Bull 1991, Schumm 1991). Tintic Valley's early roads, for example, tended to be located along valley floors, where the terrain is most amenable to human, animal, and animal-powered vehicular traffic. Such locations are where finer textured, more readily erodible soils tend to accumulate, and where gully formation, by definition, occurs. Further, ephemeral streams of semiarid regions are inherently unstable, while climatic change has the capacity to initiate dramatic changes in the fluvial system without decreased resistance or lowering of base levels (Bull 1991).

Inability to consider change in gully depth (due to absence of data for this parameter in the 1874 data set) meant that quantification of channel entrenchment over the study period was not possible. Consequently, regardless of the paired t-test results, it is difficult to be comfortable with the view that this analysis adequately depicts the magnitude of change in the Tintic Valley network over the study temporal framework. It is entirely possible, for example, for a gully to maintain its width while continuing to downcut (Cooke and Reeves 1976, Schumm 1991). Furthermore, the possibility that multiple cycles of deposition and entrenchment have occurred at least locally in the channel network cannot be ruled out. Therefore, these results should be viewed as a highly conservative estimate of the degree of gully network change that has taken place in Tintic Valley since Euroamerican settlement.

Even using this conservative approach, the Tintic Valley channel network is revealed to have changed in a manner that is statistically highly significant over the study period, supporting rejection of the null hypothesis of no change. Lowering of the base level of the study area drainage basin by 4.5 m alone suggests historic era rejuvenation of the Tintic hydrogeomorphological system (Renwick 1992) and a change in behavior of the Tintic landscape across the study interval (Bull 1991). This in turn supports the broader hypothesis that a state transition has occurred in the dynamics of the study area since Euroamerican settlement (Chorley 1962, Leopold and Langbein 1962, Bull 1991, Renwick 1992).

Conclusion

Kondolf (1993, p. 226) has recognized channel geomorphology as "...the framework upon which the ecosystem develops." Channel geomorphology integrates the energetics of the landscape system (incoming solar energy, gravity via topography, and energy dissipation via physical and biological landscape features). It thus offers promise as an indicator of landscape integrity. Lags in channel system response to landscape disturbance, however, may render channel geomorphology an imprecise tool for monitoring. "Rivers and streams are often said to have 'long memories,' a notion derived from the fact that adjustments may continue for decades after the initial perturbation. Thus, channel adjustments to the elimination of stresses...may take a long time to become manifest" (Kondolf 1993, p. 226).

Campbell (1970) noted that generalizations with respect to regional arroyo dynamics are difficult due to the lack of long-term climatic and livestock data and historic vegetation surveys, as well as regional heterogeneity. Thus case studies such as reported here may be the only way of approaching the question of gully formation and change. While this investigation fails to definitively ascribe cause to the gullies of Tintic Valley, it does establish that many of the most significant gullies evident in the Valley today originated in the historic period and reveals a spatial and temporal association between the cultural artifacts of roads, railroads, canals and those gullies.

Wasson and Galloway (1986) found post-European settlement sediment yields in the Australian Barrier Range, a region with a mining and grazing history similar to that of Tintic Valley, to be some fifty times that of the previous 3000 years. They concluded that loss of relictual soils to historic erosion had resulted in the crossing of a threshold of system degradation to a state of irreversible change. Sediment transport capability of the Tintic Valley fluvial system in the historic era similarly appears to have increased.

Cycles of arroyo trenching and filling can be seen as examples of geomorphic change caused by positive feedback resulting in the crossing of a threshold into a new domain of system behavior (Chorley 1962, Schumm 1991). Bull (1991) has suggested that the threshold concept is especially appropriate in the context of human interaction with the environment, while cautioning that a temporary variation in the rate of aggradation or degradation alone does constitute a threshold. Rather, a threshold involves a change in the behavior of the geomorphic system, a change in system state.

While changes in vegetation cover, including species and physiognomy, have been shown to have a significant effect on infiltration rates and thus on rates of erosion (Spaeth et al. 1996), and while such changes have certainly occurred in Tintic Valley over the study period (Chapter V), concentration and channelization of overland flow by Tintic Valley transportation corridors appear to constitute overriding influences in the initiation, location, and configuration of Upper Tintic Valley gullies. The extension of the Tintic Valley gully network between 1874 and 1943, followed by relative stabilization since that time, suggests the system has moved toward a new dynamic equilibrium (Heede 1975, Renwick 1992), following a period of disruption coincident--in both space and time--with Euroamerican land uses in the Valley.

CHAPTER VII

CONCLUSION

All biological systems are open, demanding supply and removal of material and energy. Chorley (1962) has suggested that treating landscapes within an open system framework illuminates the relationship between form and process. Application of the open system perspective to landscapes draws attention to the multivariate character of most landscape phenomena, and directs attention to the whole landscape assemblage, rather than to the often minute elements imagined to have historical significance. Finally, the open systems paradigm acknowledges the pivotal role of the human animal and its cultural accoutrements in structuring landscape pattern and process.

From the record of historical impacts compiled here, it is evident that significant change in the Tintic Valley landscape has occurred in the historical period as a direct function of human action. Through intensive anthropogenic manipulation, patterns of the Tintic landscape have been altered. Evidence of changing patterns of vegetation, fire behavior, and geomorphology supports the hypothesis that landscape processes too have changed.

Bull (1991) has suggested that the threshold concept is especially appropriate in the context of human interaction with the environment. Many of the most significant gullies evident in Tintic Valley today are spatially and temporally associated with roads, railroads, and canals. This in turn suggests increase in the sediment transport capability of the Tintic Valley fluvial system and loss of relictual soils, constituting a change in system behavior, which Bull (1991) has suggested is a necessary and sufficient condition for the recognition of the crossing of a threshold to a new system state (Chorley 1962, Wasson and Galloway 1986, Schumm 1991).

Concentration and channelization of overland flow by transportation corridors appear to constitute overriding influences in the initiation, location and configuration of Tintic Valley gullies. Changes in vegetation cover, however, including species and physiognomy, have been shown to have a significant effect on rates of evapotranspiration, infiltration rates, and rates of erosion (Spaeth et al. 1996). Thus, the changing landscape vegetation mosaic revealed here has undoubtedly also played an important role in the rescaling of soil and water movement upon, through and from the Tintic landscape.

In suggesting that culture is an emergent, regulative property of the Total Human Ecosystem, Naveh (1987a) placed culture at the boundary between the environmental and human realms; a function of the relationship between the two. The lesson of over 11,000 years of human occupancy of the Great Basin suggests that relationship flourishes within strict, yet elastic, boundaries, defined by human material culture on the one hand and environmental constraints on the other (Grayson 1993). Environment delineates the boundaries of ecologically viable human behavior, while human culture, in a classic example of self-organization, both shapes and is shaped by that environment. To the extent that human impacts on the environment transcend the bounds of ecological viability, it is culture that fails us.

Turner et al. (1993) have noted that landscape equilibrium is a scale-dependent concept, and echo Naveh's (1987a) observation that different spatial and temporal scales of disturbance result in fundamentally different landscape dynamics. However, both Turner et al. (1993) and Naveh (1987a) addressed disturbance-mediated landscape dynamics in the context of repeated disturbance over time, even where the spatial and temporal scales of that disturbance may change. This work leaves little doubt that Tintic Valley has experienced significant disturbance in the historic period. Yet this disturbance, rather than a recurring, system organizing process, appears to fit a catastrophe model of change (Waddington 1975). Cumulative impacts on the Tintic landscape in the historic era can be seen as constituting a single event in landscape evolutionary terms. Spatially extensive, yet essentially instantaneous in time, this disturbance has resulted in the reconfiguration of both biotic and abiotic patterns and processes of the Tintic landscape. Such change, by definition, constitutes the crossing of a threshold to a new realm of system behavior, a new system state (Naveh 1987a, Bull 1991).

Chorley (1962) suggested that the relative value of a closed versus an open system paradigm depends upon the speed with which landscape features of interest become adjusted to changing energy flow through the system. Catastrophic change suggests rapid adjustment of the system, arguing for an open system conceptual framework in the examination of historical ecological change. While the temporal extent of this study has allowed only a glimpse into the past dynamics of Tintic Valley, it reveals how a unit of time longer than a human life may constitute but an instant in the evolutionary history of a landscape.

Neither open nor closed system models are capable of explaining all phenomena (Chorley 1962), yet equilibrium in closed systems is associated with stationary conditions at the point of maximum entropy; in biological systems this state is recognized as death. Recognizing landscapes as biogeocultural systems dictates that we regard them as open, living systems, capable of complex patterns of response, self-organization, and change.

Thus the lesson of Tintic Valley is both historical and timely. It begins by suggesting that people have always had a place on the land, a place we inherit by birth, yet retain by commitment. It teaches that human interaction with land, to endure, must be defined by relationship, rather than ownership. It teaches that culture divorced from place cannot last. The lesson of Tintic Valley is that our taking from the land must be inseparable from our giving, not as obligation, but as privilege.

CHAPTER VIII

SUMMARY: MANAGEMENT IMPLICATIONS AND SUGGESTIONS FOR FUTURE RESEARCH

This work has been an attempt to view historical change of a specific Great Basin landscape within a broader framework of ecological theory. Moving beyond narrative, the work has both provided a contextual analysis of the present state of the Tintic Valley landscape and rendered the historical ecology of Tintic Valley a useful analog for aiding in the understanding and prediction of ecosystem changes both within Tintic Valley itself and elsewhere in the region (Havstad and Schlesinger 1996). This work has revealed the Tintic Valley landscape to be unequivocally anthropogenic; landscape patterns and processes today are a function of historic and current human land use and resource exploitation practices upon, and in interaction with, nonhuman biotic and abiotic factors. Because so much of the ecological change reported here appears to reflect degradation of the landscape system that is Tintic Valley, this work, to some degree, also constitutes an assessment of historic damage to the integrity of that system.

Ecological histories offer insight into system dynamics by helping to define ranges of system behavior that may not be evident under current conditions. While ecological histories may thus serve as points of reference, historical system states should not necessarily serve as archetypes for modern management objectives. It would be particularly ill-advised to attempt to restore historic landscape pattern without reference to underlying processes (Tongway 1990, West and Whitford 1995), including the cultural ecology of system users. Too often, for example, non-use is lauded as the penultimate tool of ecological restoration, without reference to the specific system state to be "restored," the processes, including indigenous management practices, that initiated and/or maintained that state, or recognition of the assumptions underlying a paradigm in which rest is assumed to lead to a linear advancement of successional processes.

By understanding a landscape system's historical context and capabilities, the ecological potential for emergence of new system properties and the mechanism of positive feedbacks by which such properties emerge, managers have the potential to address the seemingly conflicting demands of preservation, restoration, sustainability, and production within a framework of the ecologically possible. The potentialities of any one ecosystem are clearly not limitless. Within inherent ecological limits, however, most particularly those of climate, some system dynamic can be achieved, through management of disturbance types and system components already present within the spatial and temporal domain of that system, that is optimum for the meeting of manager-defined objectives. Such management will be absolutely system-specific, yet at least one basic universal principle can be readily distinguished, that is, the appropriate scaling of system disturbances and management interventions for achieving specifically defined objectives. In this context, rest, as epitomized, for example, in fire suppression, itself must be seen as a disturbance that, when improperly scaled, can result in significant changes in system behavior (Holling

1986). This is graphically illustrated in the catastrophic fires currently (August 1996) burning throughout the Western United States in the aftermath of 50 or more years of active fire suppression in the region.

While land ownership in Tintic Valley is predominantly public, the interspersion of public and private lands and fragmented land use patterns of both, have historically resulted in a conspicuous lack of an ecosystem perspective in the management of the Valley's rich biotic potential. Historically, natural resource management in Tintic Valley, as throughout the West, has been characterized by the management of relatively static resource uses and commodities, rather than the management of dynamic processes (Wood 1994). The historical failure to manage Tintic Valley within an ecosystem framework results in, and from, the inability to focus available management resources --whether labor, livestock impacts, prescribed fire, seedings, etc.-- upon those system processes, or at scales, with the greatest potential to effect system change (Hilborn et al. 1995).

Constraints to such appropriately scaled management include the general failure of land management agencies, whether public or private, to recognize the complex, non-linear behavior of the system processes underlying the patterns they seek to preserve or change. Too often, system managers devote their increasingly limited resources to managing component parts of the system and/or addressing the perceived needs of a limited, commodity oriented constituency, thereby truncating the opportunity to manage the system as a whole (Allen and Hoekstra 1992). This dilemma is perpetuated, if not caused, by a reliance on a natural resource science which, as currently structured, avoids addressing ecosystem-oriented questions (Ludwig 1993). Thus, for example, research into methodologies for reseeding of rangelands has tended to focus on the development of specialized technologies and the use of exotic species considered desirable from a livestock production perspective, rather than on the identification of management strategies for enhancing natural processes, such as self-seeding of desirable native species, system hydrology, biodiversity, etc. (Havstad and Schlesinger 1996).

For example, evidence of significant change in the extent of the Tintic Valley gully network within the historic period suggests at least the following changes in Tintic Valley landscape dynamics: 1) increase in topographical relief due to channel entrenchment and lowering of base level of the Valley floor; 2) concomitant increases in basin-level potential energy, leading to increased erosivity of even "normal" overland flow and storm events; 3) decreased NPP due to decreased retention of water in Valley floor soils and probable loss of highly productive riparian and wet meadow sites. Xerification of the Valley floor, particularly at the McIntyre Tintic Ranch meadow, may have precipitated the change from cutting of native hay to the growing of irrigated alfalfa, which in turn may be leading to increased salinity of Valley floor soils as suggested by the presence of *Distichlis* and *Tamarix*. Implicit in the lowering of the Valley base level by at least 4 meters (Chapter VI) is the loss of hundreds of thousands of tons of sediments and soils from the Tintic Valley drainage basin, representing a hemorrhage of productive potential in the historic period.

Change in the Tintic landscape involves complex interactions among multiple factors, including landscape vegetation pattern, fire dynamics, and hydrogeomorphology. Regardless of the proximate causes of historical changes in the Tintic landscape, no attempt to restore or ameliorate the soil and water-holding capacity, and thus the productive potential, of the Valley can succeed without application of a systems-perspective in which the entrenched gully network is considered. Stream diversions, culverts, and channelized flow are all significant hydrogeomorphological issues in Tintic Valley that will have to be addressed in any landscape restoration plan or more localized range improvement efforts. Attempts to alter Tintic's vegetation from more xeric to more mesic species through reseeding or reintroduction of fire, for example, would and most certainly prove more successful if the issue of gully entrenchment is considered in site preparation.

Management of individual system components, without reference to the dynamics of the system as a whole, characterizes land management in the West. This is to some degree a function of land ownership patterns, which serve to fragment landscape pattern and process in both space and time, interrupting integrative landscape functions and, often, degrading or even eliminating those functions. Even where ownership patterns do not themselves result in fragmentation of ecologically rational management units, failure to overtly recognize and manage with system processes can result in system-undermining fragmentation. Such fragmentation occurs in both space, as exemplified in ecologically arbitrary livestock grazing allotment boundaries on public lands, and in time, as manifested, for example, in calendar-based grazing seasons and rotations that at best only coincidentally correspond with range readiness as expressed in plant phenology or soil conditions.

This type of management is rooted in the assumption that, left to themselves, landscape dynamics are essentially equilibrial in nature. This initial misconception underlies and justifies a model of natural resource management in which the role of management is to maximize economic offtake while minimizing impacts on the system. This perspective fails to recognize change as fundamental in landscape dynamics. Given the inevitability of change, maintenance of a desired system state over time necessarily involves some degree of perturbation to restrict system change within some acceptable range. An extreme example of the role of perturbation in maintaining a system state is the monocropped agricultural field, in which frequent soil disturbance in the form of cultivation is employed to maintain the system in the early phase of primary succession to minimize competition between the crop and weed species. An example more directly relevant to the landscape dynamics of Tintic Valley is the role of episodic fire in maintaining an open savanna system in the absence of edaphic limits to woodland occupation of steppe-dominated sites.

The key to ecosystem management is to maximize the natural functioning of the system while minimizing artificial subsidies; effective management results in maximization of the system's capacity to subsidize the management effort (Allen and Hoekstra 1992, Hollick 1993), while minimizing dependence upon ultimately unreliable technological solutions (Hollick 1993, Ludwig 1993, Stanley 1995). In this sense, it can be seen that what is needed for successful ecosystem management is not necessarily additional reductionist research, but scaling up from a mechanistic to a systems perspective in order to view the behavior of the system as a whole. I would argue that it is significantly more important to reintegrate fire into the landscape dynamics of Tintic Valley, for example, than to delay such an action until research into the effects of such a management strategy on every system component has been completed. This is not to suggest that fire alone, independent of explicit management objectives, is sufficient justification for such a proposed prescribed fire regime. What is known, however, is that Tintic Valley, along with much of the West, will burn. Failure to implement an intentional fire program with explicit management objectives (including fuel reduction) only serves to guarantee a future of large, expensive wildfires such as the region has experienced over the past decade.

At the same time, it must be recognized that identification of any "optimum" system state is a function of the demands placed upon it by a society which is itself in a state of dynamic flux, a flux that is not necessarily scaled to the dynamics of the ecological systems from which it draws its material sustenance. Bringing society's demands in line with the real-world capabilities of the systems that support it is the great challenge of our time, and system managers must be both realistic and firm in holding the ground against demands that are beyond the inherent capacity of the systems they manage (Clark 1995).

Because management without reference to a desired system state is impossible, the concept of managing for system integrity is inextricably linked to the cultural values of the system manager (Kay 1994). The simultaneously increasing, and apparently conflicting, needs for human sustenance and protection of global biodiversity may help define the general outlines of an "optimal" system state for many, if not most, managed ecosystems. Specifically, the challenge facing human society as a whole, and natural resource managers in particular, is the identification and implementation of management strategies that maximize and conserve local biodiversity, sustain and enhance landscape function, and produce a biological surplus (Rapport 1989, Hilborn et al. 1995). Further, under the currently dominant global economic paradigm, this surplus must enable offtake at an economic level that will, at minimum, meet the costs of managing the system while providing some degree of buffering against exogenous perturbations, whether biotic, abiotic, or cultural. The plummeting numbers of farmers and ranchers in the United States over the past five decades and the global trend toward urbanization of human populations attest to our failure to meet this challenge and underscores the urgency of our dilemma.

The failure of land management to meet the challenge of ecologic, economic, and cultural sustainability is at least as much a function of the economic system within which natural resource management occurs as it is a failing in the ecological finesse of land managers. If, for example, conservation of soils or species has no recognized social or economic value, support for such efforts will be lacking. Aldo Leopold (1966) noted this fact 50 years ago, and called for an economic partnership between farmers and game hunters to form a mutually beneficial relationship whereby habitat might be preserved. Today, his insights remain unclouded, while the stakes surrounding the issues he sought to bring to public awareness have only continued to rise.

Future Research

This work has provided evidence that historic, anthropogenic disturbance of a single landscape in central Utah has resulted in dramatic change in both landscape patterns and processes. That these changes have been primarily degradational is suggested both by the nature of those disturbances and by their consequences, written upon the landscape itself. Implicit, therefore, is the understanding that the productive potential of Tintic Valley is probably greater, perhaps much greater, than current landscape conditions would suggest. This hypothesized latent productivity in turn suggests a number of avenues for future research.

Jordan (1993) has argued that one way to determine the nature of human influence on an ecosystem is to attempt to reverse that influence through management. Fire regimes, perhaps more than any other disturbance type, have been altered by human activity (Christensen 1988), both through use and suppression (Jordan 1993). Thus, one of the most important hypotheses to be tested through future research in Tintic Valley is that pertaining to the role of anthropogenic fire in system organization and productivity. How might a change in fire regime have led the system across a transition threshold from a metastable state to a less ordered state? How might an appropriately scaled fire regime drive the Tintic Valley landscape to a higher level of organization? Undertaking such research would require clear, *a priori* decisions as to how such changes in system state will be recognized and/or quantified. Such ecosystem-oriented research could potentially be carried out using multiple paired watersheds nested within the Tintic landscape.

A critical research question that could contribute to this broader research agenda is that of the prehistoric fire regime(s) of Tintic's woodland and steppe communities. "Optimum" fire frequency under current cultural paradigms and global environmental conditions may, however, be quite different than that recognized as optimum by indigenous system managers. If maximization of carbon sequestration in biomass or soil, for example, is a management objective under a modern scenario of global warming precipitated by rapidly increasing levels of atmospheric carbon dioxide, a research agenda focused on identifying strategies for achieving this objective may take precedence over one seeking, for example, to identify strategies for increasing seed production in native perennial grasses. Similarly, a fire regime appropriate for maximizing carbon sequestration in soils may or may not prove the most appropriate for enhancement of sagegrouse habitat, etc. Thus, a range of fire frequencies and severities, along with variable degrees of livestock herbivory and tree removal, could serve as treatments within such an experimental program. Such a research program can be seen as a critical element in an adaptive resource management strategy (Allen and Hoekstra 1992, Hilborn et al. 1995, West and Whitford 1995).

Given the evidence of hydrological change in Tintic Valley provided by this work, it would be interesting to investigate alluvial soils along Tintic's main drainage, Tanner Creek, for insight into previous hydrologic regimes, evidence of beaver activity, charcoal deposits, lead, mercury, etc. Further, to help inform the choice of desired system state, there is an obvious need to identify those community and landscape vegetation patterns in Tintic's woodlands and steppe that are most desirable from a biodiversity perspective. Similarly, there is a need to identify management practices, including fire and agroforestry practices such as windbreaks and live snow fences, which can lead to enhanced production of economic components of the system, however defined (Rapport 1989). While livestock products may yet remain the most economically desirable yield from Tintic's rangelands, changing societal perceptions of values provided by rangelands (Havstad and Schlesinger 1996) may mean water, forage, and other rangeland components have the potential to outyield livestock in purely economic terms. For example, a comparative analysis of the economic and caloric yields of a perennial bunchgrass seed crop versus beef produced from the same land area could prove interesting.

There is a need throughout the Rangeland West to begin to view livestock production not as an end in itself, but as a by-product of a sophisticated land-use system (Havstad and Schlesinger 1996), in which enhancement of landscape integrity is the definitive management objective. This does not necessarily imply a decline in stocking rates, but will demand an unprecedented degree of cooperation among graziers, researchers, and agency personnel in both defining and achieving such an objective. Tintic Valley, with its mix of federally and privately owned land and an existing research presence under the auspices of Utah State University, has the potential to serve as a proving ground for such an approach in the pinyon-juniper/sagebrush steppe biogeocultural system.

The findings reported here suggest that historically disrupted processes in Tintic Valley include nutrient cycling functions linked directly to fire dynamics as well as soil building and stabilizing functions linked indirectly to fire dynamics via complex spatial and temporal relationships among plant community and site factors. Additionally, Tintic Valley hydrological functions have been disrupted directly by significant changes in the landscape gully network and indirectly by changes in overland flow and infiltration dynamics resulting from changes in the spatial and structural patterns of the landscape vegetation mosaic. As noted above, restoration or enhancement of these processes will require implementation of a sophisticated and flexible management strategy employing herbivory, fire, and other management tools to achieve specifically defined ecosystem and landscape objectives.

Theory and Management

Allen and Hoekstra (1992) have suggested that the great value of restoration ecology is as a device for the testing of ecological theory. Biocybernetics, including positive and negative feedbacks, self-organization, and the concept of system states and transitions between those states, offers a comprehensive theoretical framework for understanding observed change in the woodland/steppe system and for prognostication of modern management possibilities within that system.

Ability to predict the direction of system change is a requirement for managed restoration or enhancement of system dynamics. Thus, the theoretical perspective employed here is important insofar as it suggests a degree of predictability, however general, in the management of system behavior. It thereby suggests a mode by which management can move beyond addressing the visible symptoms of system degradation toward managing system dynamics. Just as grazing prescriptions derive from a theoretical framework in which factors as diverse as the ecophysiology of individual plants and the socioeconomics of ranching are components, so must any attempt at landscape management consider diverse interactions of multiple factors and processes. Without an overarching theoretical framework within which to organize myriad system components and processes, it is difficult to imagine how any landscape management model may be applied, tested, monitored, or evaluated.

Allen and Hoekstra (1992) have argued that natural resource management provides an ideal opportunity to investigate the effects of scale and the nature of hierarchical arrangements in natural systems. The theory of self-organization of complex systems provides a conceptual framework for entertaining the possibility that properly scaled use may have a role in sustaining, restoring, or improving ecosystem integrity. At the same time, it is recognized that natural systems are singular in form and process in space and time (Schumm 1991), so that extrapolation across or between landscapes may be difficult. Thus, while the specific processes and history of Tintic Valley should not be assumed to represent conditions on other landscapes of the region, they may nevertheless serve as potentially useful analogs of processes elsewhere in the Intermountain West. The potentially generalizable insight to be gleaned from specific case studies can be seen as further justification for use of a broad theoretical framework from within which to view location-specific phenomena

(Shrader-Frechette and McCoy 1993, Kay 1994). Finally, Jordan (1993) argued that real insight into ecological processes can only be derived from attempts to apply ecological understanding to management or restoration of the system of interest, thus enabling the testing of hypotheses about the workings of that system.

Risk, Management and the Future of Rangelands

Under a paradigm of nonequilibrial dynamics, ecosystem change is the rule, rather than the exception. In the face of global anthropogenic disturbance, passive management strategies which rely on "natural" successional processes are, by definition, *a priori* doomed to failure. Management of ecosystems must be a proactive process, if only to counteract those anthropogenic disturbances, such as fire, fire suppression, livestock impacts, timber harvest, etc., which, when improperly scaled, so often serve to compromise the integrity of ecosystems. By embracing disturbance as a mediator of system behavior, managers can recognize these same "disturbances" as tools with which to maintain the system within a specific realm of behavior, or move the system across positive thresholds of change into desired domains.

All rangelands are, by definition, at risk of degradation through injudicious use and/or the collateral effects of human impact on the greater global environment, including climatic change. To maximize rangeland ecosystem potential, that is, productivity, stability, resilience, and diversity, we need to begin to manage our rangelands proactively. We need to recognize rangeland systems as open, living systems and recognize their capacity to respond synergistically, via processes of positive feedback and self-organization, to effectively transcend limits imposed by current state variables. And we need to recognize ourselves as critical, keystone elements in those systems.

The end of the American Frontier means that we must begin to take the long view, to engage with and protect both landscape processes and the diversity deriving from those processes (Naveh 1994). To restore what has been lost will demand a restoration of human commitment to, responsibility for, and relationship with land. While this must ultimately involve transformation of the individual, the spatial and temporal scales involved in the bulk of global ecological processes suggest that landscape restoration must be engaged as a cultural phenomenon if it is to be successful.

We must stop viewing our landscapes as two-dimensional phenomena in which the function of management is to maintain an arrangement of static figures in the image of a pristine chimera. Under current global conditions of nearly universal ecological degradation and rapidly increasing human population, it is imperative that we begin to think and act four-dimensionally, recognizing landscapes as structured processes, i.e, structures in time and processes in space. Landscapes are dynamic, operating always within some range of potential that is itself changing over time in response to both local and global factors. We must begin to manage our landscapes as what they are--dynamic, living systems with demonstrated capacity for catastrophe, but also for change, growth, and surprise.

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APPENDICES

APPENDIX 1

SIGN TEST ANALYSIS

QUALITATIVE CHANGE IN GULLY CHARACTERISTICS

1) 1874-1943.
Ho1: There is no difference in gully conditions of Tintic Valley for 1874 and 1943. ($P = 0.5$)
Ha1: condition of the gully network of Tintic Valley changed 1874-1943. (P ne 0.5).

$n = 64$. Four (4) differences were classified as positive (+) (improvement in gully network conditions); Sixty (60) differences were classified as negative (-) (decline in gully network condition).

for the lower 95% confidence limit:
$v1 = 2(n-X+1) = 122$
$v2 = 2X = 8$
$F_{0.05(2),122,8} = 3.73$, and,
$L1 = 4/4+(64-4+1)3.73 = 4/231.53 = 0.017$

for the upper 95% confidence limit:
$v'1 = v2 + 2 = 10$
$v'2 = v1 - 2 = 120$
$F_{0.05(2),10,120} = 2.16$, and,
$L2 = 4+1(2.16)/64-4+(4+1)2.16 = 6.16/70.8 = 0.087$

Thus the "true" proportion of '+' changes, 1874-1943, is between 1.7% and 8.7%, while my observed proportion is $4/64 = 0.0625 = 6.25\%$, at a level of confidence of 95%.

The exact probability for the observed results can be derived using the Exact Binomial Test (Susan Durham, pers. com., Zar 1984) where:

$P = P(X \leq 4, n=64, p = 0.5) + P(X \geq 60, n = 64, p = 0.5)$.
$P < 0.0001$. As noted above, this P value, while strongly supporting rejection of the null hypothesis of no change in condition of the gully network, 1874-1943, does not yield as much information as the confidence interval approach.

Repeating the above Confidence Interval test procedures for the remaining two temporal periods:

2) 1943-1993:
Ho1: There is no difference in gully conditions of Tintic Valley for 1943 and 1993. (P = 0.5)
Ha1: condition of the gully network of Tintic Valley changed between 1943 and 1993. (P ne 0.5).

X(-) = 7, and n = 50, so that p(-) = 7/50 = 0.14 and,
for the lower 95% confidence limit:
v1 = 2(n-X+1) = 2(50 - 7+1) = 88;
v2 = 2X = 14
$F_{0.05(2),88,14}$ = 2.58; and,
L1 = 7/7+(50-7+1)2.58 = 7/120.52 = 0.058

for the upper 95% confidence limit:
v'1 = v2 + 2 = 16
v'2 = v1 - 2 = 86
$F_{0.05(2),16,86}$ = 1.97 and,
L2 = 7+1(1.97)/50-7+(7+1)1.97 = 15.76/68.76 = 0.229

Thus the "true" proportion of '-' changes, 1943-1993, is between 5.8% and 22.9%, while my observed proportion is 7/50 = 0.14 = 14%, at the 95% confidence level.

By the exact binomial test, P < 0.0001.

3) 1874-1993:
X(+) = 8, and n = 60, so that p(+) = 8/60 = 0.133, and:
for the lower 95% confidence limit:
v1 = 2(n-X+1) = 2(60 - 8+1) = 106;
v2 = 2X = 16;
$F_{0.05(2),106,16}$ = 2.40, and;
L1 = 8/8+(60-8+1)2.40 = 8/135.2 = 0.059
for the upper 95% confidence limit:
v'1 = v2 + 2 = 18
v'2 = v1 - 2 = 104
$F_{0.05(2),18,104}$ = 1.89, and,
L2 = 8+1(1.89)/60-8+(8+1)1.89 = 9.89/69.01 = 0.143

Thus the "true" proportion of '-' changes, 1874-1993, is between 5.9% and 14.3%, while my observed proportion is 8/60 = 0.133 = 13.3%. P < 0.0001, at the 95% confidence level.

APPENDIX 2

TINTIC VALLEY PRECIPITATION

Figure A.1 shows annual precipitation as recorded for all known Tintic Valley precipitation stations (table A.1). The longest continuous record available for the region as a whole was the ninety year monthly record from the Elberta station, which is located in Goshen Valley, approximately nine km east of Tintic Valley. Although consistently slightly drier than Tintic stations, this record was used to describe precipitation patterns in Tintic Valley because of its longevity. The few values missing from the record were derived using the ten year mean for that month, calculated from the five years preceding and following the missing value. The Elberta record was used to derive a twenty year running mean of precipitation, thereby revealing longer term trends in precipitation pattern for the region (figure A.2). Figure A.3 shows annual deviation from the mean precipitation of 270 mm for the Elberta record. The coefficient of variation for Elberta's ninety year precipitation record is just under 26%.

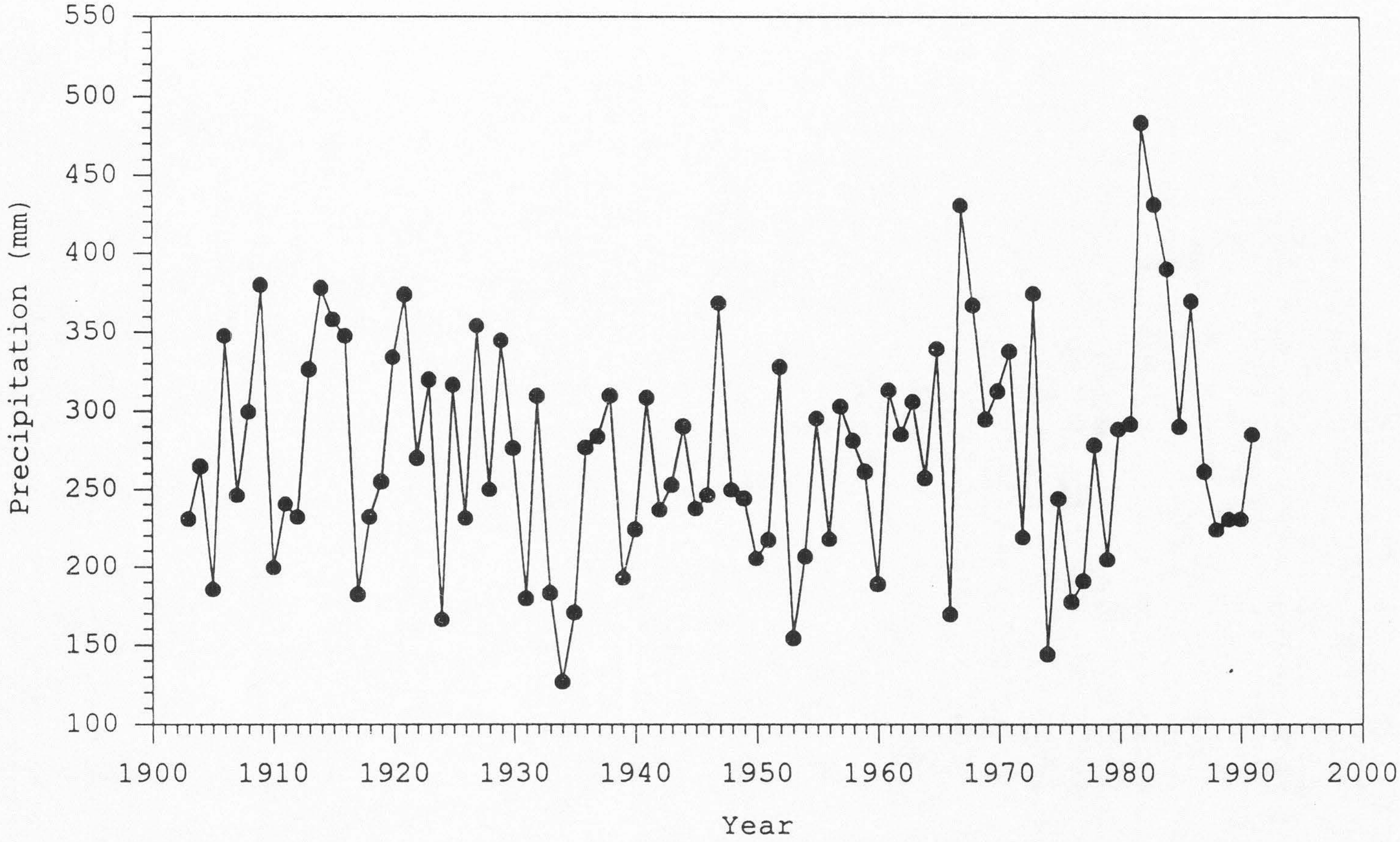

Fig. A.1. Water year precipitation. Elberta, Utah, 1903-1991.

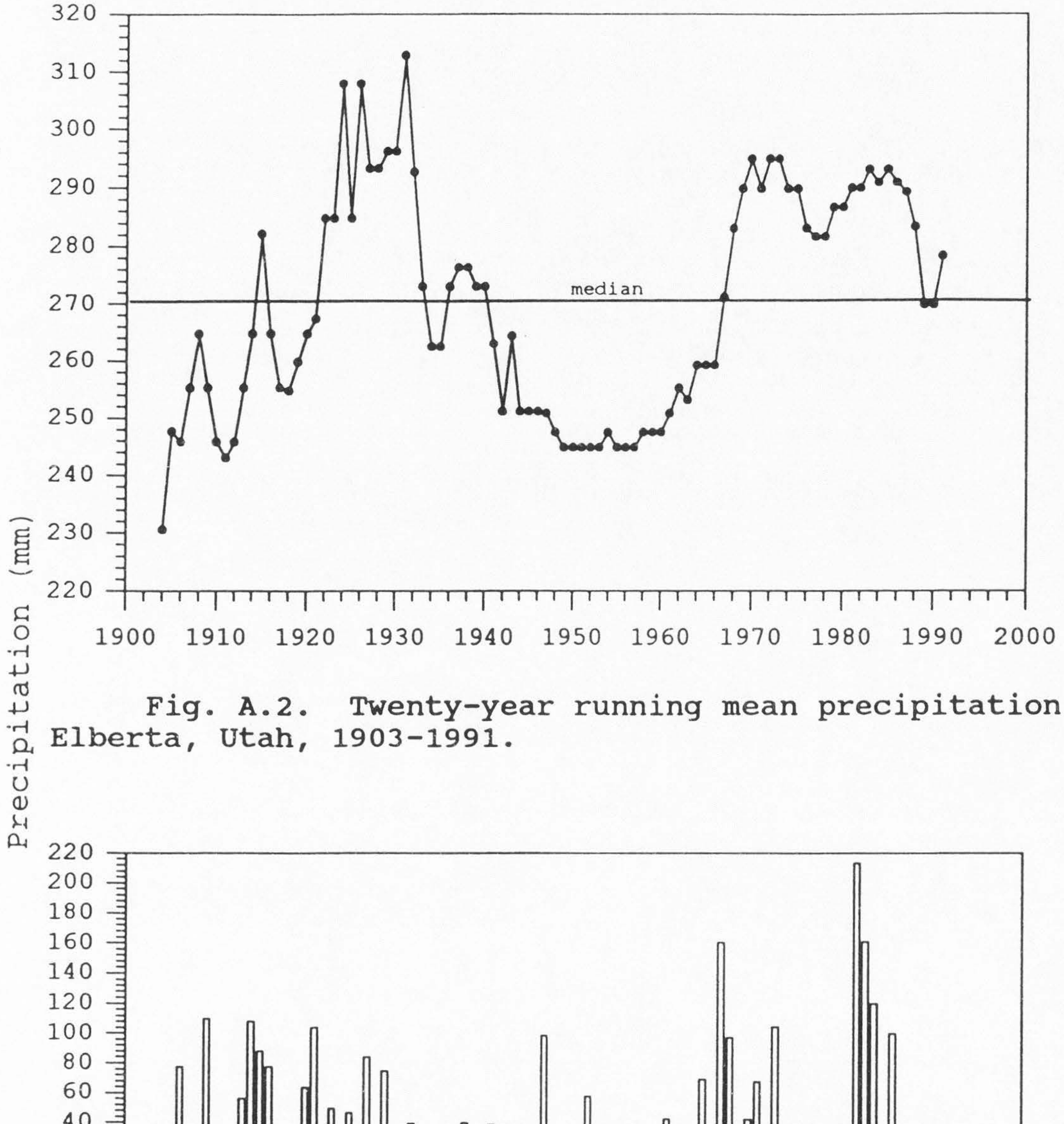

Fig. A.2. Twenty-year running mean precipitation. Elberta, Utah, 1903-1991.

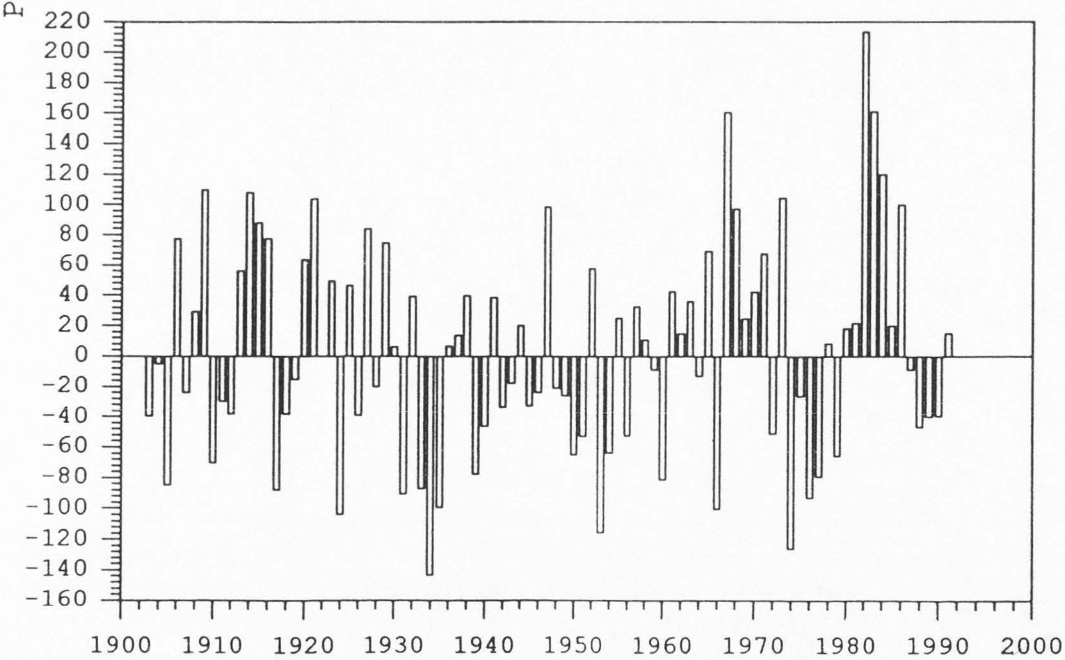

Fig. A.3. Deviation from median precipitation. Elberta, Utah, 1903-1991.

Table A.1. Precipitation stations in or near Tintic Valley.

Station	Latitude(dd)	Longitude(dd)	Elevation(m)	Period
Elberta	39.95	-111.95	1427	1/02-8/92
Silver City	39.92	-112.13	1869	1/10-5/17
Eureka	39.95	-112.12	1976	4/30-2/80
Tintic	39.88	-112.13	1793	3/80-10/90

dd = decimal degrees

All data was derived from monthly records, except Silver City, which was derived from a daily record. All stations had some missing values.

Sources: Utah Climate Center, Utah State University, and Garrett Bartells, Department of Rangeland Resources, Utah State University.

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(October 1996)

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