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*The state of the physical environment is reviewed and the importance of grazing in complex rural livelihoods is assessed in the hitherto little studied Tarija altiplano, Bolivia. Past and contemporary climatic fluctuations have dominated environmental change and are reflected in landforms, soils, vegetation, and land use. Broad fluctuations of dry and wet phases, 200–500 years long, occurred between BC 1500 and the 19th century. Warming has taken place during the 20th century, the final decades characterized by sharp climatic fluctuations (drought and floods) typical of the El Niño southern oscillation. Grazing by sheep and cattle—introduced by Europeans 500 years ago—has affected vegetation, but current grazing pressure alone does not explain the differences in biomass. In most of the areas grazed, present-day herds appear not to affect the quality of the vegetation any more than during the past 500 years. The term overgrazing is misleading, given the complexity of vegetation changes. Transhumance, shareherding, rotations, and the use of microenvironments (*bofedales *and marshland) ensure optimum recovery of pastures. Given access to other pastures at times of climatic stress, as well as seasonal migration, existing resource use appears ecologically sustainable. It is uncertain whether the security offered by pastoralism will meet the rising livelihood expectations of the young.*

Keywords: *Grazing; vegetation; household livelihoods; Tarija altiplano; Bolivia.*

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Introduction

Grazing is frequently blamed for the sparse vegetation on much of the high plateaus of the central Andes. This article describes and assesses the effect on the natural environment of land-use systems prevailing in the altiplano of Southwest Tarija in the late 1990s. The role of grazing as one part of complex household livelihood strategies is analyzed, as well as the extent to which the use of natural resources by households is sustainable.

An interdisciplinary team of social and natural scientists has carried out fieldwork in the highlands and valleys of Tarija since 1992 (Figure 1). During this time we have become increasingly aware of the importance of altiplano and mountainside pastures to both altiplano and valley dwellers as well as the role of livestock in the livelihoods of households (Preston 1998). Detailed fieldwork and archival research by a team of geographers, botanists, and an agricultural scientist focused on a series of altiplano and valley communities and provided a basis for understanding their livelihood strategies. Mapping of vegetation by Beck et al (2001) involved fieldwork covering the whole area between the Río San Juan del Oro and the eastern margins of the Tarija valleys to the south of the city of Tarija. Geomorphological research reported by Maas et al (2001) included mapping flood histories by means of lichonometry and detailed morphological mapping with dating supplemented by ^{14}C and photoluminescence in the upper Alizos Valley and the Quebrada de Barbascuyo in the valleys of Tarija and the Turcumarca subcatchment on the adjacent altiplano. More detailed research based on field observation and interviews with groups and individuals in over a dozen valley and altiplano communities focused on recent past and present livelihoods, management of environmental and other risks, and local perceptions of environmental change (reported in Preston 1998; Fairbairn 1999, 2000). Most of the detailed fieldwork in the altiplano was carried out in the communities of Copacabana and Arenales. Current work is based in Chorcoya. Research on the soils, vegetation, and landforms has provided important evidence of how the environment is changing during a 100- to 500-year period. This article presents a synthesis of the work by scholars from different disciplines and offers some conclusions about the consequences of the interaction among people, their livestock, and the environment in the Tarija altiplano, a hitherto little studied part of highland Bolivia. It shows how traditional and modern elements of production are interwoven in contemporary livelihood strategies over a much wider range of localities than might be expected.

Since the land reform of the 1950s, land-use systems in the Tarija altiplano seem to have changed slowly. Livestock numbers appear to have increased during the first half of the century—although data from tax records for 1906 are not entirely reliable—but have changed only a little in the period since the land reform, as shown by excellent baseline data collected as part of the land reform process and in a number of recent surveys (Preston 2000). Travel to Argentina has become easier and more common. The sheer proximity of the Argentine border—only a couple of days' walk or a few hours by bus or lorry from the lakes of Tajzara—has facilitated migration from Southwest Tarija. The opportunities for employment (at least before the economic collapse of 2001–2002) and the markedly better quality of life in Argentina encouraged migration. Altiplano household livelihoods incorporate earnings from

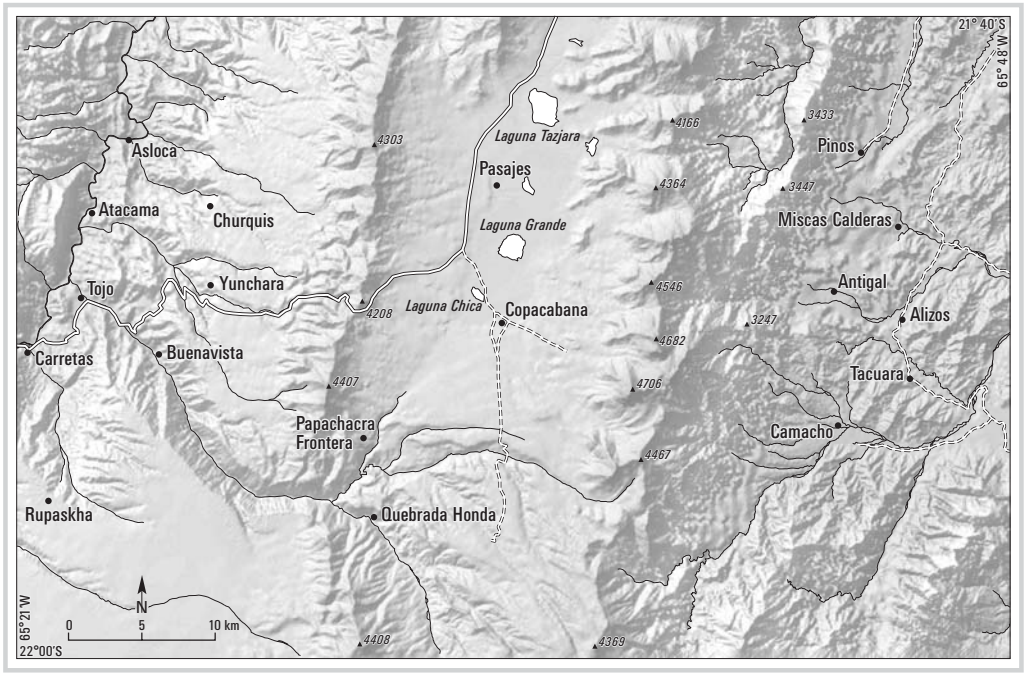

FIGURE 1 The Tarija altiplano in Bolivia. (Map courtesy of the University of Cantabria; see Silió Cervera et al 2001)

periods in Argentina to allow an adequate quality of life to be maintained in conjunction with pastoralism and some cultivation (Fairbairn 1999). This poses important questions about pastoralism in the future.

This article first reviews the state of different elements of the physical environment to show the nature of past and contemporary changes, in order to consider the sustainability of current household livelihoods. The second part describes and analyzes the structure of livelihoods to show the relative importance of grazing to altiplano households.

Climate, landforms, and vegetation

Climate imposes stresses on farmers through periods of drought as well as events such as floods. As in the Central Andes as a whole, in the Tarija altiplano and adjacent valleys, 95% of the annual rainfall falls in the months of October–April. There are long periods of the year with very little rainfall, during which plants and livestock are under considerable stress. During the wet season, rainfall is not evenly distributed, characteristically falling during short, intensive storm events. This makes management of natural resources challenging and risky for the local population (Fairbairn 2000).

There is also a strong annual to decadal pattern of climatic variability associated primarily with the El Niño southern oscillation (ENSO). During strong ENSO events, drought commonly occurs on the Andean Altiplano in the austral summer, whereas during anti-El Niño or La Niña phases, precipitation increases (Thompson et al 1984; Tapley and Waylen 1990). Our work in the Alizos catchment identified links between strong La Niña events and flooding in the Alizos catchment (Maas et al 2001). However, because of the high degree of variability of precipitation, wetter than average months also occur during dry ENSO periods (Preston 2000).

The climate has changed markedly throughout the period of human occupation of Southwest Tarija. Periods of relatively high rainfall that would facilitate plant growth and allow livestock to graze on abundant vegetation alternated with centuries of drier or colder climates. Historical human land-use systems will have responded to these changes (Figure 2). The 20th century can now be seen as a century during which warming took place (Vuille and Bradley 2000). The last decades of the century experienced more of the sharp climatic fluctuations typical of conditions influenced by the southern oscillation.

FIGURE 2 Vestiges of prehistoric terraces near Chorcoya, Tarija altiplano. These remnants indicate that the climate was once more favorable to cultivation in this dry area. (Photo by David Preston)

Landforms and earth surface processes

The basins of the Tarija altiplano are internally drained, and lakes mark points of water accumulation.

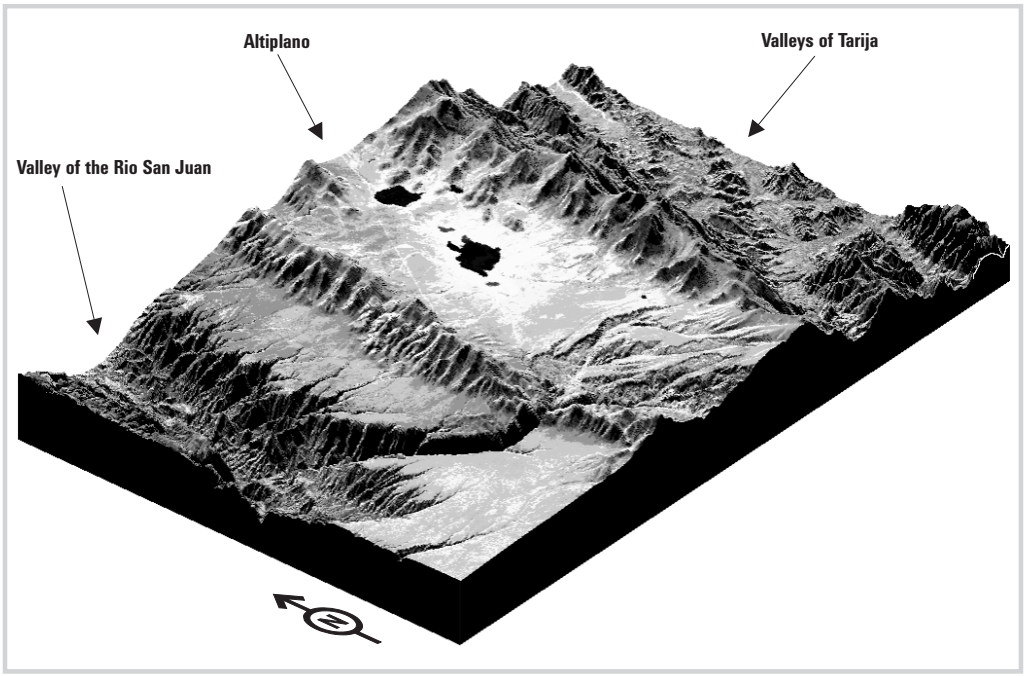

FIGURE 3 Block diagram of the Tarija altiplano looking eastward. (Source: Silió Cervera et al 2001)

The excess of evaporation over precipitation sometimes leads to saline accumulations in the soils and around the lakeshores. Slopes are predominantly gentle, except for the steep mountain front that drops from the edge of the altiplano to the valleys to the west and east. Areas of most active erosion are found on the steep slopes where parent material is most easily eroded and at the heads of valleys incised into the altiplano surface. These are most visible in the southwest of the altiplano, where western margins are not marked by low hills and the Río San Juan cuts back into the flat surface most dramatically in Quebrada Honda (Figure 3).

Local evidence can thus be added to that from elsewhere in the Andes to suggest how climate change affected landform processes, in particular erosion and the deposition of sediments. Erosion is particularly active when aridity (and other factors such as grazing) reduces vegetation cover and makes storms more able to remove surface materials. The recent decrease in flood frequency and severity—also noted in the Tarija valleys—suggests that vegetation cover is now better than during the Little Ice Age (Maas et al 2001).

Soils

Characteristics of soils and soil-related factors can act as indicators of environmental change. Based on preliminary study of chemical and physical soil properties, surface characteristics, and biomass, the effect of grazing pressure on environmental change was assessed (Coppus 2000). Studies of this type in the semiarid Andes are scarce (Denevan et al 1986; Woodward 1994; Eash and Sandor 1995) and contain little quantitative data. Although biomass is generally low when compared with studies in similar ecosystems (Liang et al 1989; Archibold 1995; Zhang and Skarpe 1996), on the Tarija altiplano it varies considerably from 300 to 3800 kg/hectare (Coppus 2000). In the mountains and footslopes, biomass is higher than on the gentle slopes of the plateau and is particularly low close to the lakes. The biomass gradient partly reflects greater rainfall in the mountains than on the plateau, and the low biomass close to the lakes reflects the saline soil conditions (Figure 4).

Grazing pressure alone cannot therefore explain current differences in biomass. Sheep graze both the plateau and the mountain slopes and also graze pastures on the other side of the watershed. It is probable that the use of multiple zones has increased with time because livestock numbers have increased and alternatives to the more convenient plateau grazing were needed. The low biomass on the plateau may be influenced more by historical than by current grazing pressure.

FIGURE 4 Tarija altiplano south of Chorcoya. This view shows walled fields, some of which are seasonally cultivated, extensive grazing areas, saline lagoons, and an accumulation of wind-blown sand in a small area of sand dunes. (Photo by David Preston)

Vegetation

Only traces remain of the vegetation that prevailed before human interference. Climatic change as well as direct and indirect human influences during the past 20,000 years have left a landscape dominated by low scrub and grasses. Trees occur only on isolated mountainsides. Given the antiquity of the major changes, identification of these during the past century is complex. Detailed palynological studies are needed using cores from the lakes in the Tarija altiplano. They could throw much light on the history and trajectory of change.

Current vegetation formations offer specific resources to grazing livestock. The vegetation of the Tarija altiplano is largely composed of open tussock grassland, a low grass sward in the small humid depressions, and a low evergreen scrub with spiny shrubs, small rosette, and cushion-form plants such as *Plantago tubulosa* and *Hypochaeris taraxacoides*. The vegetation cover is relatively scanty; there are areas with a large proportion of the soil bare and others with relatively high vegetation. On the hill slopes there are a few places with patches of low but open forest, dominated by small evergreen trees such as *queñua* or *quewiña* (*Polylepis tomentella*).

Local people report that the grazing available on the higher slopes (and over to the east), where cattle graze throughout the year and sheep during the dry season, is of relatively poor quality. Neither *iru ichu* (*Festuca orthophylla)* nor *paja amarilla* (*Stipa leptostachya*) offers good grazing other than from the young shoots. Some humid areas, where clouds gather on the east-facing slopes, have better pastures.

The lower slopes, toward the basin floor, offer the best grazing for sheep. The *chillagua* (*Festuca hieronymi*) is particularly valued for its high protein content (8%), as well as other grasses such as those of the genus *Deyeuxia*. Most of the fenced pastures are in this area, where *chillagua* grows to a height of 1 m, offering abundant forage in comparison with the open grazed areas. In the lower areas and near the lakes, *k'hanlli* (*Tetraglochin cristatum*) is considered a good source of forage by local people.

The nearby humid *bofedales,* as elsewhere in the Andes, represent an important resource for grazing livestock, especially in winter, when other areas have little plant growth. The soils rich in organic matter and with adequate moisture for year-round growth are able to support quite high livestock densities. The dense swards that develop where there is moisture near lagoons and in depressions where runoff collects after storms are grazed intensively. The perennial grasses *brama* (*Distichlis humilis*) and *bramilla* (*Muhlenbergia fastigiata*) grow quickly after rain and are important for grazing, as well as other species such as *Chondrosum simplex*. These species tolerate the salty conditions of the dry season.

The need to enable adequate growth of vegetation after grazing and the seasonal differences in forage availability have prompted people to manage grazing through a complex daily, weekly, and seasonal set of livestock movements. Cattle graze the highest areas but especially the more humid east-facing high mountain slopes, where moisture from clouds allows plant growth even during the dry season. The dense grasslands contain several species of *Deyeuxia, Agrostis,* and *Bromus,* some *Stipa* species, and creeping herbs such as *Lachemilla pinnata* that are preferred grazing for the cattle. Here, cattle from altiplano communities graze near cattle from the valleys, also seeking dry-season pasture. Access to these pasture areas is controlled by custom, but conflicts between communities occur.

Livestock management systems

Livestock are managed in various ways in the altiplano and adjacent valleys to make use of very different environments. The Tarija altiplano has large open plains bordered on both sides by steep mountain slopes, dissected by seasonally dry river valleys. The houses are located at the foot of these slopes and within the shelter of the larger river valleys. Sheep are grazed in weekly rotations on the flat surface and on the hill slopes. In the dry season they are taken to the higher pastures and return to the plateau when the rains begin. Sometimes the flock is divided, and some graze the lower areas and others the higher areas. Some take their sheep over the watershed to high slopes overlooking the Camacho Valley between April and June (cows and sheep) and also between September and November (sheep). Ewes with newly born May lambs graze in walled pens (*potreros*) with tall grass while their offspring suckle. The grass lasts until around August, when the lambs are commonly fed barley. Lambs born in October graze the slopes directly. Local grazing patterns are complex and involve constant movement of livestock to make the best use of available pasture. Sheep are corralled at night, allowing the accumulation of valued dung for use on cultivated fields or (rarely) fenced pastures and for sale outside the community.

Grazing and the landscape

Grazing by domesticated animals inevitably modifies the vegetation in comparison with its pristine state. A widespread assumption exists in parts of the scientific community and in the local government that a form of grazing exists that damages the environment. It is thus labeled as overgrazing. Such a term is misleading because any grazing removes plants that would otherwise be undisturbed, and this might constitute overgraz-

ing. A number of recent papers have questioned the validity of this term, whose use is rarely supported by evidence. Human-induced factors clearly play a part in reducing vegetation cover in rangelands. However, few studies quantify the influence of grazing on erosion and loss of productivity. Those that have made such an attempt highlight the complexity of vegetation cover changes after intensive grazing. Wilson and MacLeod (1991), for example, comment on the lack of concrete evidence to back up broad claims that the world's rangelands (particularly in Australia, the United States, and Africa) are overgrazed. Even in controlled experiments in paddocks, they found it very difficult to quantify overgrazing, which suggests that it may be more imagined than real. Vegetation changes are complex and could involve removal of plants, introduction of species, or accelerated growth. Similarly, the loss in animal productivity may be related not only to the lack or reduced quality of pasture but also to factors such as diseases.

It is difficult to distinguish between the effects of past and current grazing on pastures. Experiments in a natural montane grassland in central Argentina (Diaz et al 1994) compared vegetation changes under different grazing intensities in areas with different land-use histories. There was no significant difference in species composition and richness between sites with different grazing intensities, but there were differences between postagricultural sites (with more exotic species) and land not cultivated previously. Diaz et al (1994) concluded that grazing should not be considered a disturbance in these montane grasslands. Seasonal changes also are complex. Washington-Allen et al (1998) used time series Landsat images to detect changes in vegetation cover in the Bolivian altiplano. They highlighted the rapid recovery of vegetation cover after the 1983–1984 drought, demonstrated that 90% of vegetation cover had not changed from 1972 to 1987, and concluded that grazing does not contribute to resource degradation when measured in terms of change in vegetation cover.

Hence, there are significant difficulties in disentangling the effects of environmental conditions and land use on vegetation. Recent work by Adler and Morales (1999) in Northwest Argentina, at an altitude comparable with our study area (3000 m), measured the relative influence of environmental factors and sheep grazing on local plant species composition, diversity, and soil organic matter. They concluded that environmental variables explained 22% of the variation in species composition between sites, and grazing-related variables explained 24% of the variation. They also identified differences in the susceptibility of pastures to degradation and changes in species composition, related to aspect and season of grazing. Their conclusion that wet-season pastures on north-facing slopes were more susceptible to change suggests that protecting pastures during summer should be an important complement to traditional management efforts to reduce stocking rates.

Our aim is to use a multidisciplinary perspective to assess whether contemporary land management practices (particularly grazing) are leading to a deterioration in vegetation that might prevent future human populations from continuing similar practices.

In the Tarija altiplano the effects of grazing are seen in the composition of the flora. The consequences of trampling and compaction of the soil, as well as close grazing of selected plants, have led to the elimination of the most palatable species from certain areas, particularly close to settlements where livestock pass daily. For instance, the swards of annual graminae of *Poa* and *Agrostis,* and perennials such as *Deyeuxia* and *Festuca,* seem to have been replaced in some areas by hardier and less palatable species such as *paja amarilla* (*Stipa leptostachya*), *iru ichu* (*Festuca orthophylla*), and *k'hanlli* (*T. cristatum*) (Beck et al 2001).

Some of these changes are doubtless very ancient and reflect the nature of grazing during the 500-year period when sheep have grazed the highlands, but others are more recent. It is also necessary to take into account that the numbers of native grazing animals—vicuña and guanaco—have probably been greatly reduced during the last century. Descendants of the Lema family (who owned an extensive area in the altiplano) remember numbers of guanaco and vicuña being hunted there during the 1930s (Ruiz, personal communication). This might be hypothesized to have a positive effect on the vegetation, although camelids graze very differently from sheep.

Some informants commented that the increased use of the higher pastures and the construction of temporary shelters there occurred after the breakup of the estates following the land reform. Landlords kept very few livestock of their own on these estates and relied on a tribute payment of a proportion of the workers' animals, according to older informants and the land reforms dossiers for the estates of Arenales, Copacabana, and Patanka (Preston 2000). On some higher mountain slopes regular burning is said to be more frequent and intended to encourage the growth of pasture grasses, but the importance of this too is uncertain. Likewise, the practice of fencing or walling some areas to protect pasture from casual grazing is new. During the period of the great estates (before 1953), older informants said that more use was made of the lagoons and their aquatic plants, and there was better grazing around depressions. The extent to which the latter change is also a consequence of changes in water quality and precipitation is uncertain.

Changes in offering seasonal grazing access to

sheep from the valleys seem to have occurred after the Revolution of 1952. In the Camacho Valley, older people have told of the long-standing custom of taking sheep in the wet season up to the altiplano, where they grazed either altiplano pastures or possibly land on the upper slopes of the Río San Juan Valley. After the land reform of the 1950s and the associated formation of peasant unions (*sindicatos*), the newly independent former hacienda communities became free to decide on access rights to their land. By 1984 many of the altiplano communities had decided to prevent access. This will have decreased grazing pressures in some areas.

Shareherding is still important for communities of the dry valleys of the catchment of the San Juan del Oro River. Households from the valley communities of Tojo and Carretas still send sheep as well as some goats to communities near Rupaska on the edge of the altiplano to be cared for, often for the whole year. This practice allows valley households to incorporate the valued sheep into their livelihood strategies and offers poorer altiplano people fruit and other valley produce in return for tending the sheep. The continuance of this practice also implies abundant available altiplano pasture.

During the past 50 years it seems that there has been little change in livestock numbers. Some grazing management practices have changed, and although in some places environmental changes seem to have occurred (lakeshores and area of sand dunes), it is uncertain whether these are a consequence of changes in grazing practices. The priorities of altiplano farmers and graziers, identified in the community of Chorcoya in participatory workshops during current research, are droughts and disease and their effect on sheep rather than inadequate grazing land (Ruiz de los Ríos 2000). This further suggests that current grazing practices are not leading to environmental deterioration such that present livestock numbers cannot be maintained.

Livestock and livelihoods

Livestock are just one part of altiplano livelihoods. They provide meat, wool, and manure, a means to obtain fruit, vegetables, and other goods by trading, and a source of status. Livestock may have been a more important element of livelihoods in the past, when trading links with lower-lying areas were stronger than today and diets less diversified. Wool, dried meat, and manure can be traded with valley communities that have more arable land and fewer livestock. The diversification of highland household activities includes arable farming that allows more self-sufficiency at the household level, and this may have decreased the overall importance of livestock within livelihoods. Empirical models tested in the Bolivian altiplano (Valdivia et al 1996) have shown that there is no inverse relationship between the number of livestock and the level of diversification.

Livestock provide security. The role of livestock in minimizing the element of risk within livelihoods in the Andes and other mountain areas has been widely recognized (Brunschwig 1986; Browman 1987; Devereux 1993; Valdivia et al 1996; Preston 1998). Local people consider that livestock are an ambulant bank and as such a buffer against adversity.

As in many parts of the Andes, the Tarija altiplano households depend on a combination of livestock and arable farming and work outside the community. They also may engage in activities such as spinning, weaving, basket making, and the collection and sale of fuelwood and manure. The relative importance of these distinct elements and the type of crops and animals produced vary considerably in response to topography, climate, traditions, and particular choices of individuals and households. Fairbairn has analyzed this in both the Tarija altiplano and the Río San Juan Valley (Fairbairn 1999), and altiplano respondents insisted on the importance of each element of their livelihood. Referring to agriculture and grazing, one respondent said, "you can't separate them: if there is a shortage from one activity, there'll be something from the other" (Fairbairn 1999, p 8). Likewise, difficulties resulting from a drought and the loss of many sheep are compensated by migration to work in Argentina in order to earn money to sustain the household during the period of shortage.

Because households are not totally dependent on livestock, they are not encouraged to put stress on grazing resources by keeping more sheep to cushion the effect of drought and high mortality. The resilience of their livelihood strategy allows other resources to be used—migration to Argentina or, in the past, to lowland Bolivia—until environmental resources have recuperated.

What is the future of pastoralism?

Livestock contribute to the well-being of the human populations of the high plateaus, but they are also one of many factors contributing to environmental degradation in some places. The important conclusion that can be drawn from our work in the Tarija altiplano is that in most of the area, contemporary grazing does not affect the quality of vegetation any more than it did during the past 500 or even 1000 years. Seasonal movements are important in spreading the grazing over a much wider area than might be imagined from the distribution of livestock at any given moment.

Local changes are reported to have occurred, that is the moving sand dunes near Copacabana and the changed lake flora, but these may be the result of a

wide range of factors, of which locally intensive grazing is just one. Woody vegetation, particularly *thola* (*Baccharis incarum*), varies in density, indicating that people extract fuelwood from it. Degraded areas of *k'hanlli* (*T. cristatum*) may likewise be the result of bad soil quality, groundwater, and wind erosion as well as grazing.

If people continue to have access to other grazing areas at times of climate stress, the existing use of resources appears sustainable as long as there are sufficient female labor resources available to care for sheep, allowing males to migrate. Some people protect small areas to be grazed by sheep at times of greatest need, but others may calculate that the risk of lamb mortality is balanced by not having to invest time in maintaining walls. After severe drought, sheep numbers recover more slowly than vegetation: this allows more rapid environmental regeneration.

Whether pastoralism has a long-term future in the livelihood strategies of households in the Tarija altiplano depends on whether it can offer an adequate quality of life for its human population. An adequate range of services, particularly schools, must be maintained, and there must be enough children to justify multiclass schools that can offer a good quality of education. Schools, at present, are not experiencing a decrease in the number of children enrolling. The popular seasonal fairs make nonmonetary transactions easy and allow a degree of regional self-sufficiency that reduces cash needs.

The ability of household members to migrate is related to the type of livestock and the gender composition of households. Whereas cattle require very little labor (Brunschwig 1986), sheep and goats require constant attention because they are taken out to graze every morning and brought back every evening. This makes it easier for those (usually men) looking after cattle than for those (usually women and children) looking after sheep to migrate. Women in the Tarija altiplano are much less likely to migrate seasonally than men, and they look after the flocks in addition to carrying out the traditionally male tasks (such as collecting *thola* for fuel). The importance of migration in livelihood strategies does not appear to be causing a reduction in the importance of livestock grazing in the Tarija altiplano.

Although pastoralism is a crucial element in the livelihood of altiplano people, like crop farming (Figure 5), it offers security rather than a satisfactory income or a good quality of life. It is uncertain whether livelihoods that combine pastoralism, some cultivation, and seasonal migration will be able to meet the rising

FIGURE 5 Community livelihood in Chorcoya depends on seasonal migration, grazing, and cultivation where water is available. Pictured here are oats and broad beans irrigated from a hillside spring. (Photo by David Preston)

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