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10 Vegetation and Grazing Patterns in Andean Environments: A Comparison of Pastoral Systems in Punas and Páramos

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INTRODUCTION

The Spanish conquest generated profound transformations in Andean cultures and environments. The introduction of new plant and animal species and the implementation of new technologies had a variety of impacts on the environment and on traditional land use practices (Thomas 1979; Little 1984). One of the consequences was the change in traditional grazing patterns, which had developed during the millennia of interactions of human populations with mountain environments. The success of these strategies was based on a thorough knowledge of these environments and of the genetic makeup of domesticated Andean animals, resulting from thousands of years of selection (Brush 1984).

In the punas of the Central Andes, the most important change was the replacement of native llamas and alpacas by animals introduced from Europe (mainly ovines and bovines). In some cases, the new animals were incorporated into the management systems within the framework of ancient practices and ideologies (Merlino and Rabey 1983; Rabey and Merlino 1988). However, in extreme highland areas, the lack of adaptation of the introduced livestock to the demanding climatic conditions constituted a barrier for the replacement of domesticated camelids (Wheeler 1988). Even so, the Spanish conquest was the starting point of an expansion process of ovines and bovines in the Central Andes that has been linked to profound impacts on the original vegetation and soils, and on the community organizations and grazing strategies (Flores Ochoa 1988a, b).

The Spanish conquest also introduced cattle into the páramo of the northern Andes, which was unfamiliar with large herds grazing, as in the puna region. This process was linked to the introduction of new crops and cereal technologies (Monasterio 1980). However, in a few hundred years, new grazing patterns were developed, strongly linked to the agricultural calendar with a typical agropastoral strategy (Molinillo 1992; Molinillo and Monasterio 1997).

The use of natural resources with "traditional" animals and technologies, adapted to local environmental conditions, has generally been associated with stable production systems of high productivity (Little 1984), whereas the use of exotic animals in the Central Andes has been linked to overgrazing. Even though this has been considered an ancient problem (Browman 1974), overgrazing produced large-scale soil erosion problems and drastic changes in vegetation structure, mainly during the postconquest era (Eliminar las Citaas de Koford 1957; Mann 1968 cited by Thomas and Winter-halder, 1976).

The exclusive use of sheep in the altiplano region has produced changes in the vegetation, related to the local extinction of palatable pasture species with high nutritional value (Millones 1982). This has been explained in terms of the inability of introduced animals to adapt to the characteristics of Andean ecosystems (Flores Ochoa 1979; Millones 1982). Similarly, toward increasing dominance of grasses and shrubs of a low forage value and a low vegetation cover in the punas of northwestern Argentina have been attributed to overgrazing by exotic animals (Solbrig 1985).

The magnitude of the environmental impact of new grazing regimes on the páramos and the punas depends, to a large extent, on the spatial patterns of livestock movement, which have been, in turn, controlled by the spatial and temporal distribution of natural forage and the animals' ability to utilize pastoral space. The efficient use of pastoral space depends on the grazing strategy used for exploiting the forage resources of a given region. This pastoral strategy includes the daily and seasonal patterns of animal movements on pastoral space and the animals' requirements. Efficiency in the use of pastoral space has direct environmental consequences. A low space-use efficiency leads to the concentration of livestock in the few places that meet animal requirements and/or intentional alteration of vegetation to increase the surface area of optimal sites.

In this chapter, pastoral strategies, space-use efficiency, and their relationship with dominant vegetation patterns are compared in three Andean systems: alpacas and llamas in the punas of the Ulla-Ulla altiplano (Bolivia), ovines in high-altitude grasslands of the Cumbres Calchaquies (northern Argentina), and cattle in the páramos of the Cordillera de Mérida (Venezuela).

METHODS

To analyze the use of pastoral space, an attribute known as the *capacity* of a given territory for the development of a specific activity is calculated (Cendrero 1982; Gómez Orea 1992). To evaluate a territory's capacity for grazing, geographic information systems (GISs) and multicriteria evaluation (MCE) techniques were used. MCE techniques are based on the use of matrices of alternative criteria and the assignment of weights to each criterion, developing a hierarchy. The criteria were expressed as thematic maps whose units represent the different alternatives offered by a given territory (Eastman et al. 1995; Barredo 1996). Then, the grazing capacity was calculated for each region through a linear weighted sum. In all cases, the criteria to assess the maximum grazing capacity were: (1) areas with the highest forage quality, (2) areas with the shallowest slopes, (3) areas closest to water sources, and (4) areas with the highest accessibility for grazing. Based on the following criteria, thematic maps were drawn: forage supply, slopes, distance to water sources, and distance to human settlements. For mapping, different value scales and weight hierarchies were used, depending on the conditions of each region and the characteristics of the animals. In each case, pastoral space was expressed as the percentage of the total area where the highest values of grazing capacity are found.

Forage supply maps were obtained from vegetation maps using the following equation:

$$\mathrm{OF} = \frac{\dfrac{[(WP_1 \times FC_1) + (WP_2 \times FC_2)] \times [TFC]}{SF}}{100}$$

where, WP_1 is the weight for palatability in scale 1, WP_2 is the weight for palatability in scale 2, FC_1 is the forage cover of palatability 1, FC_2 is the forage cover of palatability 2, SF is an index of the seasonality of forage, and TFC is the total forage cover for each vegetation unit.

Information on palatability was obtained from different sources: preference sampling of animals in the Venezuelan páramos (Molinillo 1992; Molinillo and Monasterio 1997); specific secondary sources for Ulla-Ulla in Bolivia (Bárcena, 1988; La Fuente et al., 1988), and Tacanas in Argentina (Molinillo 1988, 1990, 1993) and general secondary sources for the puna region (Tapia and Flores Ochoa, 1984; Ruiz and Tapia, 1987).

Vegetation maps were obtained by processing a Landsat 6 image from 1996 (Venezuela) and a Spot image from 1986 (Argentina) and by simplifying the vegetation map for the Ulla-Ulla region (Seibert 1994). In every case, field controls were taken through random sampling of each vegetation unit using 0.25-m^{-2} quadrats for swards and 1-m^{-2} quadrats for shrubland and grassland areas. In each quadrat, species cover, forage supply, and other variables such as dry matter, bare soil, soil humidity, and stoniness were measured. To analyze the relationship between animal management and the vegetation structure, multivariate analysis (principal components analysis, PCA) was used. The analysis combined the data from field quadrats with grazing distribution data. Slope maps for the three regions were obtained from digital elevation models derived from the official cartography at a 1:100,000 scale (Argentina and Venezuela) and from the 1:50,000 topographic map of Ulla-Ulla (Bolivia) by Seibert (1994). The water sources and human settlements distance maps were drawn by calculating buffer zones between hydrographic elements (rivers and lagoons) and human settlements.

To assign weights for factors and alternatives, matrices were built using the analytic hierarchies method (Saaty 1980; Barredo 1996). Here, weights are assigned based on pair comparisons, so that a relative weight is assigned to each factor in relation to all other factors. This method provides more realism than a simple procedure without weights. By assigning weights to each factor in the different regions, the influence of these factors on the particular grazing systems in that region could be evaluated.

RESULTS AND DISCUSSION

Grazing Areas and Animal Management

The Ulla-Ulla altiplano region (above 4000 masl) in the Bolivian puna is characterized by a cold and dry climate with strong winds (dry and very cold). Rainfall is concentrated in the summer months (less than 500 mm per year), showing marked interannual variability. The vegetation shows marked differences between *bofedales* (irrigated areas) and dry plains. In the inundated bofedales, species with high forage value dominate (*Distichia* spp., *Lachemilla* spp., *Plantago* sp., etc.). In contrast, the dry plains are covered by relatively isolated bunchgrasses (*Stipa* sp., *Festuca* sp., *Calamagrostis* sp., etc.) and cushions (*Arenaria* sp., *Aciachne* sp., etc.) growing on soils of limited pedogenetic development. Hence, these areas are only used during the wet season. The transition zones between wet and dry areas create a complex vegetation mosaic controlled by seasonal water availability. The Aymara communities utilize the bofedale and its surrounding areas for herding llamas and alpacas. Each family has an average of 200 animals, with twice the number of alpacas than llamas. They also herd cattle and sheep, but in fewer numbers. Alpaca herds graze in the bofedales most of the year, separated in groups of males and females. Animal loads in these sites can reach more than two alpaca units per hectare. The llamas graze the plains and neighboring sierras (highlands), particularly during the wet season (summer) when they benefit from the growth of seasonal pastures. During the dry season (winter), grazing of female llamas and alpacas is mainly on the irrigated bofedales. Those communities without access to irrigated bofedales must take their animals to natural pastures in high-mountain areas for green forage vegetation. In a few cases, forage (mostly oats) is cultivated in small plots near the farmers' houses and then stored.

In the Cumbres Calchaquíes region of northwestern Argentina, the high belts (between 2500 and 4000 masl) are characterized by a climate with marked seasonality: temperate and humid summers (December to March) and cold, dry winters (June to September). Vegetation types include high-altitude grasslands (dominated by *Festuca* spp.), swards in the upper limits of *Alnus acuminata* forest, and both puna and prepuna shrublands. The traditional grazing system is based on seasonally migratory ovine and bovine cattle. Inter-Andean valleys above 3500 masl that are covered with grasslands are used during the wet season, whereas slopes with pastures and swards in the forest limits (between 2500 and 3000 masl) are used during the dry season. Within each vegetation belt, a temporary settlement is established, allowing better control of animals during grazing. With the arrival of summer, animals are concentrated in the pastures and swards of the high inter-Andean valleys, areas where animal loads can reach two sheep units per hectare in 4 to 5 months. Low temperatures and dry conditions have made herders look for better forages in the low wooded slopes, where they spend the rest of the year.

In the Sierra de la Culata region in Cordillera de Mérida (western Venezuela), an agro-pastoral system (potato/cereal agriculture and bovine grazing) has been developed in the páramos in a cold and humid climate (above 3500 masl). This environment shows a less discontinuous rainfall distribution pattern than the puna, though, there is a clearly defined dry season. In the slopes of the Andean belt, between 3700 and 4100 masl, the dominant vegetation is an *Espeletia schultzii* rosette–shrubland community. Higher up, in the high-Andean belt, giant rosettes of *E. timotensis* dominate, interspersed with areas of sparse vegetation cover in the periglacial desert. Both in lower and high-Andean belts, swards of Gramineae and Cyperaceae in the valley bottoms and slope landings are distributed in patches along watercourses. These sites are the main grazing areas. Animals move between sward patches, establishing circuits in which vegetation can regenerate after short periods of intensive grazing. Here, animal loads can reach 0.4 bovine units per hectare. In contrast to the situation in Bolivia and Argentina, there are no human settlements in these grazing areas. Animals are taken above the agricultural belt to the páramo areas several hours away (by horse or on foot) and controlled once or twice each month. In the agricultural zone (3000 to 3700 masl), animals find supplementary forage in fallow areas and in the stubble of potato and wheat crops, or in plots with oats or grass. Animal movement between vegetation belts is strongly linked to the agricultural calendar.

Use of Pastoral Space

Grazing capacity maps in the three regions indicate that, in general, the areas with the highest forage supply correspond to the high-capacity areas (Figure 10.1). Bofedale sites located near human settlements between watercourses on shallow slopes show the highest-capacity values in the Ulla-Ulla region. This results in a pastoral space of 60% of the total surface area for llamas and only 40% for alpacas. In the Tacanas region (Argentina), the high-capacity class is occupied by swards on slopes and the summits of the Tacanas River sources, where temporary and permanent settlements for grazing are located. In this case, pastoral space corresponds to 25% of the total surface area. In the Sierra la Culata region (Venezuela), the highest-capacity class is occupied by the swards, rosette–swards, and the marshes in shallow slope areas in the valley bottom, crossed by watercourses that are less than 5 km away from human settlements. These places correspond to only 20% of the total surface area.

In the Ulla-Ulla altiplano, a more limited pastoral space for alpacas can be explained by their requirement for tender and green fodder, which can only be found in the bofedales. Even though the alpacas also eat the dry and hard fodder characteristic of the puna (such as tussocks of *Festuca* sp. and *Stipa* sp.), they cannot eat it continuously without the risk of malnutrition and negative effects on the quality of their delicate wool (Palacios Ríos 1988). Alpacas are taken out of the bofedales and swards only during the wet season. In some cases, this is done to remove them from flooded or humid areas to avoid diseases. Consequently, their permanent corrals are located at the border of the bofedales, and the size of the bofedales determines the number of alpacas that a family or a community can maintain (as these are the only means of survival for the animals during the dry season). The situation with llamas is different. Their wide feeding range and their ability to digest the dominant hard fodder in the puna slopes (Genin et al. 1994) allows them to use the pastoral space better. Hence, there are only two strategies available to widen the alpaca's pastoral space: to look for natural bofedales on the steep areas (dependent on glaciers) and to increase the size of the bofedales through irrigation technology.

In the Sierra de la Culata (Cordillera de Mérida), limitations, as to the use of the páramo pastoral space for bovines, have meant that animals are restricted almost exclusively to valley bottom areas with sward patches of high forage

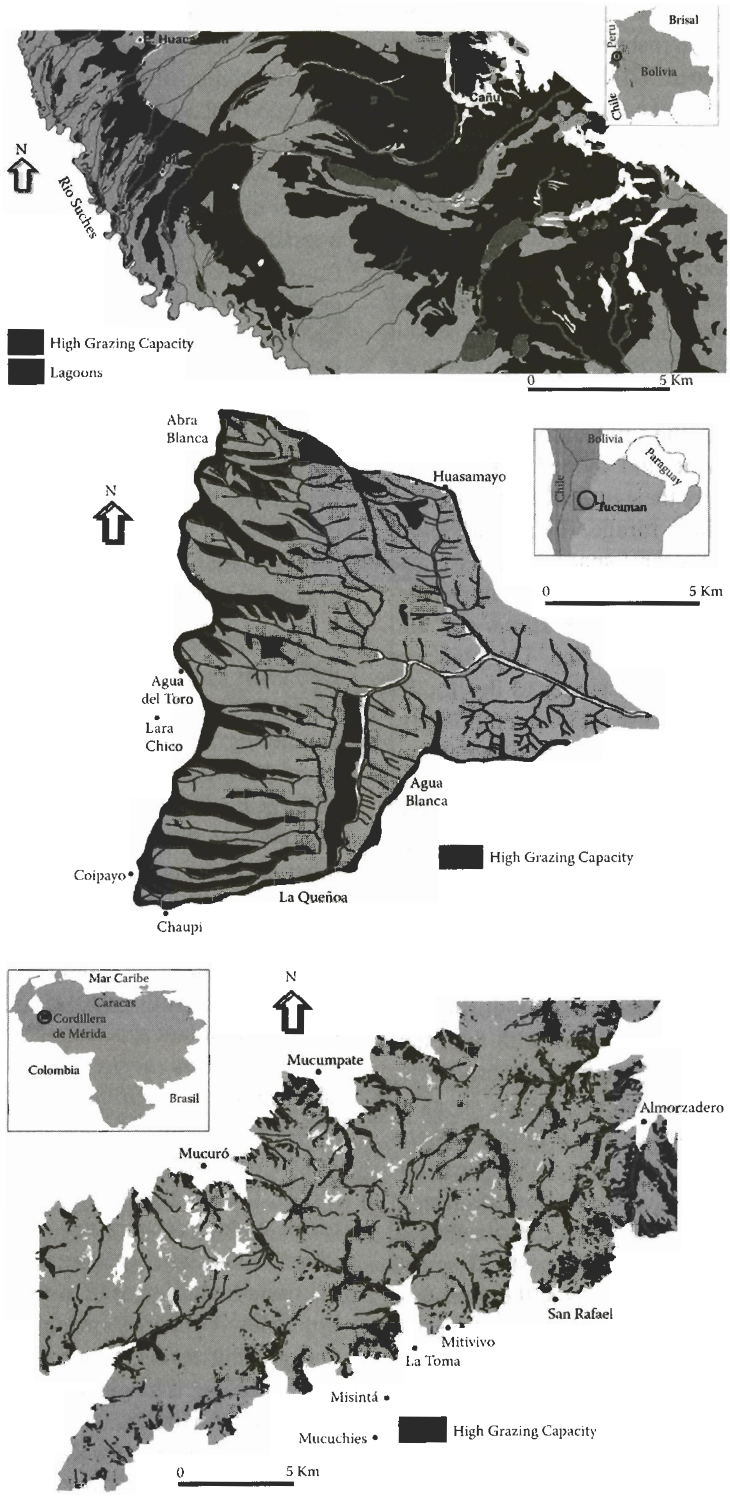

FIGURE 10.1 Areas with high grazing capacity in the study area. Top: Punas of the Ulla-Ulla altiplano (Bolivia). Center: forest and highland pastures of the Tacanas watershed (Argentina). Bottom: páramos of the Sierra de la Culata (Venezuela).

quality. They can graze very extensively only on the shrubland and rosette areas that dominate most slopes between 3700 and 4100 masl. In the páramos, the forage quality limitations for cattle are much more severe than in the northern Argentinean highlands. Here, the mosaic of sward patches and marshes with high grazing capacity is used intensively by cattle. However, supplemental food from the agricultural belt is almost indispensable to sustain cattle grazing in the páramos, especially during the dry season when their rangeland forage capacity decreases abruptly (Molinillo and Monasterio 1997).

In the Tacanas, the small amount of acreage available for bovine and ovine cattle grazing can be explained by their limited ability to consume the dominant forage (Molinillo 1990, 1993). To widen pastoral space, shepherds use several practices. Intentional fire setting, particularly in the pastures of *Festuca* sp. and *Stipa* sp., is a common practice. The objective is to increase the ratio of tender to dry fodder so that the animals can use (at least temporarily) vast pastureland extensions, which would not be accessible in the mature state of vegetation. Another common strategy used is to change pasture areas daily and seasonally. Both of these practices are aimed at maximizing the utilization of forage resources, given the constraints imposed by grazing animals. For example, the shepherds of the Lara River valley (near the Tacanas River watershed) transit during the summer daily by several routes with their animals, which they alternate or temporarily change within their pastoral spaces so as to maximize availability of the different vegetation types available (Molinillo 1988). Seasonal animal movements also allow for the use of forests, highland pastures, puna shrublands, and prepuna vegetation, widening pastoral spaces considerably. Even so, animals still concentrate in the best forage areas, located near watercourses on shallow terrains.

Grazing and Vegetation Patterns

In all three cases discussed in the preceding text, the size of the pastoral space has been strongly influenced by vegetation structure and its composition, particularly in those areas that maintain the highest grazing loads. Figure 10.2 shows the four groups in the Ulla-Ulla region classified according to the relation between the floristic composition and the environmental and management variables. Within this organizing pattern, the most meaningful variable is the soil water, which forms a gradient in axis I, and the fodder quality and grazing density, which form a gradient in axis II. The flooded bofedales (group 1) with high grazing density and fodder quality, the scarce bofedales (group 2) with fodder quality from intermediate to poor condition, the transition pastures (group 3) with low fodder quality and little grazing density, and the vegetation of plains (group 4) with high proportion of bare soil and little water supply on the ground are each characterized by a floristic composition, mostly derived from the interaction between environmental conditions and grazing frequency.

The floristic composition in the bofedales is related to their high soil water levels and moderate to high animal densities. Under these conditions, species such as *Distichia filamentosa*, *D. muscoides*, *Lachemilla diplophylla*, and *Plantago tubulosa* dominate. The fact that in bofedales where grazing has been excluded, other species such as *Calamagrostis ovata* and *Juncus arcticus* dominate over *Distichia* spp. supports this conclusion (Seibert 1994). At the other extreme of the humidity gradient, in dry flatland areas with relatively high grazing levels, the dominant species are *Stipa ichu*, *S. brachyphylla*, *Bougueria andicola*, *Cardionema* sp., *Paronychia andina*, and *Selaginella peruviana*. Human disturbance and grazing has been linked with the presence of *Stipa ichu* (Seibert 1994). These are low-carrying-capacity areas or areas under regeneration that were probably subjected to llama grazing. The rest of the sites are transitional forms between dry flatlands and bofedales, both in terms of water availability and grazing levels. When the water supply to the bofedales is neglected (through site abandonment or deficiencies in the maintenance of irrigation channels, for example), their floristic composition changes to plant formations dominated by *Azorella diapensioides*, *Plantago rígida*, *Werneria apiculata*, *Festuca andicola*, *Gentiana sedifolia*, and *Lachemilla pinnata* in the humid areas, and *Aciachne pulvinata, Mul-*

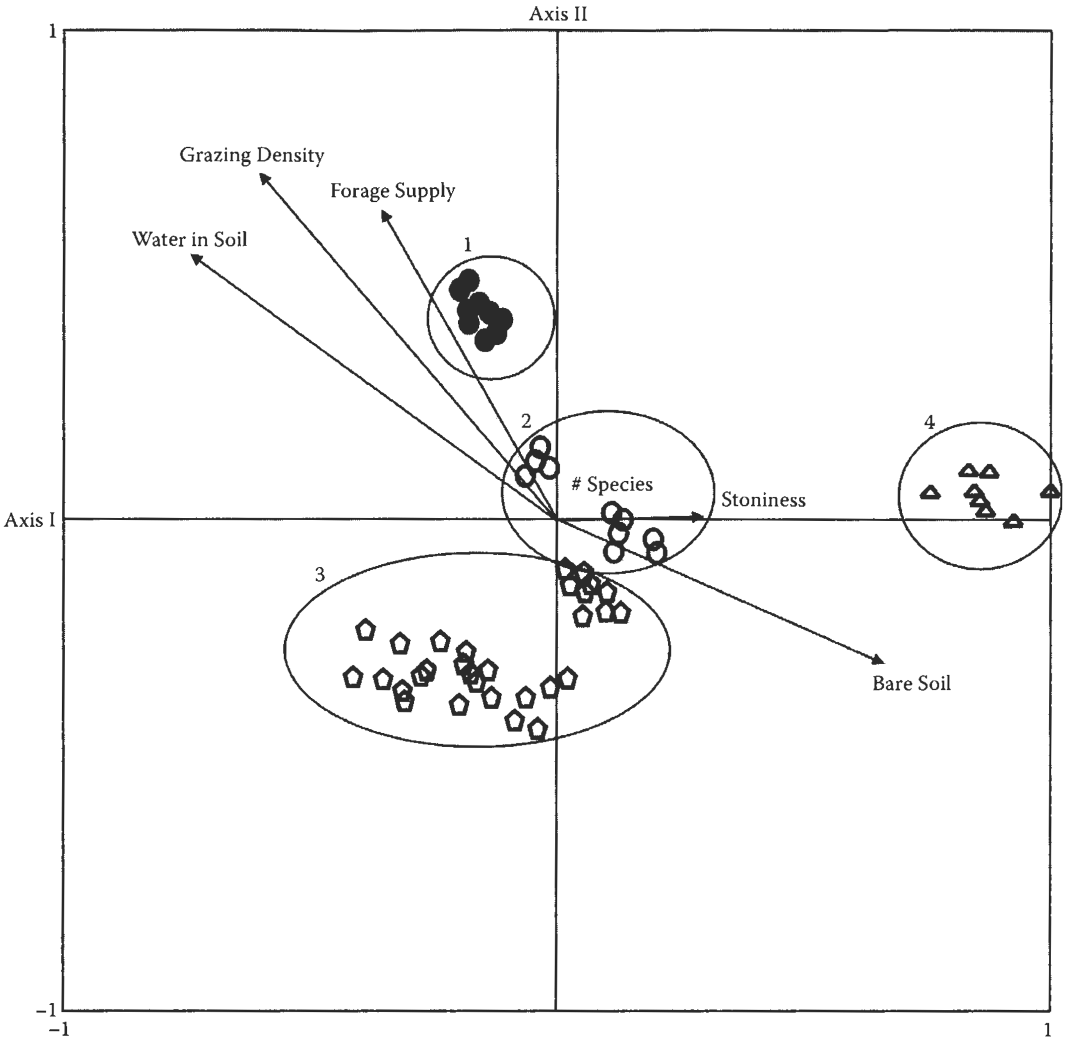

FIGURE 10.2 Ordination diagram (PCA) of 60 sampling quadrats in terms of their floristic composition in the Ulla-Ulla altiplano (Bolivia). On Axis I is a gradient of bare soil and soil water. On Axis II is a gradient of forage quality and grazing density. ()) high and very high for alpacas and llamas. *Group 1:* bofedales inundated of *Distichia filamentosa, Distichia muscoides, Lachemilla diplophylla, Plantago tubulosa, Caltha sagitata. Group 2:* abandoned bofedales dominated by *Calmagrostis* sp., *Azorella diapensioides, Festuca andicola, Plantago rigida, Werneria apiculata, Gentiana sedifolia, Geranium sessiliflorum, Ranunculus cymbalaria. Group 3*: transition zones dominated by *Festuca andicola, Werneria apiculate, Lachemilla pinnata, Eleocharis tucumanesis, Scirpus* sp., *Aciachne pulvinata, Mullenbergia* sp., *Calandrinia acaulis. Group 4*: Plains dominated by *Stipaichu, S. brachphylla, Bourgueria andicola, Cardionema* sp., *Paroychia andina, Selaginella peruviana.*

lenbergia sp., *Scirpus* sp., and *Calamagrostis minima* in the dry areas.

In the extensively grazed areas of northwestern Argentina, grazing and (almost certainly) fire have created mosaics of low pastures and swards in the forest belt, highland pastures, and prepuna shrublands. In Figure 10.3, the organizing pattern classifies seven groups according to their floristic function and altitude gradient (axis I), and to the pasture quality and grazing density (axis II). Taking into account only the influence of grazing upon the vegetation, the features to be highlighted are high-quality fodder and grazing density (group 4), the patches of higher-altitude swards and marsh (group 5), and the low grasses on slopes with floristic composition due to grazing pressure and availability of water on the ground (group 6).

These grazing-induced swards are dominated by the preferred forage species, resistant to moderate to high seasonal animal loads. In the Tacanas River watershed (below 3200 masl), permanently humid soil and a high grazing density of ovines and bovines most of the year, are associated with swards of *Alchemilla pinnata*, *Hypoxis* sp., *Juncus* sp., *Tripogon spicatus*, *Bromus unioloides*, *Vulpia bromoides*, *Hypochoeris meyeniana*, and *Paspalum pygmaeum*. In the high valleys of the Lara River watershed (3200 to 3800 masl) moderate to high ovine loads during the summer are associated with swards of *Alchemilla pinnata*, *Eleocharis* sp., and *Koeleria permollis* along the river banks and the low pastures of *Stipa uspallatensis*, and *Festuca lilloi* on the humid slopes and the summit surfaces.

Finally, in the páramos of the Sierra de la Culata region in Venezuela, the pattern in Figure 10.4. shows five major groups according to the floristic composition, water in the soil, fodder quality (axis I), and grazing density (axis II). The grasses and the swamps (group 1), flooded most of the year, have very good fodder quality but low grazing density because of difficult accessibility. The degraded swards (group 3) with colonizers that, in the past, were subjected to high grazing pressure and showed little water provision for their recovery, and the continuous grasses (group 5), with high fodder quality, that get flooded only part of the year, and have high and seasonal grazing density. The moderate to high seasonal bovine loads that concentrate in shallow valley bottoms near the water sources are associated with swards of *Calamagrostis mulleri*, *Carex albolutescens*, *Lachemilla* spp., *Muehlenbergia ligularis*, and *Agrostis breviculmis* (group 5). The presence and frequency of animals on these swards is strongly linked to the agricultural calendar and the supplementary forage offered by the agricultural belt. The establishment of an equilibrium between water availability (allowing growth after grazing) and the type and duration of animal loads favor the maintenance of good-quality forage species in swards. A drastic decrease in grazing in the marshy inundated areas changes species composition toward the dominance of *Carex albolutescens*, *C. humboldtiana*, and *Juncus* sp. (group 1). Areas that remain inaccessible for several years can favor the establishment of tussock grass species, such as *Festuca tolucensis* and *Calamagrostis ligulata* (group 2). On the contrary, swards with limited water availability and high animal accessibility are dominated by native weeds and exotics such as *Rumex acetosella*, *Aciachne pulvinata*, *Acaulimalva acaule*, and *Geranium* spp. (group 3). Low forage supply and abundant cattle dung (past grazing indicator) determine the low present-grazing loads in these units. In all three cases analyzed, no significant relationship has been found between species richness and the vegetation units under grazing. Table 10.1 shows correlation of the variables with the first three axes of the ordination analyses. In no case does the variable number of species reach significant values and, as can be seen in Figure 10.2 to Figure 10.4, this variable does not correlate with the grazing-density variable. In the Tacanas region (Argentina) and La Culata (Venezuela), the impact of moderate to heavy grazing on low pastures and swards is associated with an increase in the number of native weeds and exotic species. Hence, species richness tends to be maintained at similar levels as that of the other vegetation units.

The Use of Pastoral Space and Its Grazing Impact

The pastoral space of the livestock farming systems analyzed is intimately related to the impact of grazing on vegetation structure. In the Ulla-Ulla altiplano, the wide pastoral space of llamas has allowed the development of livestock farming activities with minor impacts on the dominant vegetation (at least in recent times), which is in sharp contrast with the Andean systems based on exotic animals. The establishment of bofedales through irrigation has allowed the maintenance of species with high nutritional value and resistance to grazing loads. Here, changes in vegetation composition

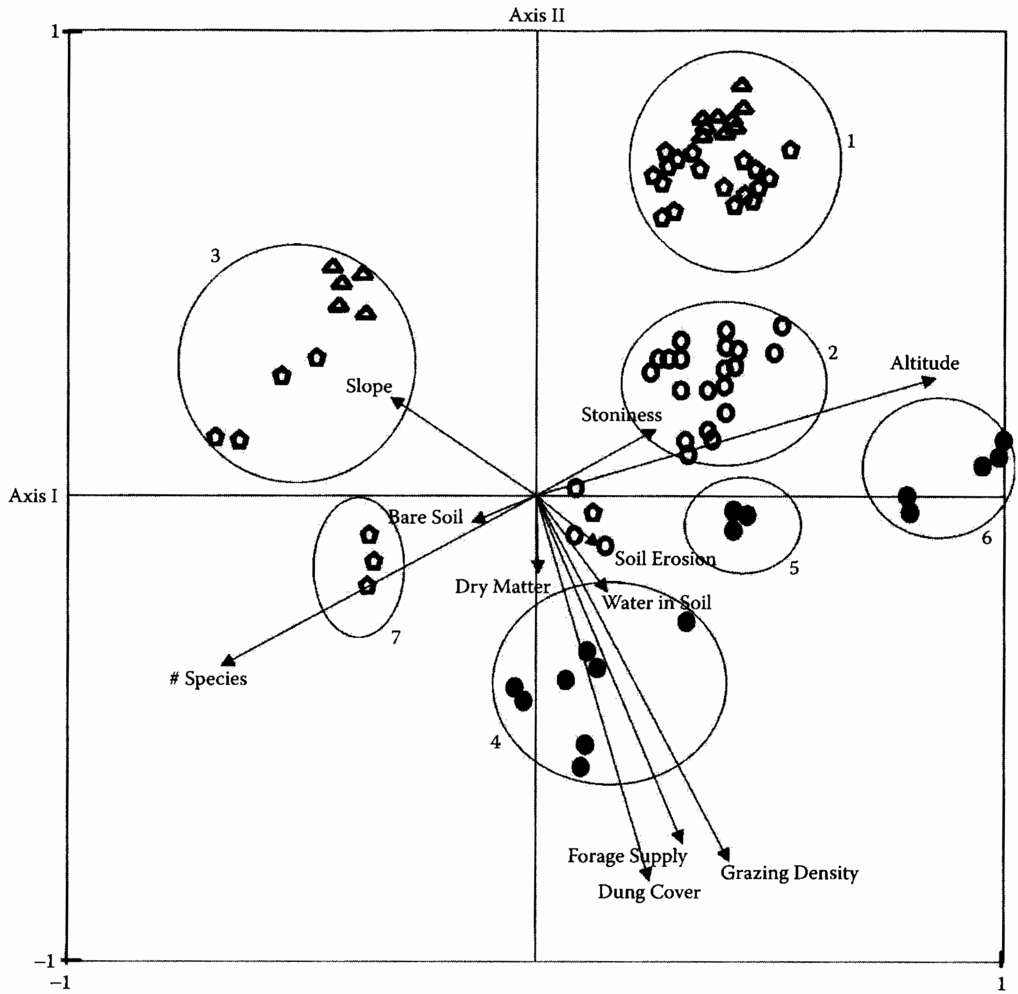

FIGURE 10.3 Ordination diagram (PCA) of 85 sampling quadrats in terms of their floristic composition for vegetation units of *Alnus* forest and highland pastures between 2000 and 3800 m asl at the Cumbres Calchaquies (Tucuman, Argentina). Axis I is a gradient of height, Axis II is a gradient of forage quality, grazing density and dung quantity. *Group 1*: shrublands dominated (>3000 masl). *Parastrephia phylicaeformis, Chiliotrichiopsis keidelli, Adesmia horridiuscula, Baccharis polifolia, Fabiana densa, Senecio argophylloides* y herbs like: *Glandularia incise, Paronichya setigera, Bidens* sp. *Group 2:* grasslands and shrubland-grasslands (>3000 m asl). *Stipa leptostachya, Festuca weberbaueri, F. hieroyimii, Parastrephia phylicaeformis, Chiliotrichiopsis keidelli, Solanum* sp., *Astragalus* sp., *Geranium* sp., *Plantago* sp., *Tarasa* sp., *Perezia* sp. *Group 3*: Forests and shrublands (>3000 m asl). *Siegesbeckia jorulensis, Calamagrostis poligama, Bidens andicola Duchesnea* sp., *Pteris* sp., *Dunalia brachiacantha, Tibouchina paratropica, Ichnanthus minarun, Pennisilum latifolium, Jungia pausiflora, Adiantus* sp., *Ophryosporus* sp., *Digitaria ternata, Setaria geniculata, Hyptis mutabilis. Group 4*: swards (2500 to 3200 m asl). *Alchemilla pinnata, Hypoxis* sp., *Juncus* sp., *Tripogon spicatus, Bromus unioloides, Plantago* sp., *Vulpia bromoides, Hypochoeris meyeniana, Paspalum pygmaeun. Group 5*: swards and marshes (>3200 m asl). *Eleocharis* sp., *Koeleria Permolis, Gamochaete* sp. *Group 6*: low pasturelands (>3200 m asl). *Stipa uspallatenis, Festuca Iilloi, Boulesia* sp., *Geranium* sp. *Group 7*: disturbed vegetation near pens dominated by weeds: *Lepidium bonariensis, Cynodon dactylon, Dichondra repens, Amaranthus quitensis, Calycera* sp., *Tagetes* sp., *Erodium* sp., *Cuphea* sp., *Rumex* sp., *Cirsium* sp.

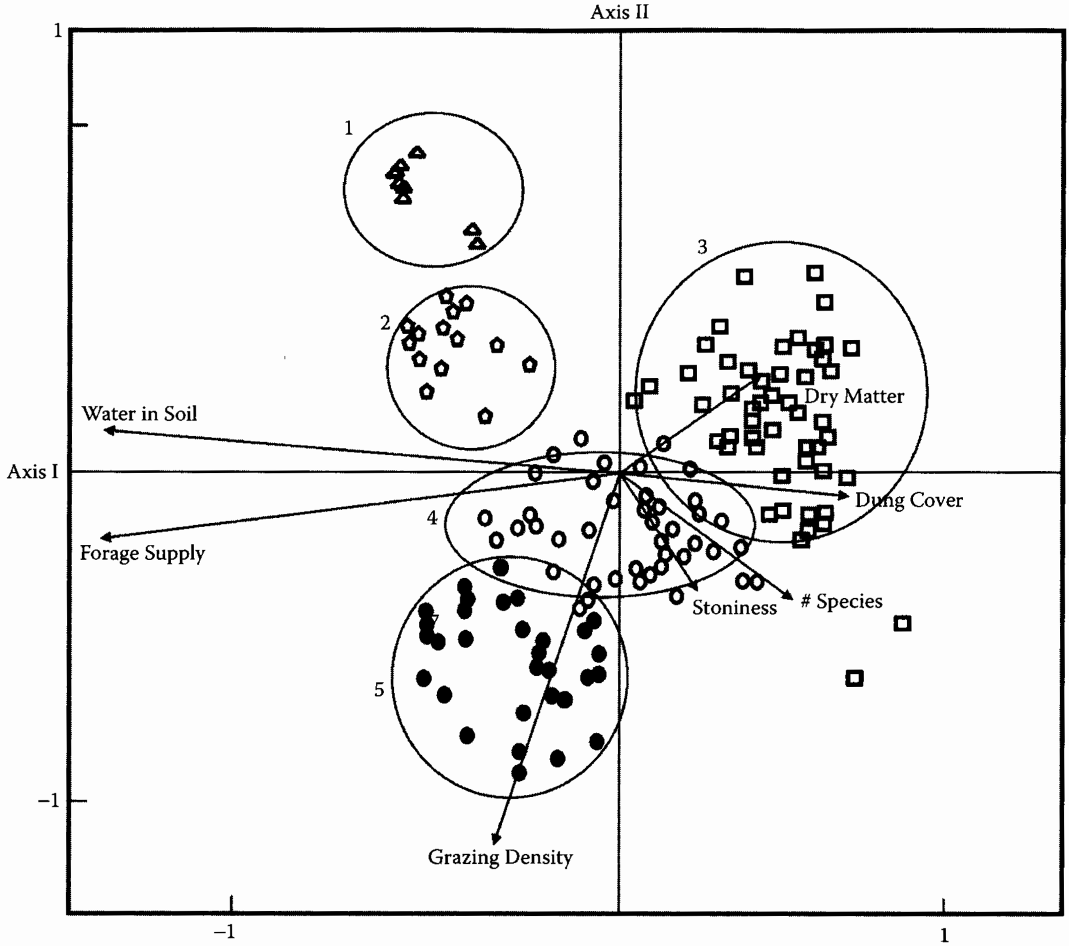

FIGURE 10.4 Ordination diagram (PCA) of 200 sampling quadrats in terms of their floristic composition in páramo swards between 3800 and 4200 m asl at the Cordillera de Mérida (Venezuela). Axis I is a gradient of soil water availability and forage quality, Axis II is a gradient of grazing density. *Group 1*: Inundated swards and marshes dominated by *Carex alboutescens, C. humboldtiana, and Juncus* sp. *Group 3*: Degraded swards dominated by *Rumex acetosella, Aciachne pulvinata, Acaulimalva* sp. *and Geranium* spp. *Group 5*: Continuous swards of *Calamagrostis mulleri, Carex albolutescens, Lachemilla* spp., *Muehlenbergia ligularis*. *Group 2 and 4*: Transition swards between inundated, degraded, and continuous swards.

are associated, to a larger extent, with irrigation technologies rather than with animal loads.

The introduction of bovines in páramos without a history of grazing by large herbivore herds, as was the case in Venezuela, or grazing with new animals (ovines, which replaced llamas) in the mountains of Argentina, has been associated with reduced pastoral spaces and changes in the structure and species composition of the dominant vegetation. In the highland grasslands of the Tacanas watershed and La Culata páramos, limited pastoral spaces translate into higher animal concentration on the few sites where plant species composition responds almost exclusively to grazing loads and water availability. These areas where grazing has induced the formation of swards are characterized by favored forage species that can resist moderate loads, but require temporary grazing exclusion and water to recover. The grazing strategies developed have favored the permanence of these swards, critical for successful livestock farming. However, these delicate equilibria can be easily disrupted by an increase in animal loads or frequency of grazing events.

TABLE 10.1
Correlation of variables with the first three axes of the ordination analyses with the correspondence analysis for the sites on the Ulla-Ulla Plateau (Bolivia), the Tacanas River Basin (Argentina), and the Sierra de La Culata (Venezuela)

	Ulla-Ulla (Bolivia) Figure 10.2			Tacanas (Argentina) Figure 10.3			La Culata (Venezuela) Figure 10.4		
Variables/Axes	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
Water in soil	0.7268[a]	0.5316	0.2580	0.1366	0.1937	0.2209	0.8423[a]	0.0518	0.0836
Forage supply	0.3487	0.6151[a]	0.5440	0.3106	0.7101[a]	0.0971	0.8788[a]	0.1073	0.1031
Alpaca density	0.5928	0.6944[a]	0.2573	—	—	—	—	—	—
Llama density	0.5769	0.6172[a]	0.1219	—	—	—	—	—	—
Sheep density	—	—	—	0.4007	0.7429[a]	0.1231	—	—	—
Cattle density	—	—	—	—	—	—	0.2281	0.6418[a]	0.2224
Stoniness	0.2982	0.0034	0.1446	0.2543	0.1364	0.1615	0.1367	0.1676	0.6089[a]
Species number	0.0118	0.0002	0.0276	0.6619[a]	0.3509	0.3239	0.3133	0.1796	0.2217
Bare soil	0.6460[a]	0.2845	0.3858	0.1296	0.0612	0.1694	0.0530	0.0446	0.0211
Dung cover		—	—	0.2351	0.7796[a]	0.2313	0.3814	0.0399	0.0163
Dry matter	—	—	—	0.0101	0.1621	0.4145	0.2593	0.1243	0.1026
Slope	—	—	—	0.3077	0.2031	0.4448	—	—	—
Altitude	—	—	—	0.8351[a]	0.2349	0.1889	—	—	—
Soils erosion	—	—	—	0.1310	0.0993	0.2310	—	—	—

[a]Significant correlations.

In other mountains of the world, the establishment and maintenance of swards has been directly linked with animal movements and their preferred grazing areas (Brasher and Perkins 1978; O'Connor 1978; García Gonzáles et al. 1990). These grazing-induced swards can represent a permanent increase in forage supply, species diversity, and stability as long as they are subjected to controlled grazing in which loads are regulated. In other words, a lower efficiency in the use of pastoral space must correlate with strong regulations on grazing, as overgrazing can too easily result on sites with inherent limitations.

Grazing history, the type and response of vegetation, and soil water availability (Milchunas et al. 1988) seem to be critical factors in explaining the causes of impacts on vegetation of these Andean livestock-farming systems. Pronounced changes on vegetation structure have also been reported in other Andean mountains where livestock farming shows limited pastoral spaces. This has been the case in the fire-grazing strategy for the exploitation of forage resources in the highlands of the páramos of Colombia (Hofstede, 1995; Verweij, 1995) and Ecuador (Hess, 1990; White and Maldonado, 1991; Laegaard, 1992). Under the influence of the fire-grazing cycle, the páramo grasslands were transformed into pasture mosaics of different structure and composition, in which ecological dynamics are linked to the frequency and intensity of the cycle (Molinillo and Monasterio 2003). Therefore, these transformations have produced an increase in diversity on a regional scale, because of the decrease in dominance of large tussock grasses and the increase of sward and herbaceous species. In these mosaics, the swards offer the highest forage supply and diversity levels, but there is an increase in the presence of native and exotic weeds (Verweij 1995). However, although these swards are relatively grazing-resistant if exposed to frequent and heavy loads, they can give way to open herbaceous formations with a low forage quality and a sharp decrease in species diversity.

In contrast with these strategies to increase the use of available pastoral space in the Sierra de la Culata páramos, the relationship between livestock farming and agriculture is responsible for the extra forage supply, resulting in less severe environmental consequences. Sometimes, fodder and cereal cultivation, crop residues, fallow and stubble fields, and natural vegetation areas can all reduce cattle loads on the páramos at critical times. Similarly, in the Cumbres Calchaquíes, a strategy based on animal management (seasonal migrations and daily changes in grazing paths), and not environmental transformations, has allowed moderation of the impact of grazing on the sites with the best natural forage supply. However, in some of these places, the lack of grazing control has led to erosive processes and the predisposition of slopes to mass-movement processes that are related to wet cycles in the local climate (Molinillo 1993).

Finally, in the Ulla-Ulla altiplano, an efficient water management for irrigation and good organization of community work have favored the expansion and maintenance of large bofedale extensions that sustain high animal loads, especially during the dry season (when, due to lack of forage in the plains, alpacas join the llamas in these wetlands). However, the sustainability of the traditional system is endangered by damage to natural pastures in the plains (Alzérreca et al. 1981; Seibert 1994), the increasing concentration of grazing in bofedale areas, and a decrease in water management efficiency. In this context, farmers perceive the conservation of their vicuña populations (Ulla-Ulla is one of the largest vicuña reserves) as an extra source of pressure on the fragile system. Hence, a series of measures is necessary before the cultural and natural systems deteriorate even further. This should include the restoration of the natural pastures in the plains; better organization of water management systems; and a direct involvement of farmers in managing the vicuña, promoting a more efficient management of their populations and the generation of resources to allow a decrease in grazing pressure.

CONCLUSIONS

Grazing systems with introduced cattle and a short grazing history (Argentina and Venezuela) show a reduced pastoral space compared to the traditional camelid grazing in the puna (Bolivia), particularly of llamas. The lowest pastoral space values found for alpacas correspond to the grazing of animals with a more specialized diet that are adapted to less demanding environmental conditions. Grazing-impact magnitudes of introduced animals depended largely on the spatial patterns developed by the animals, which are controlled by the spatial and temporal distribution of natural forage and the animals' ability to exploit the dominant vegetation. The difficulties encountered by animals to efficiently obtain and consume the dominant vegetation were a major barrier in the introduction of livestock farming; this limited the available grazing areas in these environments. Animal concentration in optimal sites has been associated with the formation of grazing-induced swards. These swards, similar to puna bofedales, combine good water availability and the dominance of good forage species resistant to grazing. Above moderate loads, successional trends show the colonization of native and exotic weeds, and a decrease in forage supply. This negative impact can only be decreased through a strong control of grazing, using animal dispersion practices (Cumbres Calchaquíes in Argentina), a decrease in animal loads in critical periods and extra forage supplies (Sierra de la Culata in Venezuela), or the expansion and maintenance of optimal sites through irrigation technology (the Ulla-Ulla altiplano in Bolivia).

SUMMARY

Pastoral strategies, space-use efficiency, and their relationship with dominant vegetation patterns are compared in three Andean systems: alpacas and llamas in the punas of the Ulla-Ulla altiplano, ovines in the high-altitude grasslands of the Cumbres Calchaquies (northern Argentina), and cattle in the páramos of the Cordillera de Mérida (Venezuela). GIS and multicriteria assessment methods are used to map the vegetation and its capacity for grazing. Multivariate analysis techniques are used for analyzing the vegetation structure and the effects of management variables. The results show that pastoral systems with more recently introduced animals (Argentinean grasslands and the Venezuelan páramos) have limited available grazing area, related to the concentration of the animals in a

few optimal sites and the limited capacity of the animals to utilize effectively the dominant vegetation. These sites are characterized by high ground water availability and the dominance of species with high palatability and grazing resistance. The same characteristics are also important for the use of the bofedales in the Bolivian altiplano for alpacas, whereas the diverse diet of llamas allows them to use the widest pastoral space of the three systems analyzed. The management strategies for animal dispersion, increased forage supply, or vegetation structure alterations that could contribute to the decrease in the environmental impact of grazing in the three regions are discussed.

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