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23 Agricultural Development and Biodiversity Conservation in the Páramo Environments of the Andes of Mérida, Venezuela

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INTRODUCTION

The páramo of the northern Andean highlands is one of the most important biogeographic regions of the Andes. Extending insularly around the equator (11° N to 8° S), it protects the headwaters of the high catchments that drain toward the Pacific, i.e. the Orinoco and Amazon rivers, and plays a fundamental role in the stability of the highlands.

Moreover, the páramo is characterized by a high biological landscape and cultural diversity, a biota unique in its adaptations, its hydrological environmental services, and its large potential for tourism (Monasterio and Celecia, 1991). In fact, the páramo has been assigned high global priority for conservation (Biodiversity Support Program, 1995). However, in the tropical Andean countries of Venezuela, Colombia, and Ecuador, there is a growing need for new agricultural land due to the high demand in the national markets for crops cultivated exclusively in cold mountain environments, as well as due to the growing population. The ongoing advancement of the agricultural frontier in each of the three countries has led to alarming annual losses of natural páramo areas (Hess, 1990; Verweij, 1995; Drost et al., 1999).

In tropical mountain environments, in which the high biodiversity is endangered by dynamic processes of transformation and degradation, meeting the production needs of the

local population while protecting fragile ecosystems represents a challenge for the design of effective conservation strategies. This chapter addresses the relationship between agricultural dynamics in the páramo region and the conservation of areas providing fundamental hydrologic services for agriculture. The conceptual and methodological approach used is based on the analysis of three spatial scales, all of them integrated through water as an environmental service of the high páramo. The scale integration approach departs from the premise that the natural páramo ecosystems in which agroecosystems are embedded are components of a complex production system as important as the crop production systems themselves. The ecological functions of the páramo determine the stability of these environments transformed by agricultural processes (Monasterio and Molinillo, 2002). In this context, the high páramo belt is interpreted as an area for the conservation of biodiversity, water capture, and hydrological equilibrium of outflow rates.

This chapter aims at analyzing the relationships between agricultural dynamics and the conservation of páramo ecosystems, especially the wetlands of marshes and swards, areas of origin, and accumulation of the water used for páramo agriculture in the central core of the Cordillera de Mérida (Venezuela) above 3000 m (Figure 23.1). The present chapter has

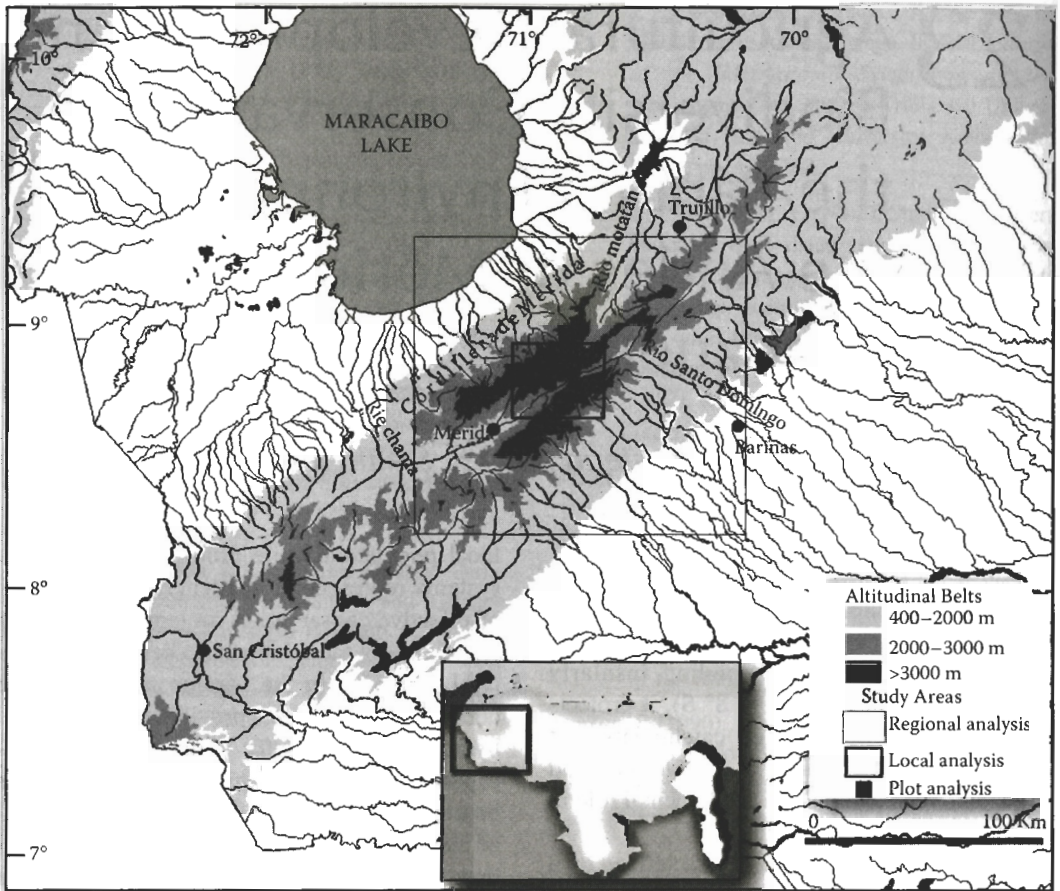


FIGURE 23.1 Study area in the Cordillera de Mérida (western Venezuela). The dense hydrographic network arising in this region flows toward the Orinoco River and the Maracaibo Lake catchments. The páramo belt, where the main watercourses originate, spatially corresponds with land above 3000 m asl. The large rectangle is the perimeter of the regional study, the small rectangle circumscribes the central páramo core, which was analyzed at a local scale, and the small black square indicates the study area at a plot scale.

been developed within the framework of the project called “Ecological and Social Sustainability of Agricultural Production in the Cordillera de Mérida: Flow of Environmental Services of the High Andean Páramos for Potato Agriculture.” Project sponsored by Universidad de Los Andes, Venezuela. It analyzes the importance of environmental services for production in the agricultural zone.

METHODS

Information gathering and analysis are carried out at three spatial scales: regional, local, and plot scale. In Figure 23.2, a diagram of the scales considered and their integration through

water as a service of the páramo is presented. On a regional scale, the spatial distributions of grass páramo and wetland páramo have been surveyed using a Landsat 7 image (006-054) established in January 2001. Based on this information, the life zones with a potential to supply other zones with water were identified.

The main páramo agricultural area in the upper basin of the Chama River was identified and analyzed. Areas with fallow and intensive agriculture as well as the zones within the páramo where the water sources used by each community for agriculture are located were mapped (marshes and swards). The analysis was based on processing the orbital spectral image Spot 4-651-332 (© CNES 2001, Spot

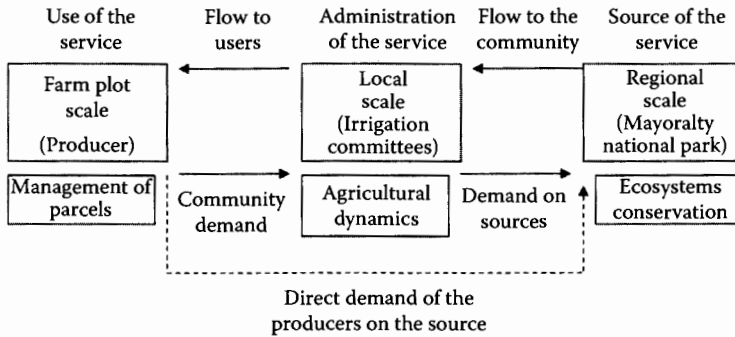


FIGURE 23.2 Simplified diagram of the links between scales that constitute the transversal theme of water as an environmental service of the páramo. The integration of scales allows a dynamic approach to the relationships between priority issues for conservation and development for the different actors and spaces. From Monasterio, M. and Molinillo, M. (2002).

Image S.A.). To classify the agricultural zone, the NDVI (Normalized Difference Vegetation Index) was used first and then pattern filter analyses. Based on pixel heterogeneity, three levels of land use intensity were derived: (1) fields of intensive agriculture (high-pixel heterogeneity PHG), (2) fallow farming (medium PHG), and (3) abandoned fields (low PHG).

On a plot scale, the vegetation of 20 marsh and sward sites was recorded in El Banco watershed. These were sampled using random quadrats. In each 1-m² quadrat, the number of species was determined, and vegetation, dry matter, and dung cover (grazing indicator) were measured; soil moisture was also determined. In each sward area, between 10 and 20 quadrats were established, and the following variables determined: altitude, slope, stoniness, forage supply, and distance to water sources. In addition, farmers were interviewed to analyze their grazing strategies, agricultural practices, and private and communal water management.

RESULTS AND DISCUSSION

PÁRAMO ECOLOGICAL BELTS AND WATER SUPPLY

The páramo of the Cordillera de Mérida extends above 3000 m asl. The altitudinal gradient is related to climatic and land use gradients that constitute true ecological belts at different altitudes. Within this altitudinal zoning, the following levels can be identified (from low to high

altitude): the Andean belt, the high-Andean belt, and the periglacial belt.

The analysis on a regional scale shows that the high-Andean and periglacial belts are indispensable sources of water to maintain páramo agriculture.

The upper limit for agriculture is confined to the high-Andean belt (3000 to 4000 m). The natural ecosystems above the present agricultural frontier have a colder periglacial climate and a sparser vegetation cover with giant Andean rosettes of the *Espeletia* genus. At these altitudes, land use is limited to seasonal low-intensity grazing in the bottom of glacial valleys covered by marshes and swards, which have a large potential for tourism.

In the periglacial belt (4000 to 4800 m), the cycle of nightly freezing and daily thaw prevents all forms of agricultural activity because of the recurrent frosts. Two plant formations colonize this environment: the desert páramo and the periglacial desert (Monasterio, 1980a). The flora, with a high number of endemic plants, has developed strategies and spectacular life-forms (giant rosettes of *Espeletia* and acaulescent cushions of different genera) that help to reduce solifluction caused by the daily freeze-thaw cycles and stabilize the mobile soils in these areas. The formation of microterraces by these species decreases soil displacements produced by cyroreptation processes. In this context, topographic and climatic conditions and a biota adapted to extreme hydric and thermic stress constitute key elements of a unique and fragile environment, which cannot

be directly utilized because of its harsh climate, low productivity, and high erosive potential.

These páramo environments are the headwaters of three important river basins: the Chama, Santo Domingo, and Motatán, three large hydrographic networks originating from superficial drainage in the highest páramos and from the approximately 400 glacial lagoons above 3800 masl. Water resources coming from the páramo are essential for intensive, year-round cultivation of potatoes, vegetables, and more recently, garlic.

AGRICULTURE, GRAZING AND WATER RESOURCES

At a local scale, the analysis dealt with the agricultural zone and the páramo ecosystems of the high Chama River watershed. The agricultural zone between the Sierra Nevada and Sierra La Culata is the main area benefiting from water generated by this watershed. This is an area of about 8400 ha extending along the Chama River valley and the transversal inter-Andean valleys that feed into it. On the one hand, the valley bottoms tend to be occupied by intensive agriculture with irrigation and highly productive crops (roots, vegetables, flowers, etc.), replacing the natural páramo ecosystem (especially in relatively flat areas of high soil fertility). On the other hand, fallow agriculture, generally without irrigation, is practiced in the steeper valley slopes at the upper limit of the agricultural belt (above 3400 m). Fallow agriculture is characterized by alternating crop and fallow cycles. Because of this management practice, uncultivated areas go through a successional process, which tends toward the regeneration of the natural ecosystem (Sarmiento et al., 1993). Hence, the agricultural frontier appears as a gradual transition zone between successional mosaics and the natural ecosystem.

On a local scale, there are two landscape elements, glacial lagoons and peatlands, which represent the most important water sources and water retention basins. Most lagoons are of glacial origin and relatively small. They are scattered mainly above 3800 masl, where glaciers were more active during the Pleistocene era. Together, they occupy more than 300 ha and constitute the main storage compartment for

surface waters. Closely linked to lagoons are the marshes covered by tussock grass and sward vegetation, which occupy more than 3000 ha between 3600 and 4200 masl. They act as true sponges, dampening runoff because of their deep soils, high soil organic matter levels, and irregular microrelief. These units are the most important temporal water reservoirs (approximately 70% of total storage capacity), which discharge slowly during the dry season. Because of a permanent water supply and the presence of tender forage, marshes and swards are the main areas where cattle grazing is concentrated (Molinillo and Monasterio, 1997a). Farmers are currently discussing strategies to protect vegetation and soils in these marshes and swards to reconcile these practices with cattle raising. Hence, analyzing the spatial location and conservation status of these wetlands in relation to grazing impacts is essential for a sustainable management of irrigation water.

AGRICULTURAL INTENSIFICATION AND SUCCESSIONAL DYNAMICS IN THE HIGH-ANDEAN PÁRAMO

The traditional land use system of the páramo is based on a shifting cultivation, with short periods of crop production alternating with longer fallow periods. After one or two cultivation cycles, plots are abandoned, and successional processes produce a trend toward a regeneration of natural páramo vegetation (Sarmiento et al., 2003). The use of the fallow not only favored soil fertility restoration (Sarmiento et al., 1993), but also had a positive effect on water dynamics, maintaining soil humidity, increasing organic matter contents, and decreasing runoff and soil loss (Sarmiento, 2000). This type of management has been the basis for the maintenance of a sustainable agriculture in these communities.

The decrease in importance or abandonment of the fallow strategy has been an important trend in the evolution of land use strategies in the last few decades. Especially since the beginning of irrigation in the late 1960s and up to the present, large areas with traditional land use of fallow agriculture were abandoned or transformed into intensive agriculture (Velásquez, 2001). The other important trend in

this process of evolution, agricultural intensification, has been of such magnitude that it shows in the positive correlation between cultivated area and potato production between the late 1950s and late 1990s (Figure 23.3). The leap in productivity from the 1970s was fundamentally determined by an increase in irrigated area and the conversion of fallow agriculture into intensive agriculture.

Plot management under intensive agriculture has translated into an increase in water demands, related to an increase in the number of crops per year and surface runoff. In this last decade, the introduction of garlic cultivation in the inter-Andean valleys has further increased water demands. Traditional crops were substituted with garlic. The advance of garlic and substitution of traditional crops happened in those plots with access to an established irrigation system. These changes are not only related to an increase in water use, but also to an increase in the private capture of water resources against communal use and the gradual drop in recent years in water levels of glacial lagoons. They have also produced a decrease in the carrying capacity for grazing in the agricul-

tural belt and an increase in the permanence time of cattle in the high-Andean belt.

These direct influences of agricultural dynamics on high-Andean grazing are part of an agropastoral strategy developed with the introduction of livestock husbandry as an integral component of wheat production technology instigated at the time of the Spanish conquest (Monasterio, 1980b). Since then, transhumance (animal movements), especially of cattle, and their permanence in the different altitudinal and vegetation belts has been determined largely by the agricultural calendar (Molinillo and Monasterio, 1997a). Animals were brought down from their grazing areas in the high-Andean belt not only because of the need for traction in plowing but also to complement their diet with cultivated forage and wheat stubble during the dry season. In the last decades, potato intensification, the introduction of garlic, and the decrease in importance and ultimately disappearance of wheat cultivation in the páramo have meant the loss of natural pasture and stubble fields for animals in the agricultural belt (Figure 23.4). As a direct

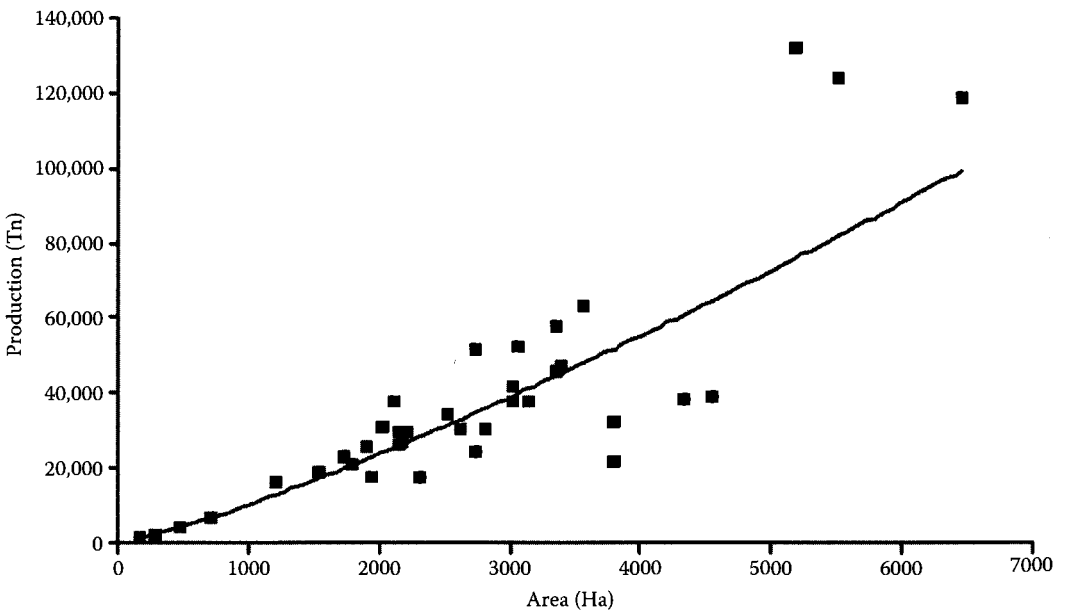


FIGURE 23.3 Relationship between production levels and surface area cultivated with potatoes from 1957 to 1997 in the Mérida state (the one with the highest páramo surface area and potato production in Venezuela). $R^2 = 0.9041$. Data source: MAC (Venezuela Ministry of Agriculture), 1958 to 1997.

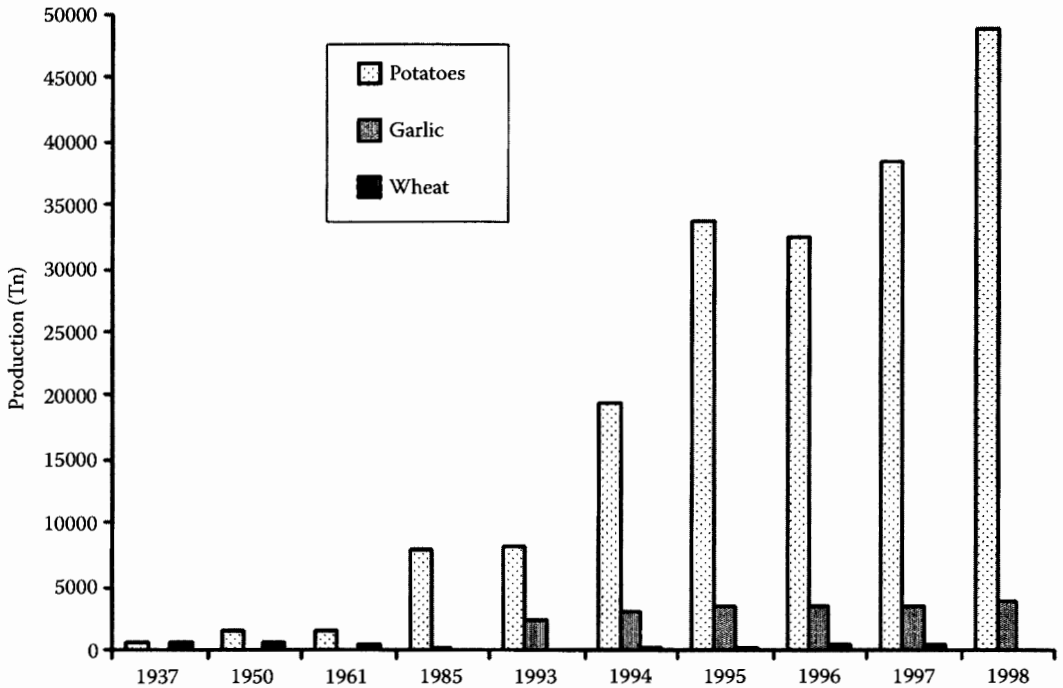


FIGURE 23.4 Production levels for potatoes, garlic, and wheat in the Rangel county (one of the counties with the highest páramo surface area and potato production in Mérida state) from 1937 to 1998. Data source: Velásquez, N. (2001), and Venezuelan Ministry of Agriculture, 1995 to 1998.

consequence, although not necessarily because of an increase in animal numbers, grazing has intensified in the swards and marshes of the high-Andean belt. The decrease in regeneration time of the large sward patches, which are grazed in rotational fashion, has accelerated the successional mechanisms through which swards are degraded (Figure 23.5).

Even though there has been a clear impact from cattle rearing, species richness in the swards of El Banco watershed (Chama River affluent) does not show a clear correlation with grazing intensity (Figure 23.6). This could be largely because of the fact that a large proportion of the increase in native weed species (*Acaulimalva acaule*, *Aciachne pulvinata*, *Geranium* sp., etc.) and exotics (*Rumex acetosella*, *Taraxacum officinalis*, etc.) during succession is counterbalanced by a fall in the number of native forage species (of the genera *Calamagrostis*, *Carex*, *Muehlenbergia*, *Agrostis*, etc.). These results seem more evident when the cover of good forage species as compared

to weeds is analyzed (Figure 23.7). Similar results were recorded for swards in the Colombian páramo (Pels and Verweij, 1992; Verweij and Budde, 1992; Verweij, 1995), and they agree with the model of Milchunas et al. (1988) on the effects of grazing in environments without a history of grazing: the large impact on vegetation physiognomy and the markedly increased potential of weed colonization.

In present environments with swards in the valley bottom of El Banco watershed, tussock grass species (species of the genera *Calamagrostis*, *Agrostis*, and *Festuca*) have been relegated to areas inaccessible to cattle because of water logging (e.g. *Calamagrostis toluensis*). They also colonize experimentally fenced off areas (Molinillo, 1992) where cattle were excluded (e.g. *Sporobolus tenuissinus*). A moderate to low stocking density favored short grass species (e.g. *Calamagrostis coarctata*, *Carex albolutescens*, *C. humboldtiana*, *Muehlenbergia ligularis*, and *Eleocharis acicularis*), which today dominate swards and marshes but which

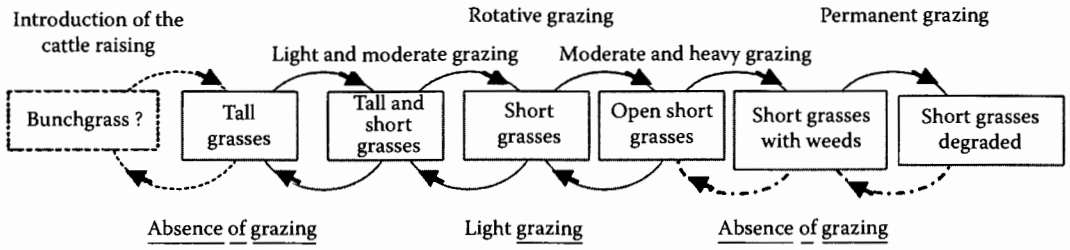


FIGURE 23.5 Simplified diagram of grass species succession under grazing in dry páramos. Successional cycles are controlled by the relationship between agriculture and cattle grazing. (From M. Molinillo and M. Monasterio, 2002.)

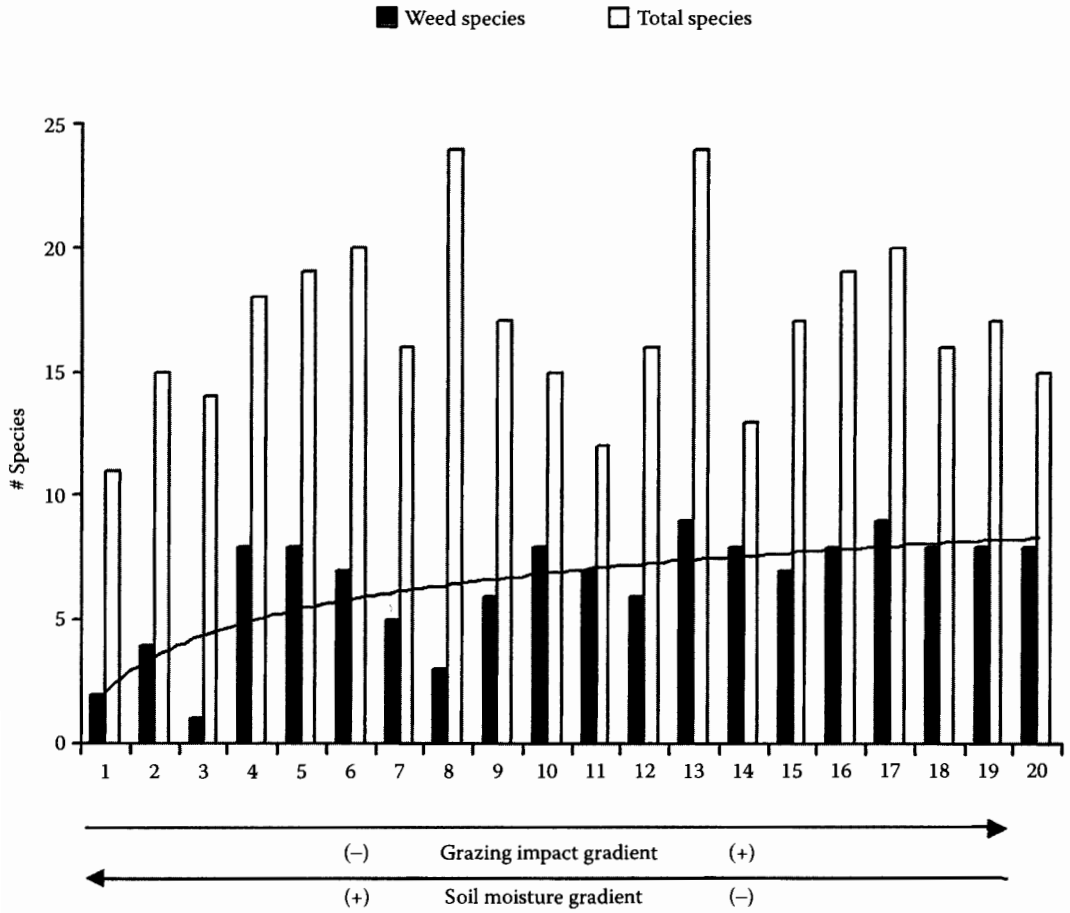


FIGURE 23.6 Number of weeds and total species richness in 20 units of marshes and swards as grazing impact increases and soil moisture levels decrease in glacial valley bottoms between 3800 and 4100 m in the El Banco watershed (Sierra La Culata, Cordillera de Mérida). The logarithmic relationship ($R^2 = 0.5206$) is for the number of weed species (both native and introduced).

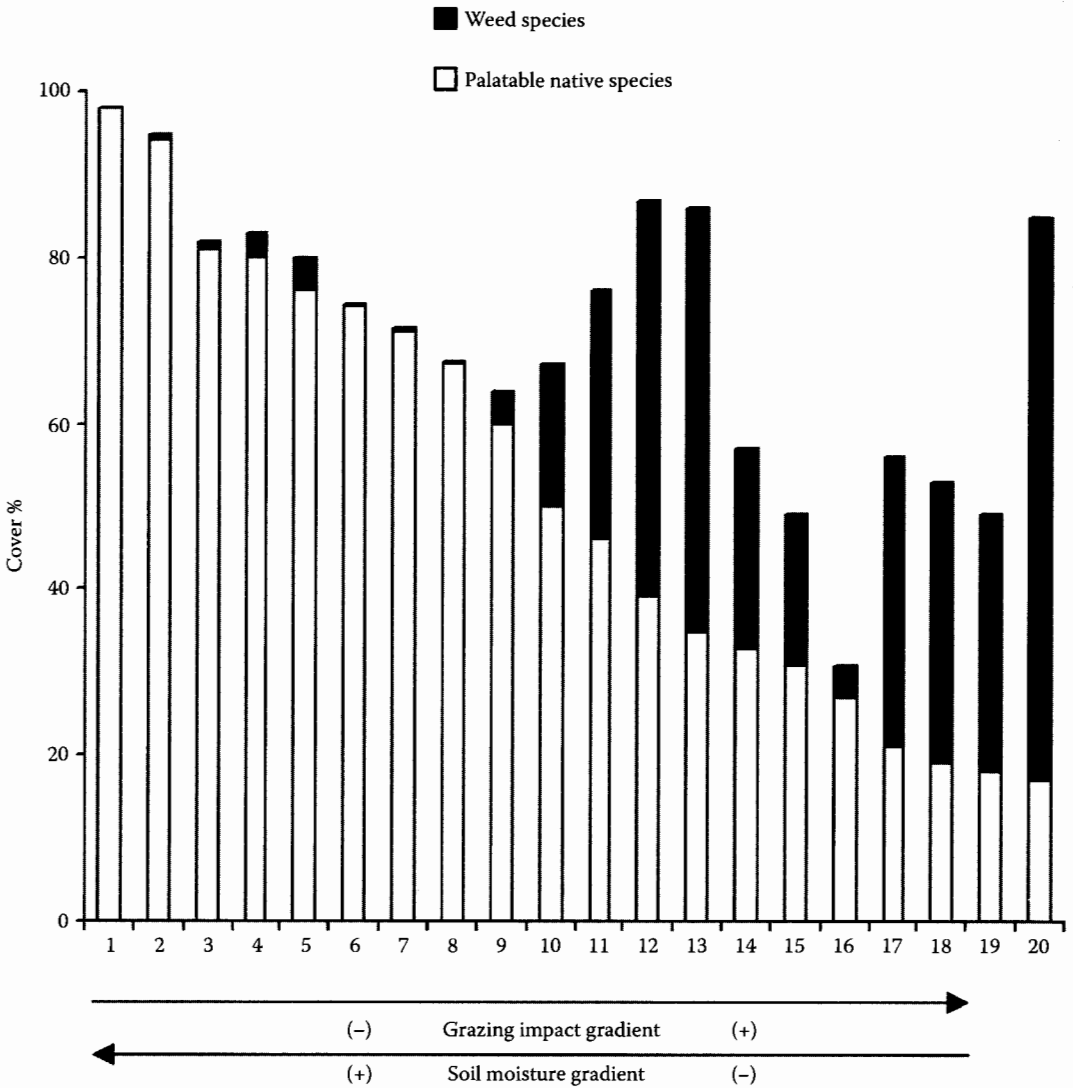


FIGURE 23.7 Changes in cover of palatable native and weed species (both native and introduced) in 20 units of marshes and swards as grazing impact increases and soil moisture levels decrease in glacial valley bottoms between 3800 and 4100 m in the El Banco watershed (Sierra La Culata, Cordillera de Mérida).

decrease in importance under heavier loads or larger animal permanence times. The appearance of species considered as native colonizers (e.g. *Agrostis breviculmis*, *Aciachne pulvinata*, *Acaulimalva acaule*, *Geranium* sp., *Lachemilla pinnata*, etc.) and exotics (*Rumex acetosella* and *Taraxacum officinalis*) has always been the case under these heavy grazing conditions.

The equilibrium in species composition and diversity in páramo wetland environments, controlled to a large extent by grazing frequency and intensity, have been strongly influenced by

agricultural trends during the last decades in the lower belts. In the El Banco watershed, potato agriculture intensification and the introduction of garlic have been fast processes that, together with the decrease and loss of wheat cultivation, led to a decrease in the carrying capacity of the agricultural belt. The consequent increase in animal permanence times in the high-Andean belt, has increased grazing impact on precisely the areas that have the capacity to store more water in these páramos. Because species composition and richness depend on grazing inten-

sity (animal numbers and permanence times on each wetland) and on soil moisture levels, the decrease in the number of native forage species and the increase in weeds can be a good indicator of the conservation status and water storage capacity of each sward unit.

SCALE INTEGRATION: RURAL DEVELOPMENT AND WETLAND CONSERVATION IN THE HIGH-ANDEAN BELT

The analysis at different spatial scales shows the tight relationship between the páramo as water sources and crop production in the agricultural belt. In this tight link, other important environmental services for agriculture are also involved, such as erosion control through soil retention, phytomass accumulation as green manure in fallow agriculture, special microclimatic conditions within slopes that decrease the incidence of crop pests, and tender forage from the valley bottom pastures for extensive cattle grazing.

The agricultural páramo region in the Cordillera de Mérida strongly depends on water supplies from the high-Andean and periglacial belts. Within the Chama River watershed, this means that most of the 8,450 ha in the agricultural zone, especially potato and garlic cultivation areas, depend on water inflow of approximately 23,700 ha of páramo environments, and especially so from the 150 ha of lagoons and 2,570 ha of swards and marshes (Monasterio et al., 2003). These last two store 70% of the water in all surface water compartments, even though they only represent 7.9% of the total surface area of the watershed. In addition, these environments constitute the most important areas for grazing cattle. Extrapolating the data from the El Banco subwatershed, we estimate that in the long run, these wetland habitats could support between 1,500 and 2,000 head of cattle under moderate to light grazing loads. This equals probably more than 80% of the cattle currently grazing in the high Chama river watershed. A large number of tussock grassland species are only found in areas of low accessibility for grazing, and the native forage species favored by medium to low grazing loads are in an equilibrium state that depends on agricultural dynamics and animal permanence times

in the high-Andean belt. Integrating data obtained at different spatial scales, it is clear that the tendencies for agricultural intensification (changes in the crop types and dynamics) not only produce a large increase in water demands and a consequent increase in pressure on water sources in the páramo but also advance the environmental degradation of wetlands.

On a plot scale, the increase in plots with little or no fallow times (i.e. the fallow strategy has been abandoned) and the introduction of crops with higher water demands generate a change in agricultural dynamics and water use, reflected in new trends toward more private management and less communal administration. At a regional scale, these trends translate into higher pressure on the resources and the need for páramo conservation.

The increased demands on the páramo environmental services of the Cordillera de Mérida, particularly water services, have not been paralleled by effective conservation strategies in the high-Andean and periglacial belts, such as grazing control on the wetlands (Molinillo and Monasterio, 1997b). Neither have control strategies been implemented for more efficient water use at the community and regional levels. One of the main reasons for this is that water-related problems operate at different spatial scales, implying different spheres, stakeholders, and policies (Monasterio and Molinillo, 2002).

Consequently, the subject of water for páramo agriculture and its relationship with conservation in these high-mountain ecosystems will become increasingly important. Hence, there is a need to involve the local population to reach a sustainable use of water resources. This can be achieved through promoting awareness of the relationship between water quality and quantity and the conservation status of páramo ecosystems. In addition, different approaches are needed to allow a better understanding of the role and relationships among the different stakeholders (farmers, grassroots organizations, local authorities, national park services, researchers, and governmental and nongovernmental organizations) involved in water management.

For the purpose of reaching these objectives, the project has supplied basic information, such

as the design of cartographic tools (topographic and ecological maps) showing in detail the spatial relation between agricultural and water capture and storage zones in the periglacial belt of each of the watersheds and microwatersheds utilized by each community. The use of these tools, combined with the scale integration approach, is intended to facilitate understanding of the relationships between stakeholders, their roles, and their spheres of influence, stimulating participatory workshops for discussion of the links between conservation of natural ecosystems and agroecosystems (Monasterio et al., 2001).

The identification and quantification of environmental services and their sources of origin in natural areas, in turn, will emphasize the value of natural ecosystems and their role in production systems. Maintaining diversity in the high Andes guarantees the sustainability and functioning of agricultural areas. Moreover, local populations, the institutions responsible for the conservation of natural areas, and researchers will have to cooperate when designing activities and strategies compatible with conservation and enhancement of the environmental functions of protected areas.

All this information, represented through cartographic tools, will be the ecological base to develop and plan local and regional agricultural policies demonstrating conservation alternatives aimed at maintaining and enhancing the role of natural areas for a more socially sustainable and ecological production strategy in páramo agroecosystems.

Within this approach, conservation plans, aimed in general at a regional scale, could not only involve measures to control human impacts on páramo water sources, but also enhance the understanding of agricultural dynamics at a community level and the use of management on a plot scale of the different types of crops. Research projects formulated on a plot scale could provide further detail on the different subjects to include, considering the possible impact of research locally and regionally. Even though these are the obvious consequences of scale integration, other implications at the community level could be essential for conservation and sustainable management at a regional and macroregional level (Monasterio and Molinillo, 2002). One of these is to be able

to take the regional importance of diversity conservation in the high-Andean wetlands to the farmer plots.

CONCLUSIONS

In the páramo of the Cordillera de Mérida, analysis at different scales shows a tight link between agricultural intensification trends and changes in grazing patterns in the high-Andean belt. This situation mainly affects the wetland habitats in the valley bottoms above the agricultural belt, precisely the areas with the best water retention, where the water resources for páramo agriculture are located. The successional dynamics of these vegetation units are mainly controlled by grazing intensity, which could be on the increase because of an increase in the permanence time of animals on each wetland. This is fundamentally due to a decrease in the carrying capacity and supplementary forage supply in the agricultural belt. In terms of plant species composition, this could, in turn, mean the gradual displacement of the dominant swards of native forage species by weeds (natives and exotics), even if species richness is not significantly affected. The spatial scales integration approach could allow producers to identify more clearly the relationship between agricultural management in their plots and high-Andean wetlands. In this context, it is essential to identify and use indicators allowing rapid determination of the status of the hydrological functioning of marshes and swards, so that effective conservation measures can be put in place. Vegetation composition, specifically the ratio between the number of native forage and weed species, is suggested as one of the most significant indicators to be analyzed.

SUMMARY

The relationship between agricultural dynamics and the conservation of páramo ecosystems is analyzed in the central core of the Cordillera de Mérida (Venezuela), particularly in the marshes and swards. These are the origin and storage areas of water for agricultural production in the region. The conceptual and methodological approach is based on the integration of

the regional, local, and plot scales through the transversal link of water as an environmental service. On a regional scale, the high-Andean and periglacial belts are identified as the most important providers of water used in the lower belts for agriculture. On a local scale, the cultivated páramo zone and its water sources in the high Chama River watershed is analyzed. On a plot scale, the dynamics of agricultural production and its relationship with grazing impact on species composition of the marshes are discussed. The results indicate that plant community structure and diversity have been influenced by agricultural intensification in the agricultural belt in recent decades. This process, together with a decrease in importance and the disappearance of wheat cultivation, have led to a decrease in carrying capacity for cattle grazing in the agricultural belt, and an increase in the permanence time of cattle in the high-Andean belt. Even though there has been a clear impact on cattle raising, species richness in the swards of El Banco watershed (Chama River affluent) does not show a clear correlation with grazing intensity. This could be due, to a considerable extent, to the fact that a large proportion of the increase in species considered as native weeds and exotics during succession is counterbalanced by a fall in the number of native forage species.

These results seem more evident when the cover of good forage species in comparison to weeds is analyzed. Grazing intensity (number of animals and their residence time in each marsh and sward) and soil water content control the equilibrium between native forage species and weeds. Hence, these variables are suggested as good indicators of the conservation status of marsh and sward environments. Finally, the use of the scale integration approach for developing a better understanding of the key issues for water management and increasing effective participation of the local population in conservation is discussed.

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