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# Balancing Conservation of Biodiversity and Economic Profit in the High Venezuelan Andes: Is Fallow Agriculture an Alternative?

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## INTRODUCTION

### Páramo: a biodiverse ecosystem

In the upper belt of the Northern Andes (3000–4800 m) the characteristic ecosystem is the paramo, a humid tropical ecosystem dominated by giant caulescent rosettes, shrubs and bunch grasses. The paramo flora is among the richest found in the high mountains of the world (van der Hammen and Cleef, 1986). Half of the estimated 3000 to 4000 species of paramo vascular plants are endemic (Luteyn *et al.*, 1992). This high biodiversity is related to the geographical distribution of the paramo which appears as a chain of islands, separated by lower altitude ecosystems. These islands repeatedly suffered processes of expansion and contraction during the Pleistocene and Pliocene that favoured alternatively the colonisation and speciation of the flora (Cleef, 1978, 1981). Also, the unique climatic conditions of the high tropical environment (drastic daily temperature fluctuations) have led to the evolution of a flora with very particular adaptations (Vuilleumier and Monasterio, 1986; Monasterio and Sarmiento, 1991).

Due to the paramo's high biodiversity, the originality of plant adaptations, the numerous medicinal plants, its importance for water availability in the lowlands, and the great potential for recreational and touristic activities, paramo qualifies as a high priority area for conservation. However, it has been subject to an accelerated process of degradation and transformation. Each year, the upper agricultural frontier rises and the pristine hill slopes are absorbed by agriculture at an alarming rate due to the pressure of increasing population. This agricultural expansion is reported for Colombia (Ferwerda, 1987; Verweij, 1995; Hofstede, 1995), Ecuador (Hess, 1990) as well as for Venezuela (Drost *et al.*, 1999; Sarmiento, 2000).

### Man's use of the paramo ecosystem

The agricultural use of the paramo ecosystem is relatively recent (Ellenberg, 1979; Monasterio, 1980). In pre-Columbian times, the Venezuelan paramos were utilised exclusively for hunting and gathering (Wagner, 1978). It was only during the colonial period when the paramos began to be used for extensive grazing and for wheat growing (Monasterio, 1980). Later, wheat cultivation decreased, and more recently potato cropping in rotation with garlic and carrots has become an important economic activity. Initially, potatoes were cultivated with long fallow systems, as in many areas of the high Andes in Bolivia, Peru and Colombia (Brush, 1976; Sarmiento *et al.*, 1990; Hervé *et al.*, 1994; Pestalozzi, 2000). Recently, fallow is being eliminated by the utilisation of large amounts of mineral and organic fertilisers. This intensification is related to the geographical accessibility. In isolated areas more traditional systems persist, while easily reached areas are intensively cultivated. The unequal accessibility causes the coexistence of a variety of agricultural systems, including intensive, transitional and extensive systems, providing a good opportunity to assess the sustainability, environmental impact, conservation value and economic profitability of different management alternatives.

To evaluate the possibilities and challenges for the conservation of the high regional and local biodiversity in the paramo regions, it is essential to understand the social and economic importance of the human activities. In contrast to the agricultural marginality of most mountain regions (Rieder and Wyder, 1997), in tropical countries like Venezuela, many crops can only be cultivated in the cool mountain climate. This production is sold to the domestic market, providing food for an increasing national population and at the same time is the base of subsistence for a numerous and growing rural Andean population. Between 1984 and 1995, potato production rose five times, garlic four times and carrots nine times in the Venezuelan Andes (Gutierrez, 1996). This increase was accomplished by intensification as well as by expanding the agricultural frontier, frequently by an advance in altitude, incorporating fragile paramo areas that often lie inside the national parks.

## Long fallow agriculture and the maintenance of biodiversity

In the tropics and subtropics long fallow agriculture is not only widespread in low altitude but also in mountain areas (Grigg, 1974; Ferweda, 1987; Kellman and Tackaberry, 1997; Sarmiento *et al.*, 1990, 1993; Knapp, 1991; Ramakrishnan, 1992; Hervé *et al.*, 1994; Pestalozzi, 2000). An old polemic exists about the sustainability of this type of agriculture. Several authors agree that it can be sustainable providing the population or economic pressures are low, but others see long fallow agriculture as a wasteful form of land use, consuming large areas in support of few people (Ingram and Swift, 1989; Kleinman *et al.*, 1995). In principle, a biodiversity comparable to that of the natural ecosystem can be maintained with a long fallow system, using the spatial coexistence of several successional stages, forming a mosaic landscape (Swift and Anderson, 1994). During the fallow period,

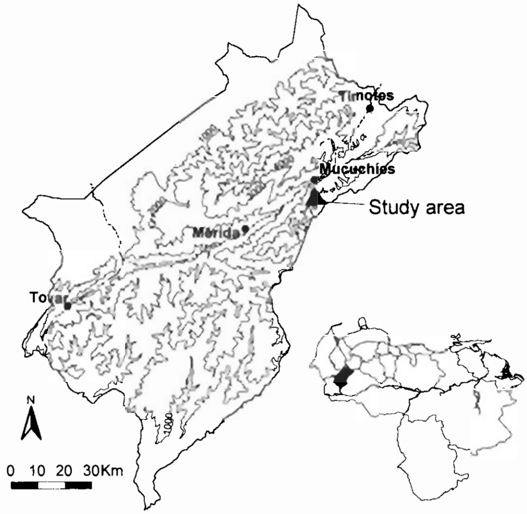


**Figure 24.1** Localisation of the study area, Páramo de Gavidia, in the Venezuelan Andes

the typical behaviour of plant diversity is to increase in the early stages, as a result of the gradual colonisation of the area; to attain a maximum in intermediates stages, when competitors coexist; and to decrease in late stages, as the system approaches its competitive equilibrium and exclusion occurs (Huston, 1994). If the successional diversity is highest at intermediate stages, a landscape managed with a fallow system can be more diverse than the natural vegetation. Nevertheless, there are many exceptions to this general trend and a wide variety of successional patterns have been reported (Huston, 1994).

# THE STUDY AREA: PÁRAMO DE GAVIDIA

## A long fallow system in transformation

The study area, Páramo de Gavidia, is located in the Sierra Nevada National Park, in the state of Mérida, between 3200 and 3800 m asl (Figure 24.1). The area is a narrow glacial valley where agriculture is practised on steep slopes and small colluvial and alluvial deposits (Figure 24.2). The mean temperature ranges between 5 ° and 9 °C and the mean annual precipitation is 1300 mm. The present population

**Figure 24.2** Panoramic view of the study area, the glacial valley of the Páramo de Gavidia (3200–3800 m asl)

(400 inhabitants) settled in the valley at the end of the nineteenth century, giving it a relatively short land-use history (Smith, 1995). The management system is long fallow agriculture, where potatoes are grown for 1 to 3 years and then the fields enter the succession–restoration phase (Sarmiento *et al.*, 1993). In some cases, wheat or oats can follow the potato crop. The majority of the potatoes are grown for the local market and the cereals for home consumption. The current average fallow period is 4.6 years, but a large variability, from 2 to more than 15 years exists. This management system generates a landscape mosaic where cultivated and fallow fields coexist with areas of natural vegetation. At present, the surface under fallow agriculture is 192 ha and the total surface of the study area is 464 ha. The 59% of the area still under natural vegetation is progressively being incorporated into the agricultural cycle. Between 1992 and 2000, 22 ha of natural vegetation were ploughed, corresponding to an increase of 11.5% of the area in the cultivation–restoration cycle.

In 1972, a road to the valley was built, facilitating the commercialisation and the introduction of mineral fertilisers. Since then, the fallow periods have been reduced but not eliminated. In the last three decades, the system has passed from a traditional fallow system, where potatoes and cereals were cultivated mainly for subsistence, to a semi-traditional system where mineral fertiliser allows a surplus of production for sale. Currently a new transformation towards an intensive agricultural system is beginning.

### The ecological succession during the fallow period

Plant colonisation and replacement is a continuous process, but for practical reasons we differentiate four periods: early, intermediate and late succession, and restored paramo. During the early period (1 to 3 years) typical pioneer herbaceous species colonise, including *Rumex acetosella*, an introduced forb, which is the dominant species. Other species during this phase are *Vulpia muyrus*, *Lachemilla moritziana*, *Senecio formosus*, *Lupinus meridanus* and *Poa annua*. During the intermediate phase (4 to 6 years), *R. acetosella* and *L. moritziana* reduce their cover, while *L. meridanus* and *V. myurus* become more abundant. Newly arrived species include *Gamocheta americana*, *Geranium* sp. *Trisetum irazuense*, *Acaena elongata*, etc. Also, in this phase, some dominant paramo species increase their abundance, such as *Espeletia schultzii* and *Hypericum laricifolium*. In the late phase (more than 6 years) other species become dominant, including *Baccharis prunifolia*, *Noticastrum marginatum*, *Stevia lucida*, *Pernettya prostrata*, *Bromus carinatum*, etc. *E. schultzii* and *H. laricifolium* continue to increase their cover and the physiognomy changes from herbaceous to the typical rosette–shrub paramo. Finally, the restored paramo is dominated by *E. schultzii*, *H. laricifolium*, *P. prostrata*, *Calamagrostis effusa*, *Agrostis tolucensis*, *B. prunifolia*, *Nassella mexicana* and *Arcytophyllum nitidum* among many others (Figure 24.3).

## RESEARCH QUESTIONS

In this study, biodiversity is addressed at two different scales, the field and the whole valley. At field level, we focus on the dynamics of restoration. If the fallow period is too short, the natural ecosystem will not be restored and consequently the agricultural practice will lead to ecological degradation. The research question

**Figure 24.3** The paramo vegetation, with the characteristic rosettes of *Espeletia schultzii*

is: how much diversity can be attained with the present fallow length in relation to the natural paramo?

At local or valley scale, we examine the spatial coexistence of fields in several successional stages. This coexistence could theoretically generate greater biodiversity than that of the natural ecosystem, by the juxtaposition at local level (in neighbouring fields) of species characteristic of the different successional phases (pioneers, intermediates and climax species). The central question is whether this long fallow system increases or decreases biodiversity at the local scale compared to the valley with only natural vegetation.

The current changes that the agroecosystem is undergoing, such as fallow time reduction and ploughing of natural areas, are also analysed. The problems addressed are how important is maintaining areas of natural vegetation for local biodiversity, and how does shortening of the present fallow lengths affect local biodiversity?

Finally we analyse which agricultural land-use system could optimise the relationship between biodiversity and economic profit and thus answer the questions: Are long fallow systems the best alternative to maintain high plant diversity or are there other alternatives that could optimise the relationship between conservation of plant diversity and the needs of the human population?

## METHODOLOGY

### Part 1: Biodiversity and richness along the succession gradient

For the estimation of species richness and diversity along the succession gradient, 150 fields with different fallow lengths (1 to 12 years) and eight areas with natural, never ploughed, vegetation were selected using a spatial database with information on the fallow lengths of 1200 fields.

The vegetation was sampled using the point-quadrat method (Greig-Smith, 1983). A pin was placed 100 times at random in each field and the touching species were recorded. Richness was estimated as the total number of species recorded in each plot. Species abundance was calculated as the number of contacts. Alpha diversity was calculated from the species abundance using the Shannon index. Beta diversity along the successional gradient was calculated using the equation of Shmida and Wilson (1985).

### Part 2: Biodiversity at local scale and possible future scenarios

Local biodiversity was estimated by extrapolating the data obtained in the individual plots to the entire valley. All the fields with the same fallow time and natural vegetation areas were considered as landscape units. The species abundance of each landscape unit was calculated as the average abundance of all the studied plots with the corresponding fallow time. Then the species abundance in the valley was calculated by weighting the abundance of each landscape unit by its surface:

$$\mu_i = \sum_{k=1}^{n} a_{ik} s_k \Big/ \sum_{k=1}^{n} a_{ik}$$

where $\mu_i$ is the abundance of the $i$th species in the valley, $a_{ik}$ is the abundance of the $i$th species in the $k$th landscape unit and $s_k$ is the surface occupied by the $k$th landscape unit, obtained from the spatial database. The values of $\mu_i$ were utilised to calculate the biodiversity using the Shannon index ($H'$):

$$H' = -\sum_{i=1}^{n} pi \ln pi \quad \text{and} \quad pi = \mu i \Big/ \sum_{i=1}^{n} \mu i$$

where $p_i$ is the proportional abundance of the $i$th species.

Using this methodology, the local biodiversity corresponding to the current management system was calculated. In order to evaluate the effect of fallow shortening, the same methodology was utilised to calculate local biodiversity for scenarios with fallow lengths from 1 to 10 years. In this case, the surface occupied by each landscape unit ($s_k$) was calculated by dividing the total surface of the study area (464 ha) by the fallow length plus 2, considering that the fields are cultivated for 2 years before entering fallow. To examine the consequences of the yearly incorporation of never ploughed areas into the agricultural cycle, different relationships between areas under agriculture and natural vegetation were considered.

### *Definition of the scenarios*

Three groups of scenarios were defined, considering the land-use systems currently practised in the high Venezuelan Andes. In each group the relationship between agricultural and natural area is modified until 100% of the valley is occupied by agricultural land use. The three groups are:

- Fallow lengths between 1 and 10 years, with 2 years of potato cropping.
- Continuous cropping, where organic manure replaces fallow (intensive system).
- Spatial combination of intensive and 10-year fallow system

### *Calculation of the economic profit of the different scenarios*

The economic profit of each modelled scenario was calculated as the gross income minus the cost of production. The costs considered were labour, transport, mineral fertiliser and organic manure, where applied. The transport costs include the carrying of fertilisers, seeds and production between the fields and the road on horseback. For the calculation, a function of the distance to the agricultural fields, obtained from the spatial database, and the carrying capacity of mules was established. The calculation of all inputs was based on the prices of 1999 and the average amounts applied in the area. The workforce was calculated considering the preparation of the field, planting, hilling and harvesting, which varies depending on the production system.

For the yield calculations of the fallow system the restoration of soil fertility during the fallow and the fertility loss during cropping were considered. A model developed by Sarmiento (1995), using yield data from the same area, was applied. This model considers that soil fertility, defined as the capacity of the soil to produce potatoes without mineral fertiliser, increases as an exponential function of the fallow time:

$$F_t = 14\ (1\text{-}e^{-0.03t})$$

where $F_t$ is the soil fertility level in t ha$^{-1}$ after a fallow time of $t$ years.
Yield was calculate as:

$$Y = 12\ F_t\ 0.5^n$$

where Y is the crop yield in t ha$^{-1}$, 0.5 is a factor of fertility reduction after each year of cropping, $n$ is the number of years under cultivation and 12 is a factor that considers the yield increase by the application of the average dose of mineral fertiliser for the area (1.8 t ha$^{-1}$ of NPK 16–16–08). In the intensive system, a constant yield of 18 t ha$^{-1}$ was used, which represents the regional average when using organic manure. In the intensive and the fallow system the same dose of mineral fertiliser was considered.

In order to model the intensive–extensive agricultural system, a 150-m buffer zone was drawn around the existing road in the valley bottom. The area close to the road was modelled using the intensive system and the area outside the buffer zone was modelled as a 10-year fallow system.

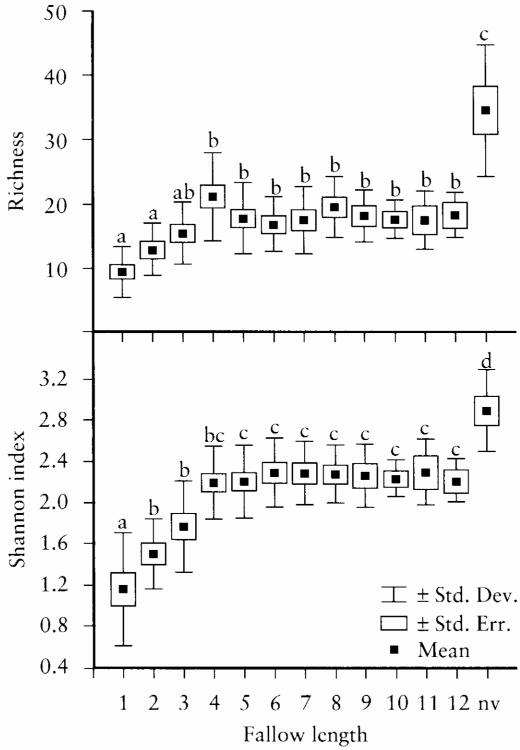


**Figure 24.4** Species richness and plant diversity estimated, using the Shannon Index, along the succession and in natural vegetation (nv). Same letters indicated not significantly different ($p < 0.05$) between successional stages (Duncan test after one-way analysis of variance)

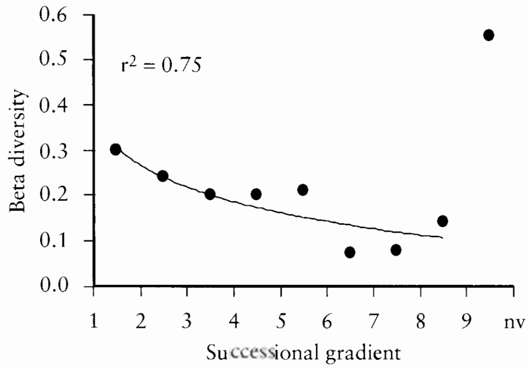


**Figure 24.5** Plant beta diversity along the successional gradient, fitted to a negative exponential model (nv = natural vegetation)

## RESULTS

### Part 1: Biodiversity during the fallow period

Species richness doubles during the first 4 years of the fallow, passing from an average of 10 to 20 species (Figure 24.4). Hereafter, the number of species stabilises, and after 12 years of fallow, the richness still remains significantly lower than in the natural vegetation, where an average of 35 species per plot was found. Alpha diversity presents a similar tendency, with an important increase during the first 4 years and a posterior stabilisation. These results show that neither the species richness nor the diversity of the original ecosystem are restored after 12 years of succession.

Beta diversity, that quantifies species turnover during succession, decreases exponentially and after 9 years, 60% of the species still have to be replaced to obtain the community structure of the natural vegetation (Figure 24.5). A successional deceleration in species turnover is evident, and the time necessary for a complete restoration seems to be much longer than the studied interval and the current fallow lengths.

### Part 2: Local biodiversity

*Effect of the fallow length and the proportion of natural vegetation on biodiversity*

Different fallow lengths and proportions of the valley under agricultural use lead to changes in local diversity. In Figure 24.6, it can be observed that local biodiversity depends more on the remaining natural vegetation than on the fallow time, which is only important when almost all the area is incorporated into the agricultural cycle. Without natural vegetation, local biodiversity is very sensitive to fallow duration. A system with only 1 year of fallow generates very low local biodiversity, which quickly rises until a 4-year fallow system is reached. After that, the increase in fallow length has little effect on biodiversity. This tendency reflects earlier results showing that

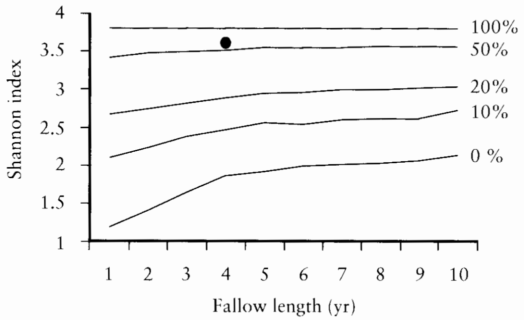


**Figure 24.6** Simulated effect of the fallow length and of the percentage of natural vegetation on local plant diversity. The different fallow lengths refer to the duration of the fallow in the valley, e.g. a system with a fallow length of 4 years has 33% of its surface under crop and the remaining 66% is divided between 1 and 4 years of fallow. The point indicates the current agricultural system

the successional rate becomes very slow after 4 years. On the other hand, we can see that biodiversity rises quickly with the increase in natural vegetation area. For example, with 50% of the area under natural vegetation, a biodiversity comparable to that of the entire valley under paramo is attained and the fallow length with which the other 50% is managed has little importance. In the current agricultural system, local biodiversity is not very different from that of the natural vegetation. This is not due to the current fallow lengths but to the high proportion of the natural area remaining in the valley.

### *Effect of different management systems on biodiversity and net economic profit*

The quantification of local biodiversity and net economic profit of the scenarios are presented in Figure 24.7. The response of the net economic profit is very dependent on the management system. The intensive system obtains much higher profits than the combination between intensive and extensive or the fallow systems. The profit difference between the 5- and 10-year fallow system is not very large and is due to the fallow effect on soil fertility. In all scenarios, biodiversity rapidly decreases when less natural vegetation remains in the area.

The current management system, while maintaining high local biodiversity, has a very low economic profit. To achieve higher profits more natural areas would have to be incorporated into the agricultural cycle, but this would lead to a rapid reduction in biodiversity and only a small increase in profit. A better alternative seems to be changing the management to an intensive system, but conserving large areas of natural vegetation. For example, a biodiversity of 3 can be reached by a 10-year fallow system with 20% of natural vegetation or by an intensive system with 40% of natural vegetation. In this case, the economic profit is three times greater in the intensive system. The same profit can be obtained using a significantly smaller area intensively and conserving the rest of the area under natural vegetation.

## DISCUSSION AND CONCLUSIONS

In the paramo environment, succession proceeds too slow to restore plant diversity in a time interval compatible with an agricultural system. However, after 12 years of succession a considerable number of paramo taxa have colonised, forming a semi-natural vegetation, physiognomically comparable to the natural paramo. Even if part of the diversity is lost, long fallow agriculture allows the maintenance of a semi-diverse system. Contrasting with the most common tendency in secondary succession, in the paramo, the diversity at intermediate stages is lower than in the climax community. This is due to the fact that just a small number of species are exclusive to the succession. Only *Rumex acetosella*, *Poa annua* and a few others, most of which are introduced species, act as real colonists. The rest of the species abundant in early and intermediate stages are paramo species with better dispersal mechanisms and other characteristics that permit higher performance during these stages. As in other extreme environments (MacMahon, 1981), there is not a real succession in terms of species replacement, but only variations in the relative abundance and the progressive arrival of the paramo species. The time necessary for a complete restoration of

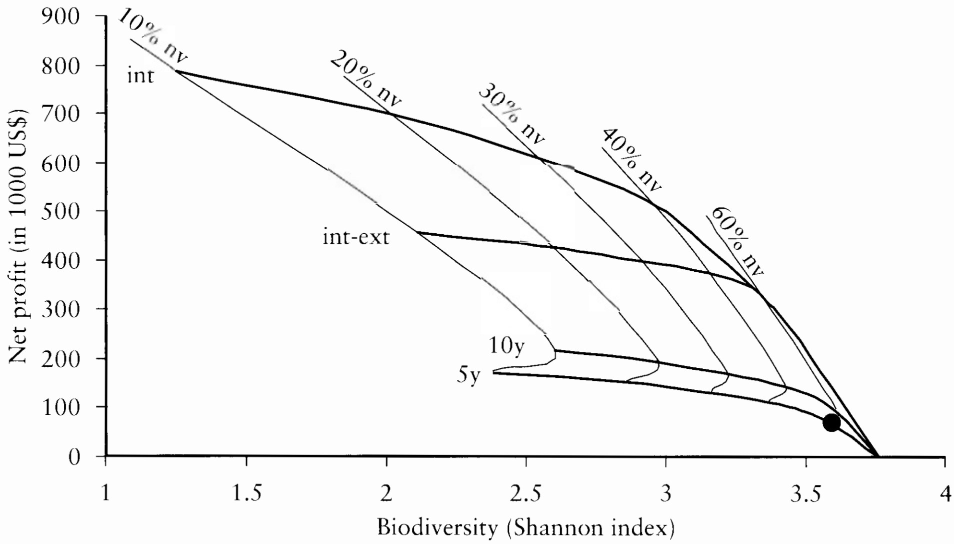


**Figure 24.7** Relation between plant local diversity and economic profit for the studied scenarios. 5y = 5 year fallow system, 10y = 10 year fallow system, int-ext = combination of intensive–extensive systems (outside a 150 m buffer zone around the road a 10 year fallow system is practised) and int = intensive agricultural system. The point indicates the current agricultural system. The percentages indicate the proportion of the natural vegetation remaining in the area

the paramo vegetation cannot be extrapolated using our data, as both diversity and richness stabilise after 4 years of succession. The fast decrease in beta diversity indicates that a total restoration of the natural paramo would take many years. Ferwerda (1987) calculated 70 years to restore the natural vegetation under a similar management system in a Colombian paramo. In our area, the figure is probably of the same order.

The dynamics of plant diversity throughout the succession period suggest that 4 or 5 years of fallow are enough to reach a stable level, and few changes will take place with fallow prolongation. Nevertheless, during the first years of succession, the dominant species are non-native and consequently these stages are less interesting for the conservation of local biodiversity and can be seen as degraded systems – less diverse and dominated by introduced species. Only in the intermediate and late phases does the vegetation begin to be dominated by indigenous taxa.

The analysis of local biodiversity of the entire valley did not confirm the initial idea that the spatial coexistence of different successional stages would enhance plant biodiversity compared to the natural vegetation. Therefore, the highest local biodiversity would be achieved with the whole valley under paramo vegetation. Nevertheless, due to the large areas of natural vegetation remaining in the valley, the current agricultural system is very close to the biodiversity measured in the paramo. Apart from the positive effect of natural vegetation on diversity, it is also essential as a reservoir from which paramo plants can spread and colonise the fallow fields, as recolonisation depends on the surrounding mosaic and its rate is higher when patches are closer together (Forman, 1997).

Although the present fallow system is very diverse, it has a low productivity compared to an intensive system. In order to increase net earnings without changing the management system, more natural areas would have to be ploughed, resulting in a large negative effect on biodiversity. A reduction in the fallow time is also possible, but in this case the augmentation in the cultivated area is counterbalanced by the decrease in productivity due to incomplete restoration of soil fertility. The effect of these tendencies, the incorporation of new areas, as well as the reduction of fallow time currently taking place in the study area, will be a progressive reduction of plant diversity.

Analysing the different scenarios, the best relationship between economic profit and biodiversity can be achieved by combining intensive land use with the preservation of large natural vegetation areas, avoiding the existence of areas of disturbed or incompletely restored paramo. Even if this is the best theoretical system, its practical implementation confronts serious difficulties. The main problem is controlling agricultural expansion over natural areas when the intensive system brings so much higher economic gains. In contrast to intensive agriculture, fallow systems *per se* regulate the use pressure and oblige the farmer to maintain a high proportion of land at rest. The intensive system, on the other hand, has no internal limitations with respect to the area under cultivation, apart from the limits imposed by capital or workforce availability. In this case, regulations must come from outside, as local or national policies, which are much more difficult to implement and control. The fallow system has the advantage that it is self-regulated. The intensive system, on the other hand, requires external regulation, which is subject to the power of the economic interests.

Apart from difficulties in controlling the extension of agricultural areas, further aspects related to intensive agriculture need to be explored. The first issue is the dependency on external factors which replace the ecological functions of the fallow period. Intensive agriculture depends on large amounts of inputs (fertilisers, pesticides, seeds, irrigation, mechanisation, etc.) and is capital-intensive and highly market-oriented. Large investments are necessary that can only be compensated if the prices obtained for the end products are high enough. This fact makes the system very sensitive to market oscillations. Consequently, it is fragile, unstable and at the same time increases social inequality. The second issue is the environmental impact. The excessive and unbalanced use of artificial inputs can have serious ecological, economic and socio-political repercussions (Reijntjes *et al.*, 1992) and pesticides may not only be a hazard to the water and soil, but also to the population's health. The overall sustainability of the intensive land-use system needs to be assessed. Fallow systems are less dependent on external inputs and, through crop field spreading, different risks, such as the impact of crop diseases and the loss of the entire harvest in the event of night frost, can be reduced. All in all, even though an intensive system in restricted areas is the best alternative from the biodiversity point of view, the negative aspects cannot be ignored and other alternatives need to be explored.

In conclusion, long fallow agriculture is not the ideal alternative to conserve the paramo plant biodiversity, but is a more secure alternative than an intensive system, where uncontrollable economic pressures can cause the reduction or elimination of natural and semi-natural areas. Nevertheless, fallow systems are progressively being transformed as a consequence of their low economic profit and following the building of new roads. Consequently, the future conservation of the paramo ecosystems will depend on effective implementation of local and national regulation policies or, if these policies are lacking, will be subject to unpredictable economic forces and cyclic variations in market prices.

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