Land use driven conditions for habitat structure: A case study from the Ecuadorian Andes

Gregor Levin & Anette Reenberg

Abstract

This paper addresses the impact of land use on local conditions for habitat structure in the eastern Ecuadorian Andes. It is recognised that agricultural expansion, by disturbing natural land cover, often negatively affects living conditions for wild organisms. In the chosen study area, a village territory dominated by dairy farming, land use dynamics and spatial habitat structure are illustrated at village and field level. The socioeconomic and biophysical character of the site is described using field cartography, household interviews, aerial photos and a digital terrain model. The effects of agriculture on spatial habitat structure are investigated by relating field specific land cover data to land use and land rights information. Simple landscape indices are used to quantify the effect of changes in spatial habitat structure on local conditions for wild organisms. Results indicate that land use and its negative effects on habitat structure correspond closely with variations in biophysical limitations that result from the mountainous topography. At a finer scale, land use patterns are influenced by land tenure and related household-specific parameters.

Keywords

agricultural systems, land use pattern, spatial structure, mountain regions, Ecuador.

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Loss of biological diversity can be linked to the destruction of natural habitats as a result of agricultural expansion, and is presently considered one of the most urgent environmental problems (Mannion, 1995). This paper addresses issues of habitat structure change caused by conversion of natural land cover to agriculture for a village territory located on the eastern slopes of the Ecuadorian Andes. In doing so, it focuses on different factors affecting the spatial structure of mountain rain forest habitats.

The eastern slopes of the Ecuadorian Andes are of great significance to the conservation of global biological diversity (DIVA, 1997). Numerous ecological zones are packed into a narrow belt with large altitude ranges, making this region the host of one of the world's highest diversities of species. Furthermore, the rugged mountainous landscape contains a large number of isolated valleys, giving the area a very high rate of endemism (Hamilton, 1995).

A considerable proportion of the region is still made up of relatively undisturbed natural land cover due in part to a poorly developed road network. However, during the last 50 years the region has been subject to an extensive infrastructural development. Since the exploitation of oil fields in the eastern Amazon lowlands beginning in the 1950s, several new roads have been built, connecting the densely populated highlands with Amazon provinces. Improved access has led to changes in market access and other socioeconomic conditions affecting agricultural strategies. As a result, during the last five decades the area has experienced tremendous land use and land cover changes (Fundatión Antisana, 1998a; Young & León, 1999).

However, land use and land cover still vary considerably within the region. Agricultural land cover is primarily situated near roads, while abundant areas peripheral to roads are covered by relatively undisturbed natural land. Similarly, agricultural practices are highly influenced by degrees of accessibility. In areas with limited infrastructural development and thus limited market access, agriculture consists mainly of small scale subsistence cropping with very little market-based production (DIVA, 1997). In contrast, areas proximate to roads are characterised by market-based agriculture with large scale cattle husbandry and cash cropping (Fundatión Antisana, 1998a).

As altitudes in the region range from under 1000 to almost

6000 metres, biophysical conditions for agricultural production are highly varying. Above approximately 3500 metres, low temperatures and high humidity restrict cropping to small scale production of a few tubers, roots and vegetables. Agriculture at these altitudes concentrates mainly on cattle husbandry, in particular dairy production. At lower altitudes more moderate temperatures allow large scale cropping of cereals, vegetables and even fruits. Lower altitudes are also characterised by large scale cattle husbandry, focusing on meat production (DIVA, 1997; Fundatión Antisana, 1998b).

The Papallacta village territory, the subject of this study, is located at altitudes ranging from approximately 3000 to 5000 metres. Since the early 1970s the village has been crossed by a paved road leading from the densely populated highlands to the eastern Amazon provinces. The main agricultural markets of the highlands are therefore easily accessible. Favourable market access together with biophysical conditions – steep slopes and a cold and wet climate – have encouraged local farmers to focus on market-based dairy production. From 1956 to 2000 the total pasture area in the village territory expanded by approximately 150 hectares, or more than 50 %. This notable agricultural expansion occurred mainly at the expense of natural land cover and profoundly affected spatial structure of mountain rain forest habitats.

Papallacta represents a model case of land use dynamics and spatial habitat structure on the eastern Andean slopes in Ecuador under conditions of easy market access. In this perspective the paper investigates the land use and land cover dynamics characterising the village territory. Furthermore it analyses how land use influences the patterns and spatial structure of natural habitats.

Theoretical background

Loss of species diversity through the destruction of natural habitats can be analysed by landscape ecological approaches that describe the spatial dynamics of species richness (Farina, 1998). Beginning with MacArthur and Wilson's island biogeography theory (MacArthur & Wilson, 1967) and Levins' metapopulation theory (Levins, 1970), recent research has traced the relationship between biodiversity and the spatial structure of habitats, especially at the local level (Kerr & Packer, 1997; Fournier & Loreau, 2001).

The influence of habitat structure is species-specific and depends among other factors on the respective species' demands on spatial structure, area and quality of habitat. The precise effect of spatial habitat structure on overall biodiversity is therefore not thoroughly understood. However, there is general agreement that through its effects on animal movement and seed dispersal, spatial habitat structure profoundly influences the living conditions of wild organisms and thereby species richness, especially at smaller spatial scales (Jongman, 2000). Atauri & Lucio (2001) investigated the role of different factors in distribution of species richness in a Mediterranean landscape and argue that spatial habitat structure and land cover heterogeneity provide the best explanation for species richness at local scale. Furthermore, they argue that conversion of natural habitats into agricultural land can influence spatial habitat structure and thereby profoundly affect species richness.

In cases where agricultural land does not expand gradually along one single frontier but in a more random way, an irregular pattern of agricultural land surrounding or cutting into natural land cover results. Natural habitats will be fragmented and isolated as patches and corridors imbedded in a matrix of agricultural land. As fragmentation continues, ecological linkages are broken, natural habitats are increasingly located close to agricultural lands and distant from each other. It is widely recognised that these structural changes negatively affect living conditions for wild organisms (Carrol, 1990).

While many studies have investigated the influence of habitat structure on other ecological phenomena and processes, relatively little research has tried to explain the spatial habitat structure and processes of habitat fragmentation themselves (Pan et al., 2001). Furthermore, most studies have focused on relating habitat pattern to biophysical conditions. However, in agricultural landscapes natural habitats usually border on agricultural land cover, and spatial habitat structure is thus primarily determined by the pattern and dynamics of agricultural land use. Biophysical properties only indirectly affect habitat structure through their influence on land use decision making.

Therefore, in agricultural landscapes the spatial structure of natural habitats must be seen in relation to local land use dynamics and their driving forces. A profound understanding of land use requires the investigation of a wide set of socioeconomic, biophysical and location factors that in combination influence agricultural practices. (Reenberg, 1996; Pichón, 1996).

Biophysical properties are the basic conditions for agriculture. Several studies show that factors including topography, climate, water availability and soil properties determine and often constrain specific agricultural land uses.

Veldkamp & Fresco (1997) and De Koning et al. (1998) show that climatic properties provide the best explanation for large scale land use and land cover variations in Costa Rica and Ecuador, whereas Place and Otsuka (2001) and Tachibana et al. (2001) underline the impact of both altitude and slopes for case studies in Vietnam and Thailand, respectively.

Physical access or distance, including access to markets (Dicken & Lloyd, 1990), access and travel distance to land resources (Christiansen, 1976; Rudel, 1993) and distance to labour markets (Liu, 2000), highly influence land use decisions.

Land tenureship and controlling land use rights also influence land use (Netting, 1993). A case study from the Ecuadorian highland shows e.g. that the majority of agricultural land is owned by large haciendas while indigenous, small scale farming is mostly restricted to small marginal plots. Due to a surplus of land on haciendas agriculture here is characterised by rather extensive cattle husbandry; while indigenous households must adopt intensive cultivation in order to meet their needs from a limited land base (Knapp, 1991).

Together with biophysical conditions and access to land, labour availability forms a main determinant for agricultural land use (Netting, 1993; Bolwig & Paarup-Laursen, 1999; Snyder, 1996). However, access to land and labour can themselves be affected by a range of other factors (Pichón, 1996). Local factors like access to capital, available technology and market access – as well as also more exogenous forces like politics or international markets – can all influence land use decision making and must not be overlooked in the analysis of land use and land cover dynamics and their effect on spatial habitat structure.

Materials and methods

The setting

The Papallacta study site covers roughly 65 square kilometres, located in the Quijos Valley on the eastern slopes of the eastern Andean Cordillera, about 50 km east of the national capital Quito (Figure 1). The parish is part of the canton of Quijos located at the western fringe of the Napo Province. The population includes descendants of original Indian inhabitants and Spanish migrants. In 1997 a total of 647 persons lived in the parish.

The mean annual temperature lies around 10 degrees Celsius and yearly precipitation rates are about 1.500 mm. Due to only little seasonal variation, the climate is ‘prehumid’

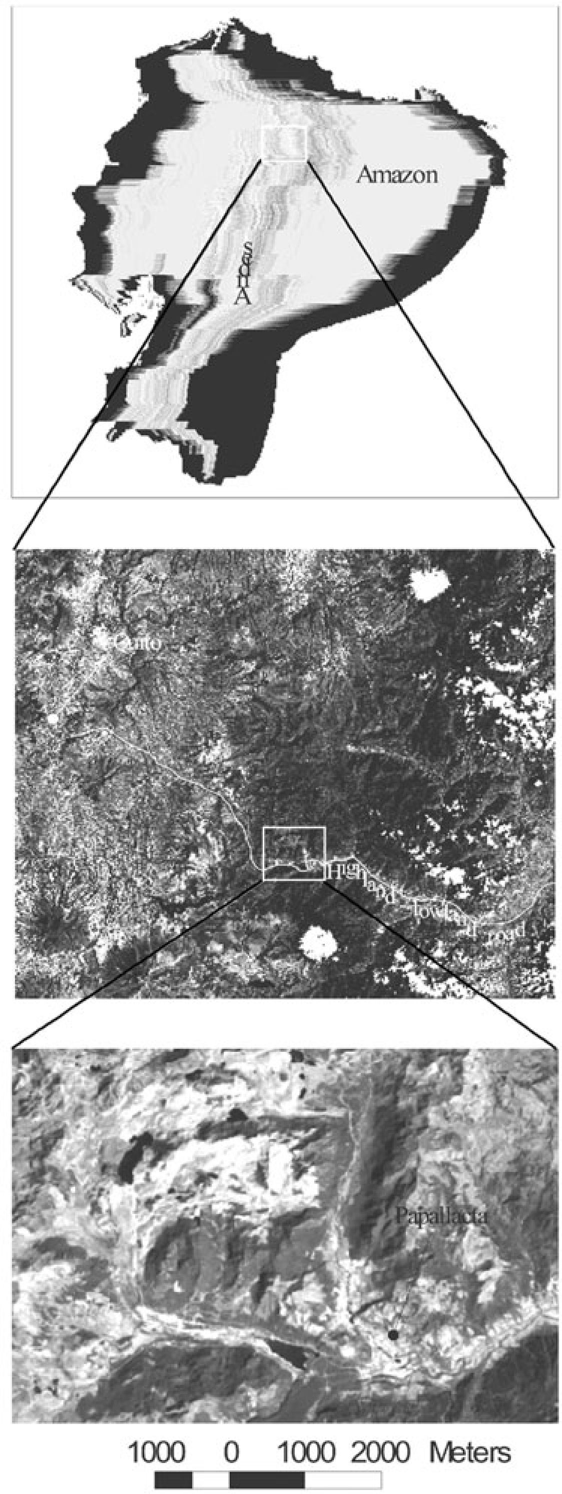

Figure 1: The location of the study area. Top: The national setting. Middle: The regional setting (the white line indicates the road between Quito and the Amazon lowlands). Bottom: The study area.

with a relative humidity of over 90 % all of the year (DIVA, 1997; Fundatión Antisana, 1998b). The topography is characterised by a mountainous landscape where less than 20 % of the whole study area has slope gradients below 10 degrees. The dominant land cover is natural or seminatural vegetation characterised by subalpine páramo above and montane wet forest below an altitude of approximately 4000 metres. With over 150 species of vascular plants and almost 500 animal species not including insects, species diversity in the area is extremely high (Fundatión Antisana, 1998b).

Agricultural land use is mainly found in the valley bottoms and on the valley slopes. Cropping is very limited and mostly found in small gardens and fields close to the village, where tubers and vegetables are cultivated for subsistence needs; the main agricultural activity is cattle husbandry with focus on market-based dairy production. The spatial organisation of cattle husbandry is highly linked to the area's topography. As illustrated in the simplified example in Figure 2, pastures are found mainly on the valley floor and on the gently to moderately sloping valley sides. Dairy cattle, which are milked at least daily, usually graze on pastures close to the village. Pastures located at greater distances are grazed by non-dairy cattle requiring less frequent care. Additionally, large tracks of páramo land are periodically grazed by non-dairy cattle, particularly calves and young bulls. Technology is simple with most agricultural

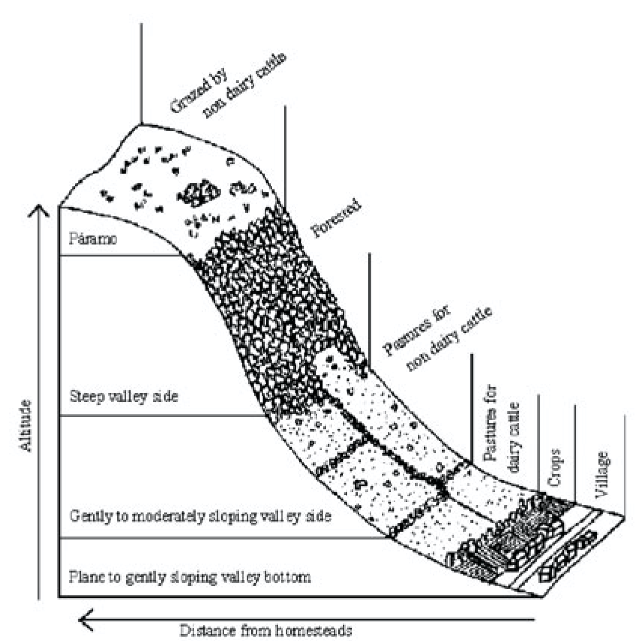

Figure 2: *Spatial distribution of cattle husbandry.*

tasks executed by hand or with the help of simple tools like machetes and digging sticks.

Besides agriculture a wide number of other economic activities and enterprises can be found, the result of easy accessibility to and from Quito. A large water works administered by The Quito Water Board, a hydroelectric power plant, a maintenance station for the national oil company, two dairies and a trout farm, as well as a growing tourist sector revolving around local hot springs – all these provide job opportunities outside agriculture. Easy access to off-farm employment results in a local economy that to a large degree is based on activities outside agriculture.

Land use characterisation

The present study focuses on how land use dynamics impact spatial habitat structure. A major methodological challenge is linked to the fact that different aspects and determinants of agricultural land use require analysis at several spatial levels. While land use decisions are usually made at local scale, factors affecting land use can be active or most discernible at other scales (Cocklin et al., 1997; Reenberg, 1996). Consequently, a profound investigation of land use pattern and dynamics must be performed within a multiscale conceptual framework. Therefore, data collection was carried out at regional, village, household and field level.

Household specific information on socioeconomic parameters and land use was obtained from a survey carried out from May to October 2000. In a pilot phase, baseline information about the area's biophysical and socioeconomic aspects as well as information concerning the land use system was collected. Based on this information, an in-depth analysis of land use decision making was carried out. The analysis covered the whole study area since all 28 village households that are active in cattle husbandry and own or access land in the village territory (less than 1/3 of the total population) were visited. Furthermore, all pastures (117) used by the 28 households were included in the study.

Quantitative and qualitative data on socioeconomic issues and land use practices were gathered by questionnaire survey, formal and informal interviews and field observations. GPS measurements in the field were combined with visual interpretation of aerial photos and a satellite image to geo-reference household and field-specific information obtained from questionnaires.

Land use mapping from field measurements, aerial photos and satellite image

Detailed statistical or cartographic information on land use and land cover, including spatial distribution and spatio-temporal dynamics, is not readily available for the Papallacta area. A combination of field cartography and interpretation of aerial photos has therefore been applied in the present study.

Aerial photos from the years 1956, 1965, 1977 and 1994 and a Landsat 7 satellite image from 2000 provide the material used to monitor land use and land cover pattern and dynamics. The photos were scanned into digital format (1200 dots per inch) and geometrically rectified to UTM coordinates using corresponding landscape features in the panchromatic channel of the Landsat 7 image. All image processing was performed in the CHIPS software package (Copenhagen Image Processing System).

Land cover mapping on the basis of the rectified photos was carried out with ArcView GIS software. For the entire study area 8 land cover classes (Table 1) were mapped through visual interpretation of the photos supported by ground 'truthing' in the field. The accuracy of the final land use maps is influenced by the quality and scale of the aerial photos, errors in visual interpretation as well as inaccuracies in the geometrical rectification process. It is thus difficult to quantify the spatial accuracy of the resulting land cover maps. However, as the 8 land cover classes are relatively easy to distinguish and the error associated with geometric rectification did not exceed 5 metres, the final land use maps should form a reliable basis for further examination.

The mapping of individual pasture fields was done in collaboration with local farmers by identifying single pastures on the 1994 photo and with the help of GPS measurements. Furthermore, access rights to all lands suitable for agricultural production were registered on the 1994 photo with the help of key informants, GPS and compass measurements.

A slope map of the whole study area was elaborated on basis of a digital terrain model. Additionally, small scale topographical features like gorges, ravines and cliff faces that are normally obscured by the rather coarse spatial scale of the terrain model were digitised with the help of field measurements and interpretation of the 1994 photo.

Detailed registration of access rights together with the collected socioeconomic and biophysical data enables a direct reference between the parameters that characterise the decision units (household scale) and descriptors of the land use pattern (field scale) (Reenberg & Fog, 1995).

Table 1: *Land cover classes digitised on basis of aerial photos.*

forest
páramo (high altitude grassland)
agricultural land (pastures and crops)
urban uses (housing, institutions and industry)
eroded land
roads
stone avalanche from former volcanic activity
rivers and lakes

Description of habitat structure

Over recent decades a number of methods have been developed to describe landscape pattern (Turner & Ruscher, 1988; Brandt & Holmes, 1995; Hulshoff, 1995; Gustafson, 1998). The elaborated spatial indicators vary considerably respective to the study purpose and the quality and type of underlying spatial data. Still, the common strain of these methods is that they are based on size, number and arrangement of landscape elements.

For the current study three simple measures of spatial habitat structure were calculated as indicators for biodiversity:

- area and percentage of natural land cover;
- number and size of isolated patches of natural land cover; and
- adjacency to agricultural land cover.

Due to limited information on different habitat types and in order to facilitate data handling, two basic land cover classes were used in the analysis: Natural land including mountain rainforest and páramo areas; and agricultural land cover (Figure 3). To minimise inaccuracies, patches smaller than 0.2 hectares were excluded from the study.

Figure 3: *Land cover map for calculation of landscape metrics. (Source: Visual interpretation of aerial photo of 1994)*

Adjacency to agricultural land cover was calculated as the percentage of all natural land that is located within a distance of 20 metres from agricultural land cover. All data handling was performed with ArcView GIS software.

Results

Farming strategies

The village survey pointed to a number of key factors determining the priority given to cattle husbandry with a focus on market-oriented dairy production. This must be seen in the light of biophysical / environmental constraining most cropping. The wet and cold climate is unfavourable for most crops (except legumes, roots and tubers). Furthermore, the scarcity and fragmentation of non-sloping land hamper the use of labour-saving technology and hence constrain opportunities for large scale cropping. Biophysical conditions do not in the same way constrain dairy husbandry. Cattle can graze on even very steep slopes. Furthermore, due to the cold and wet climate, pastures have a high nutrient content resulting in a high fat percentage of local milk (Fundatión Antisana 1998b).

Additionally, a well-developed road infrastructure results in easy market access and forms an incentive for market-based dairy production, as dairy husbandry highly depends on the rapid transfer of the product to consumers.

Labour constraints also impact land use options, since a large part of the local population are active as migrant workers or involved in extra-agricultural employment in the villages. This encourages local households to focus on less labour intensive dairy husbandry, rather than cropping.

As an illustration of the dominance of dairy husbandry, pastures for cattle grazing occupy close to 99 % of all agricultural land. Still, almost 90 % of the whole study area is made up of natural or near natural land cover, primarily mountain rainforest and páramo land. Only in the valley bottom can agricultural lands be characterised by large continuous areas of pasture.

Spatial expansion of agricultural land

To investigate how land use affects the spatial structure of natural habitats, land use maps were elaborated on basis of aerial photos. This permits a precise monitoring of land cover changes in the Papallacta area from 1956 to 2000. While only part of the village territory can be included in this analysis, as its spatial extent is determined by the area covered by the smallest photograph, results should be valid for the whole study area.

The most pronounced change in land cover is the expansion of agricultural land (Figure 4). Over 45 years, agricultural land cover rose from under 270 hectares in 1956 to over 400 hectares in 2000, a total increase of over 50 % or roughly 1 % per year (Table 2). Agricultural expansion mainly occurred at the expense of forested land that over the same period experienced a decline of 12 % from over 1550 to less than 1400 hectares, or a yearly deforestation rate of about 0.3 %. The only decline in agricultural land cover took place between 1994 and 2000, where large tracts of communal land were converted from pastures into urban uses.

Topographical constraints

As agriculture expanded a growing part of agricultural land became located on steeper slopes (Figure 5). Nevertheless, over the whole period agricultural land found at slopes over 40 degrees is negligible, never exceeding 2 %. This fact points to an upper limit for acceptance of slope degrees.

Topographical constraints on agricultural land use become even more evident when relating pattern of pasture land to small scale topographical features like cliff faces, gorges and ravines. As Figure 6 illustrates, small scale topo-

Table 2: *Land cover changes 1956 – 2000.*

	1956		1965		1977		1994		2000	
land cover class	ha	%	ha	%	ha	%	ha	%	ha	%
forest	1578	67,0	1495	63,5	1446	61,4	1379	58,6	1376	58,5
agriculture	264	11,2	338	14,4	384	16,3	412	17,5	404	17,2
urban	7	0,3	15	0,7	18	0,8	44	1,9	52	2,2
other*	505	21,5	512	22,2	524	22,3	563	24,0	574	24,4

* páramo, volcanic material, rivers, lakes, eroded land, roads
(Source: Visual interpretation of aerial photos and satellite image)

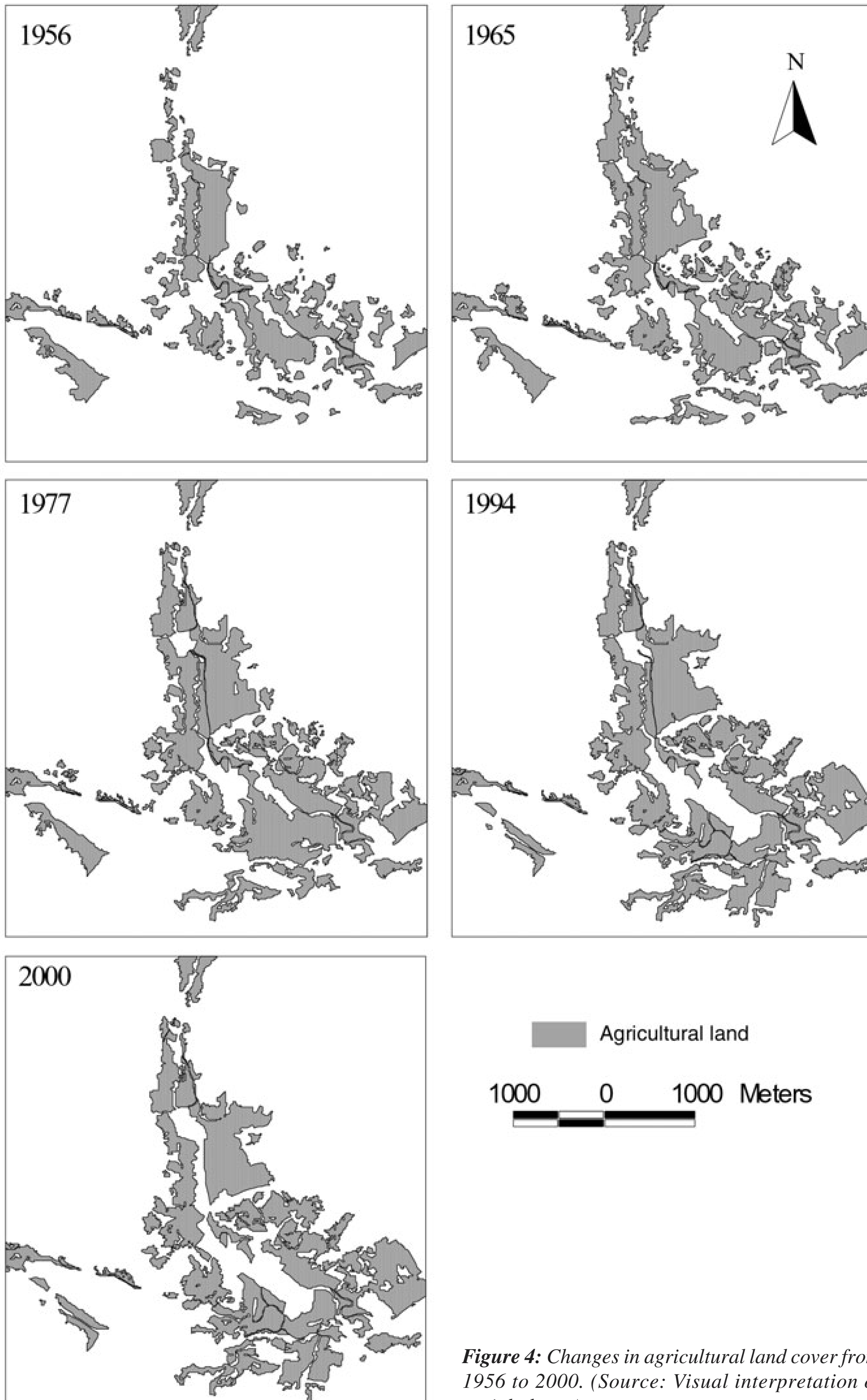

Figure 4: Changes in agricultural land cover from 1956 to 2000. (Source: Visual interpretation of aerial photos)

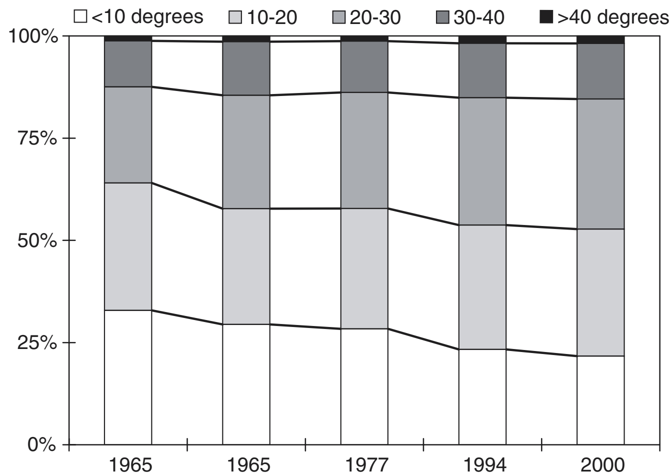

Figure 5: *Agricultural land at different slopes. (Source: Visual interpretation of arial photos and digital terrain model).*

graphical barriers are significant determinants for the spatial room for manoeuvring of pasture expansion. Since pasture land is subject to such topographical constraints, the resulting pasture pattern are thus closely related to these. At several locations small scale topographical barriers also constrain access to land that according to biophysical properties is suitable for pasture use. An example from the southern valley slopes illustrates how access is restricted to the east side of a river gorge, while an area with similar properties west of the gorge remains forested (Figure 7).

Steep slopes and small scale topographical features highly influence the spatial balance between agricultural and natural land cover. Consequently, such topographical barriers often constitute edges between pastures and natural land and affect the spatial structure of natural habitats.

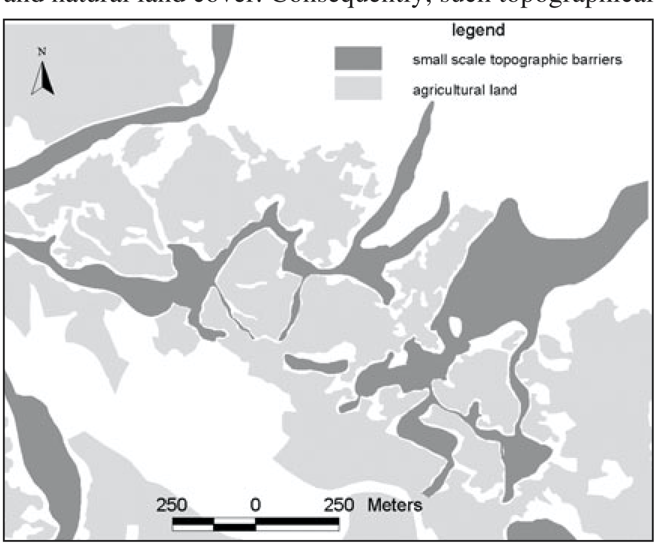

Figure 6: *Small scale topographic barriers limiting spatial extent of agricultural land. (Source: Visual interpretation of aerial photo of 1994 and field mapping)*

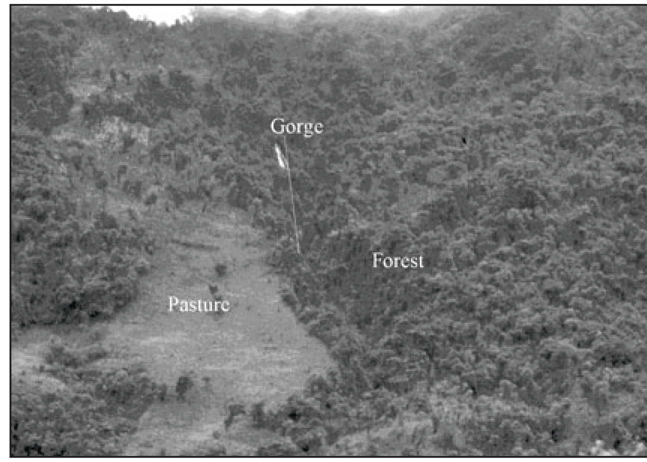

Figure 7: *Gorge constraining access to land.*

Land use pattern determined by land tenure rights

At several locations edges between forest and pastures are, however, not related to topographical limits, but correspond with property boundaries. Land tenure and controlling rights therefore become significant determinants for landscape diversity. Figure 8 shows land use rights in the study area. Almost 350 hectares of pasture are separately owned by local households. Roughly 200 hectares of pas-

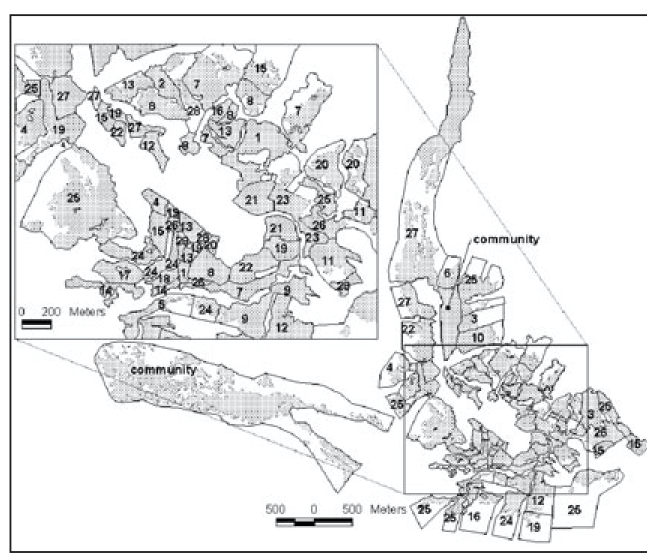

Figure 8: *The map shows access rights to land in the village territory. The numbers refer to the different accessing households. The hatched areas are used for pasture. Other land properties are primarily forested. (Source: Visual interpretation of aerial photo of 1994, field mapping and interviews with key informants)*

Figure 9: *Land cover pattern affected by tenure rights. (Source: Aerial photo of 1994 and household interviews)*

ture are commons. 15 of the 28 visited households are community members and have thus access to common lands which in practice implies access to about 13 hectares of pasture outside the individual property. Roughly 300 hectares of the village territory are potentially available for pasture use but are currently forested. Consequently, in addition to pastures, each household has on average access right to about 10 hectares of forested land.

Figure 9 shows an example from the north of the study area, where borders between pastures and forest highly correlate with boundaries for access rights. Forest - pasture edges must here be understood in relation to household specific parameters influencing respective households' land use decision-making. Figure 10 illustrates this aspect with an example from the southern slopes of the valley. The sample area's southern part, owned by household A, is characterised by only small patches of pasture in a matrix of forest cover, while the adjacent northern part, owned by household B, is entirely covered by pasture. Both households individually own approximately 10 hectares of pasture. Household A has 32 head of cattle, while household B owns 10. The household with most cattle per hectare utilises its land most extensively, where the opposite should be expected. However, survey data also show that household A has 20 head of cattle permanently grazing on community land and thus has no need to establish new pastures on its own land. By contrast, household B has no access to community land and is therefore forced to convert all its land into pastures. The example shows that, where forest-pasture edges are not related to biophysical constraints, spatial structures of natural habitats often can be subscribed to land tenure rights. Variations in household-specific parameters affect households' land use decisions which helps explain why adjacent land areas characterised by similar biophysical conditions, can be covered by respectively pasture and forest. Land tenure rights, together with household specific parameters are thus important aspects for the understanding of spatial habitat structures, particularly at finer scales.

Spatial habitat structure

On the basis of land cover data all edges between forest and pastures were mapped for the whole study area. Furthermore, with the help of spatial overlay, correspondence between forest-pasture edges and either topographical constraints or land tenure rights were registered (Figure11). Due to uncertainties connected to the accuracy of the underlying data, the results should be regarded as estimations. Yet, of a total of roughly 110 kilometres of edges, about 80 kilometres or almost 75 % can be attributed to topographical constraints. Roughly 10 % correspond closely to tenure rights and can be subscribed to inter-household variations in parameters that influence household specific land use decision-making. In spite of the lack of detailed information on former land tenure, several examples indicate that the remaining almost 20 kilometres of edges are relicts of former property boundaries that nevertheless continue to affect spatial habitat structure.

The above findings point clearly to biophysical constraints as the primary determinants for land use pattern. Biophysical constraints are, however, subject to a considerable spatial variation: they are weakest in the valley bottoms and become increasingly significant up along the valley

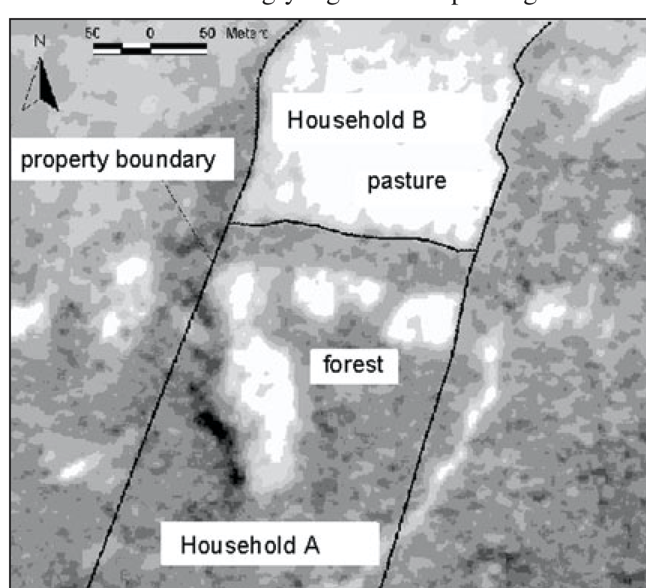

Figure 10: *Land cover pattern related to property boundaries. (Source: Aerial photo of 1994 and household interviews)*

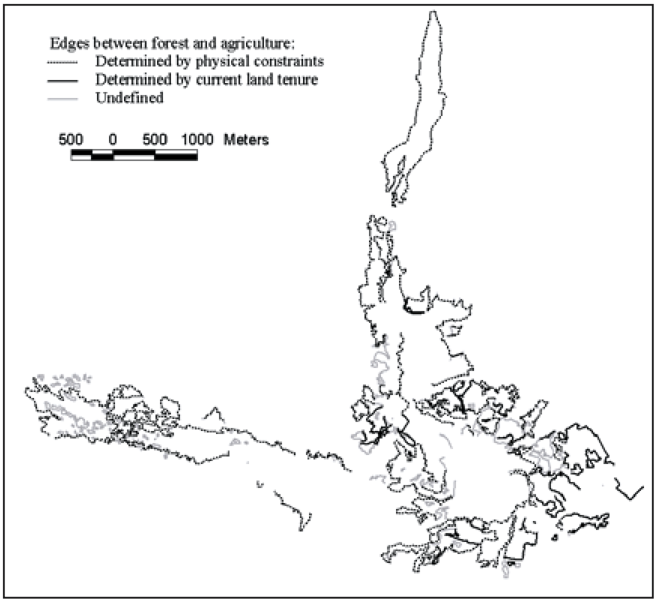

Figure 11: Edges between forest and agricultural land. (Source: Household interviews and visual interpretation of aerial photos of 1994).

slopes. In order to include this spatial variation in the investigation of land use patterns' effect on spatial habitat structure, the study area was, as illustrated in Figure 12 divided into 3 zones with different biophysical suitability for agricultural land use.

With the aim of characterising the effect of agricultural land use on the spatial structure of natural habitats, 3 spatial indicators for habitat structure were used. Percentage of natural land cover, relative adjacency to agricultural land cover and spatial connectivity are all relatively simple measures for spatial habitat structure and were calculated for the whole study area and for the 3 respective zones. The results in Table 3 indicate that the effect of agricultural land use on spatial habitat structure gradually decreases with increasing biophysical constraints.

While about 90 % of the total study area is covered by natural land, significant local variation is evident when comparing the 3 types of physical limits to agricultural land use. Less than 40 % of the inner zone, a zone characterised by the weakest biophysical constraints, is covered by natural land. In the middle and outer zone the percentage of natural land cover increases to respectively 84 and 98 %.

The same tendency applies for adjacency of natural land cover to agricultural land. Where agricultural land cover borders up to natural habitats, the biophysical environment is largely altered, often negatively affecting living conditions for wild species. In order to assess the effect of approximately 110 kilometres of edges between natural habitats and agricultural parcels, all natural land cover within a distance of 20 metres of agricultural land cover was drawn out of the data set. The distance of 20 metres is an arbitrary choice, but it captures the relative importance of proximity to agricultural land. The effect on natural habitats of adjacency to agricultural land clearly follows the same graduation as the previous measure. In the inner zone nearly 40 % of all natural lands lie within 20 metres of agricultural land. With decreasing agricultural intensity, this number declines to under 11 % in the middle and less than 1 % in the outer zone.

Whereas the negative effect of agricultural land use on habitat pattern is very clear for the two previous indicators, no similar trend emerges for spatial connectivity of natural land cover. While the percentage of all natural land comprised of patches, as well as the number of patches and total area, are largest in the inner zone, lower in the middle and smallest in the outer zone, in all 3 zones the percentage of natural land comprising spatially isolated patches is very small. This somehow contradicts with the common assertion that agricultural expansion leads to the fragmentation of natural land cover, and thus results in habitat pattern dominated by spatially isolated patches of natural land cover, hampering the dispersion and movement of wild organisms (Carroll 1990). In the Papallacta area remnant

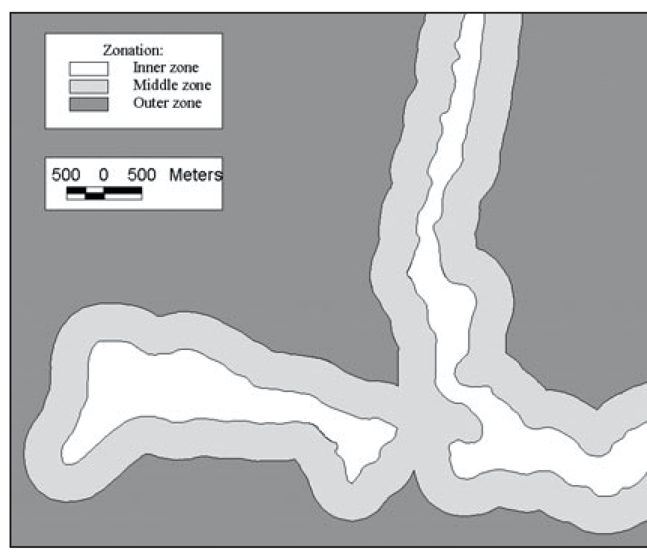

Figure 12: Zonation of the study area according to the relative importance of biophysical limits. Inner zone: located in the valley bottom and characterised by week slopes and easy accessibility; Middle zone: computed as a 500 metre wide buffer around the inner zone and characterised by relatively steep slopes and an extensive network of topographical barriers like gorges, ravines and cliff faces; and Outer zone with difficult accessibility, generally steep slopes and high altitudes.

Table 3: Indicators for spatial landscape structure.

	total study area	inner region	middle region	outer region
share of natural land cover of all land	90%	40%	84%	98%
area covered by edges, ha	20,7	11,8	6,6	2,3
share of all natural land covered by patches	0,3%	1,7%	0,4%	0,0%
number of patches	63	45	15	3
average patch size, ha	0,3	0,3	0,4	0,8
natural land within 20 metres of agriculture	5%	39%	11%	1%
natural land beyond 20 metres of agriculture	95%	61%	89%	99%

(Source: Visual interpretation of aerial photos)

natural land cover in the agricultural matrix mainly follows line elements like gorges and ravines. These features are in turn usually connected to large core areas of continuous natural land located in the periphery of the study area. The resulting pattern of natural land cover is a widespread network of corridors allowing movement of wild organisms, rather than spatially isolated patches. Due to the constraints the study area's mountainous topography places on agricultural land use, agriculture's fragmentary effect on natural habitats is only weakly articulated.

Conditions for biodiversity

The chosen indicators reveal clear differences among the three computed zones. Based on these indicators, alteration of living conditions for wild organisms are most pronounced in the inner zone, less pronounced in the middle and least pronounced in the outer zone. This indicates that where biophysical conditions are least constraining to agricultural land use, resulting land use has the most negative effect on spatial habitat structure in terms of relative percentage of natural land, adjacency to disturbing agricultural activity and spatial isolation. Where topographical constraints become more pronounced, the negative effect of agricultural land use on spatial habitat structure is diminished. In peripheral areas, where conditions for agriculture on the whole are unfavourable, the effect of land use pattern on spatial habitat structure is negligible or even nonexistent.

Only little detailed information on the spatial variation of biological diversity in the Papallacta area exists. It is thus not possible to draw any precise conclusions about the actual effect of spatial variations in the spatial habitat structure on overall biodiversity in the study area. However, as it can be assumed that spatial habitat structure affects living conditions for wild organisms, the computed indicators can be used as an approximation of the impact of land use on local species diversity.

The sparse biological data from the region indicate that both floral and faunal diversity are highly correlated with substantial topographical variations (Hamilton, 1995; DIVA, 1997; Fundación Antisana, 1998b). Since the negative effect of agricultural land use on spatial habitat structure is most prominent in the central valley, species that are found exclusively in this zone must be affected to a larger degree than species found on the valley slopes or in the páramo areas. For instance Alnus (or Aliso-) forest is only found between 2500 and 3200 metres altitude (DIVA, 1997). The clear link between land use and habitat structure at these altitudes must therefore largely affect this vegetation type and hence those floral and faunal species that depend on it.

Conclusion and discussion

Spatial habitat structure affected by local conditions for land use

The study of Papallacta has shown that adoption of dairy husbandry dominates farmers' response to local conditions for agriculture. Biophysical properties favour this land use strategy, yet the survey reveals that other parameters, particularly access to land, labour constraints and market access highly influence the priority given to dairy production. Pastures for cattle grazing therefore form the predominant agricultural land cover and were significantly expanded over the last half century.

Spatial patterns of land use are closely related to biophysical limits in terms of slopes and small scale topography. Where physical constraints hamper the extent of pastures, edges between natural forests and agricultural land occur.

In addition, land tenure and controlling access rights are an important determinant for land use patterns. Edges between forest and pastures are often closely related to either current or former property boundaries. The empirical findings indicate that where land cover boundaries correspond with spatial patterns of land tenureship, attention must be paid to parameters influencing single households' field-specific land use decision making. Factors such as access to land, number of cattle, community membership, labour constraints and off-farm incomes together determine specific households' ability and incentive to use a given plot of land for pasture or to leave it forested. The large inter-household variations in these parameters, together with the scattering of land properties throughout the village territory, implies that adjacent land areas with equal biophysical conditions can have different land cover, with profound effects for spatial habitat structure in the area and thus the living conditions for wild organisms.

Several studies indicate that in regions dominated by agriculture, landscape pattern are determined by agricultural land use patterns rather than by biophysical properties (Deffontaines et al., 1995; Apan, 1995; Pan et al., 2001). In the present case, where patterns of agricultural land use themselves closely correspond to topographical constraints, their effect on landscape pattern and particularly on spatial habitat structure is tempered by variations in the local topography. This implies that in mountainous regions, considerable biophysical constraints to agriculture prevail in terms of high altitudes, steep slopes and difficult accessibility, and limit the effect of agricultural land use on habitat structure. Socioeconomic parameters, even though significant, are subsumed by the superior constraints given by the biophysical environment.

Yet, as a result of considerable variation in both biophysical and socioeconomic conditions, land use patterns, particularly along the valley slopes, have a patchy character. Fragments of pasture lie scattered throughout the village territory and consequently affect spatial structures of adjacent natural land cover. However, the effect of agricultural land use on spatial habitat pattern is highly related to spatial variations in biophysical conditions determining land's suitability for pasture use. Spatial indicators show that agriculture's effect on habitat structure is most pronounced on valley floors where few physical constraints exist. Along the valley sides, characterised by steeper slopes and a large network of topographic barriers, these effects are less pronounced, and in the study area's periphery, difficult to access and dominated by high altitudes and steep slopes, spatial habitat structure is almost not affected. The few existing biological studies of the region show that spatial variation in the local biological diversity is highly related to the regions topographical characteristics (Hamilton, 1995; DIVA, 1997; Fundación Antisana, 1998b). The spatial variation in agriculture's effect on spatial habitat structure as presented in this paper can therefore be assumed to have a profound affect on the area's total biological or species diversity.

Stability of landscape pattern

Both results from land cover mapping as well as interviews with local farmers imply that since the early 1990s little forested land has been converted to pasture. Topographical constraints universally hamper further expansion of agriculture. Additionally, the growing importance of off-farm incomes has reduced local households' dependency on agriculture, weakening the enticement to expand agricultural land. Consequently, under current socioeconomic conditions, the spatial balance between natural and agricultural land, where large parts of the area's periphery remains covered by natural vegetation, is relatively stable.

Biophysical constraints will continue to limit the spatial extent of agriculture. Socioeconomic conditions for agriculture are, however, not fixed but subject to change over time. The price of agricultural commodities are related to the national economy and alterations can change households' land use strategies. Equally, local income opportunities outside agriculture highly depend on economic conditions at a higher scale. Limited access to off farm incomes can lead to a strengthened focus on agricultural production and hence to further expansion of pasture land.

Similarly, household-specific parameters can change over time, especially family structure and consequently available workforce and consumption needs. Agricultural decision-making is influenced by such parameters. The resulting land use pattern and hence their influence on spatial habitat structure can be far-reaching and are subject to considerable changes over time. Further expansion of pasture land can be expected along the valley floor and on abutting slopes, where conditions for pasture use are most favourable. Such agricultural expansion will influence the living conditions of those organisms adapted to these zones and thus profoundly affect the area's total biological diversity.

In recent years growing attention has been paid to the eastern Andean slopes' value in terms of biological conservation. Furthermore, the negative effect of agricultural expansion on conservation issues has been widely recognised (Hamilton, 1995; DIVA, 1997; Fundación Antisana, 1998a). As a consequence a considerable part of the region has been designated as national parklands, where agricultural land use is highly restricted. Nonetheless, many areas with a unique biological diversity, but characterised by intensive agricultural land use, as in the Papallacta area, are excluded from protected zones. Furthermore, conservation policies often oversee temporal variations in conditions for agriculture. In order to prevent future land use and land cover changes that decrease the region's value for biodiversity, greater attention must be paid to the understanding and regulation of those parameters influencing land use strategies and having a bearing on conditions for biodiversity.

Local agricultural strategies must be seen in accordance with decision-making strategies at the farm and field level, and bearing in mind the parameters and processes that are best analysed at these local scales. Location-specific case studies can therefore be helpful contributions in this context.

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