Ecological zoning of an Andean grasslands (*puna*) at the manu biosphere reserve, Peru

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Abstract: In the Andean transition area the Manu Biosphere Reserve (MBR), in Peru, located within the Amazon basin, there are natural grasslands which are suffering from human impact, due to heavy grazing activities, jeopardising their Carrying Capacity (CC). To minimise this impact, it was found necessary to understand the participation of the environmental variables and the anthropogenic activities generating zone of homogeneous areas so as to ultimately form a management plan. To achieve this goal, those variables were combined, taking into account their spatial arrangement, using geoprocessing techniques. Remote Sensing images were used to produce the land use thematic map and topographic maps were also used to produce a Digital Elevation Model (DEM). Biotic and abiotic parameters were transformed into maps within a Geographical Information Systems (GIS) environment to produce an ecological zoning map. The zoning classes were related to CC and sustainability of the grasslands, and were expressed in maps with 23 sampling units.

Keywords: slope; altitude; Carrying Capacity; CC; Environmental Fragility; EF; Sustainable Vegetation; SV; Environmental Supply; ES; vegetation coverage; height; strength; species diversity.

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1 Introduction

In the Andean ecosystem, indigenous culture developed highly productive and sustainable agriculture, based on efficient soil and water management and the integration of crops and livestock (Tapia Nunez and Flores Ochoa, 1984). However, the growing human population has increased the demand for land and food. Traditional production systems have broken down or been forgotten, and Andean resources are being degraded by grazing herds of domestic llamas, alpacas, goats and sheep, as well as by people gathering wood for fuel. Introduced and invasive species, as well as uncontrolled fires, also cause environmental problems (Tapia Nunez and Flores Ochoa, 1984).

The effect of heavy grazing on grassland plant community results in a dramatic decline of plant diversity (Bustamante, 2006), vegetation cover, primary production (Fensham, 1998), seed production and seed number in soil (Bertiller, 1996; Coffin and Lauenroth, 1989) and a significant increase in animal hoof impacts. As a result, small bare spot appeared on the ground and latter merged into large bare areas in the grasslands. With vegetation decrease due to consumption of plant matter exceeding regrowth over the long term, grassland desertification can occur (Faraggitaki, 1985; Manzano and Navar, 2000). Heavy grazing can also cause soil erosion, loss of soil structure and deterioration of soil environment (Faraggitaki, 1985; Scholl and Kinucan, 1996).

Nowadays, the sustainable use of Andean ecosystem is only possible if suitable regional planning is done, which must take into account the involved agro-ecosystem characteristics. This planning requires previous zoning including the distinct degrees of protection and intervention. One way of zoning this ecosystem may relate Carrying Capacity (CC) to biotic and abiotic parameters.

CC is defined as the most acceptable use that an area can undergo with the highest user satisfaction level and the minimum negative side effects on the resources (El Aich and Waterhouse, 1999). According to these authors, to estimate this CC, certain ecological and aesthetic aspects must be fulfilled. For this reason, it is necessary to evaluate the degree of environmental degradation susceptibility of each resource beyond land use pressure (Dos Santos, 1996).

In Andean natural grasslands, named *puna*, grazing can be a mechanism to maintain species composition within the community. According to Lombardi and Cavallero (1999) communities of natural grassland showed a loss of diversity due to the lack of grazing. In these ecosystems, sustainable use can be achieved by keeping CC at the same level of Environmental Supply (ES) (Bustamante, 2006; El Aich and Waterhouse, 1999; Hopkins and Hopkins, 1993).

The montane grassland (*puna*) of the Manu National Park (MNP), located in the Andean transition area of the Manu Biosphere Reserve (MBR), is used as natural pasture by feeding wild and domestic animals. Cattle, coming from peasant communities, invade the National Park searching for food. There are about 4000 heads of cattle in the Andean region of park (*puna*). Cattle owners burn the grasslands regularly to provide new grasses for the cattle. There is also a cattle raising project on Meseta Pantiacolla in the southwest of the park. The number of domestic animals, such as cattle, is significantly higher than of wild ones. Degradation of this habitat at present is most related to heavy grazing and seasonal burning, as well as agriculture and fuelwood collection. These use has been causing a gradual lost of eatable species and soil erosion (Antezana, 1972; Bustamante, 1994; Contreras, 1967; Farfan, 1981; ONERN, 1986; Oscanoa, 1988; Peña, 1970; Sanches, 1966). Several abiotic variables, such as altitude and slope, can be related to carrying capacity of the grassland. Biotic variables, on the other hand, can be related to the Shannon-Weaver species diversity (H') and to the prevailing vegetation condition (Bustamante, 2006; Flórez et al., 1992). To improve the land use of this transition area, ecological zoning based on specific conservation rules is necessary.

In recent years the best and most precise way of zoning is through Geographical Information Systems (GIS) (e.g. Bitencourt and Pivello, 1998; Eastman, 1995) because of their handy way of merging information derived from different sources. To better zone an area like 'puna' within a buffer zone, it is necessary to identify the best grassland areas, based on Environmental Fragility (EF) and relate them to the Sustainable Vegetation (SV) zones developed by Flórez et al. (1992). According to these authors, ES may be related to CC per cattle unit /hectare (CU/ha) to improve resource-use efficiency.

The overall aim of this study is:

1 to establish the principal abiotic and biotic variables that influence vegetation in natural grasslands

2 to elaborate an ecological model that incorporates carrying capacity within ecological zoning

3 to do so a series of maps was elaborated and merged, using map algebra and database/map cross analyses within a GIS environment.

1.1 Manu biosphere reserve

The MBR is characterised by a very high level of diversity (Natural World Heritage Site) and is considered as one of the richest biodiversity centre of the world (Davis et al., 1997). This reserve represents an Andean elevation gradient of the southeastern Peru where it covers 1.9 million hectares. Around 6500 Quechua and 2000 Amazonian peoples are living inside the reserve. This reserve protects the entire watershed of the Manu river and part of the Alto Madre de Dios river watershed, encompassing a full complement of the biological communities from the grassy Andean highlands (*puna*) at 4020 m through the eastern slope of the Central Andes (Yungas) to the lowland Amazon forests at 240 m (Dallmeier et al., 1996).

The MBR is made up of 3 main areas: a *core area* (the Manu Nacional Park – MNP) devoted to conservation, a *buffer area* including indigenous territories and private ecological reserves and a *transition area* with biogeographical boundaries and experimental, application and traditional uses areas (UNA-CEPID, 1986).

According to Terborgh (1977), five structurally distinct vegetation types along an elevational gradient are distinguished in the MBR, as follows: *lowland rainforest* occurs below 450–500 m, where it is replaced by *montane rainforest* as the slope of the Andes rise abruptly from de basin floor. This vegetational replacement is market by the loss of the emergent layer of trees, so that the upper canopy of montane rainforest is much more uniform. Floodplain forest and other vegetation types associated with rivers and oxbow lakes also disappear at this topographic transition. Montane rainforest is replaced by *cloud forest* beginning near 1400 m, where clouds form nearly every day in the slopes. The transition to cloud forest is signalled by an abrupt increase in the amount of epiphytic growth on tree limbs and thick jackets of mosses and bryophytes on limbs (Terborgh, 1971). Above about 2800 m, cloud forest is replaced by elfin forest, characterised by much lower canopy and microphyllous foliage. Forests on ridge tops as low as 1400 m can bear structural resemblance to elfin forest, although floristically they are more similar to neighbouring montane forests. Forest gives way to *puna* (open grassland) with scattered patches of *elfin forest* at about 3200 m. Depending on slope, aspect and soils, the transition between these vegetation types varies up to 400 m on different ridges within the park (Terborgh, 1977).

2 Material and methods

2.1 Study area

The study was conducted in the Andean transition area of the MBR that encompasses the Paucartambo mountain range in the southern Peruvian Andes, north-east of Cuzco, Peru (12°23'–13°15'S and 71°36'30'–72°13'W), as can be seen in Figure 1. This mountain range is oriented from south-east to north-west direction, and defines the hydrologic systems of the Paucartambo-Mapacho river (Andean – Amazon transition region) and Alto Madre de Dios river (Amazon region). The left side of this mountain range belongs to the peasant communities who speaks Quechua while the right one belongs to the MNP.

Figure 1 Partial map of the Amazon basin, showing the position of the MNP (Peru)

The montane grassland (*puna*) of the Paucartambo mountain range, of approximately 16,224 ha, is the specific area surveyed in this study. This area includes grasslands of both peasant communities and the MNP.

The life zones, according to the classification Holdridge's (1967, 1982), present in the Andean region of MBR are:

1 *subtropical montane moist forest* – the elevation range is: from 2800 to 3000 m

2 *subtropical subalpine wet paramo* – from 3000 to 3650 m

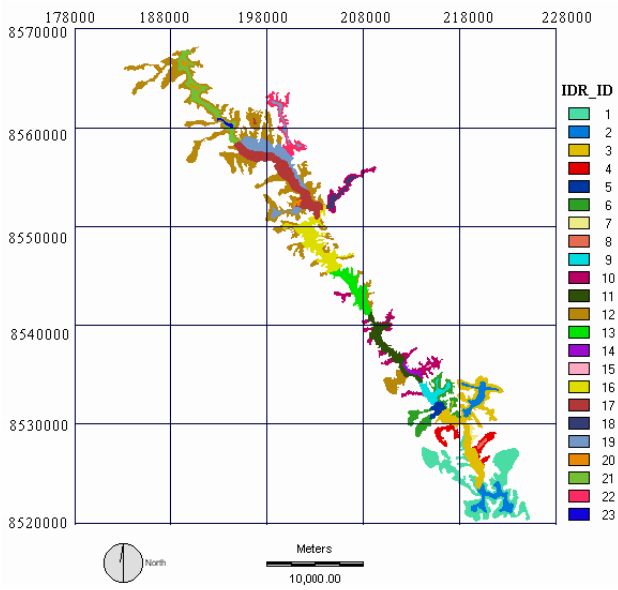
3 *subtropical subalpine moist puna* – from 3650 to 4000 m.

This life zone is comprised of certain Gramineaes species less than 35 cm high, Ciperaceaes, Juncaceaes and Compositaes. In this life zone, annual precipitation may exceed 1500 mm; June and July temperatures are around 8°C and January–March around 15°C. Along the Paucartambo-Mapacho valley, precipitation remains between 550 and 1000 mm, and the temperature between 12.5 and 18°C, depending on the altitude (Bustamante, 1994).

2.2 *Thematic maps*

The study area is dominated by herbaceous vegetation. In this area 23 sampling units, homogeneous units, (named range site) have been identified, these being obtained from the visual interpretation (texture and tonality) of radar and satellite images (1:100,000), observed from aerial-photographs (1:45,000). Subsequently this information was transferred to digital cartographic base (1:50,000) including contours of each 50 m, these resulting in the sampling units map (Figure 2).

Figure 2 Map of the study area (Andean region of MNP) with 23 polygons representing the 23 range sites (for colours see online version)



The thematic maps were produced as follows: the topography in a digital form was converted into a surface or Digital Elevation Model (DEM). From the DEM, the slope map was generated. The hypsometry (altitude) map resulted from the DEM reclassification into the altitudinal intervals of interest.

In order to determine the vegetation condition of each range site, four rating criteria (Table 1) were used in the site-potential approach, based on Humphrey (1962), Flórez et al. (1992) and Bustamante (2006):

1 Composition of desirable species

2 Forage species

3 Plant vigour

4 Erosion.

5 Determination of vegetation condition

Table 1 Classification of vegetation condition utilised to classify Andean natural grassland, using four criteria

I. Composition of desirable species	
%	*Score*
	[(Percentage of desirable species)(0.5)]
70 to 100	35.0 – 50.0
40 to 69	20.0 – 34.5
25 to 39	12.5 – 19.5
10 to 24	5.0 – 12.0
0 to 9	0.0 – 4.5
II. Forage species	
%	*Score*
	[(Percentage of forage species)(0.2)]
90 to 100	18.0 – 20.0
70 to 89	14.0 – 17.8
50 to 69	10.0 – 13.8
40 to 49	8.0 – 9.8
less than 40	0.0 – 7.8
III. Plant vigour	
%	*Score*
	[(Percentage of plant vigour)(0.1)]
80 to 100	8.0 – 10.0
60 to 79	6.0 – 7.9
40 to 59	4.0 – 5.9
20 to 39	2.0 – 3.9
less than 20	0.0 – 1.9
IV. Erosion	
%	*Score*
	[(100 – Percentage of erosion)(0.2)]
10 to 0	18.0 – 20.0
30 to 11	14.0 – 17.8
50 to 31	10.0 – 13.8
60 to 51	8.0 – 9.8
More than 60	0.0 – 7.8

Table 1 Classification of vegetation condition utilised to classify Andean natural grassland, using four criteria (continued)

V. Determination of vegetation condition	
Total score	*Quality*
79 to 100	Excellent
54 to 78	Good
37 to 53	Fair
23 to 36	Poor
0 to 22	Very poor

Source: Flórez et al. (1992).

Vegetation condition was calculated as 0.5 I + 0.2 II + 0.1 III + 0.2 IV.

1 *Composition of desirable species* is the most important of the various criteria employed. The total plant cover, within reach of livestock, was subdivided by forage-value, based on: desirable (decreasers), less desirable (increasers) and undesirable (invaders) species. These classes were determined from specialised literature on grassland species palatability for alpacas and sheep in the Andean region (Antezana, 1972; Bryant and Farfan, 1984; Contreras, 1967; Farfan, 1981; La Torre, 1963; Montufar, 1983; Peña, 1970; Reiner, 1985; Reiner and Bryant, 1986; Sanches, 1966). Composition of desirable species was determined by registering percentage of desirable species.

2 *Forage species* is usually identified as the percentage of ground surface covered by the current year's growth of desirable and less desirable species.

3 *Plant vigour* of two key forage species is a useful indicator of vegetation conditions. Vigour was determined by comparing the height of 10 plants on the area being rated with others 10 of the same species identified as vigorous and flourishing located on un-grazed areas.

4 *Erosion* is an indirect measure of vegetal cover and was determined by registering bare soil, rock and pavement, on the transect, on each range site sampled.

The checklist of species composition, palatability of grassland species and results of the 4 criteria for vegetation conditions, for the study area is in Bustamante (1994).

Shannon species diversity index [$H' = -pi \cdot \ln pi$] (Magurran, 1988; Whittaker, 1972) was determined by calculating the frequency of each plant species (*pi* = proportion of points along each transect at which species *i* was recorded).

This information was stored in the Database Workshop, as shown in Table 2. This Database Workshop is an integrated relational database management system that allowed for linking variables such as the specific diversity index and vegetation condition values with each identifier of the sampling units map, this resulting in single maps such as the diversity map and vegetation condition map.

Table 2 Database with IDRISI identifier of 23 sampling unit areas, and its respective Shannon-Weaver Diversity (*H*') and Vegetation Condition (*C*).

Identifier (ID)	*Shannon-Weaver Diversity (H')*	*Vegetation Condition (C)*
1	4.12	54.04
2	4.54	52.61
3	4.2	56.10
4	4.42	55.57
5	4.40	55.61
6	4.60	48.10
7	4.39	58.78
8	4.68	53.82
9	4.41	63.74
10	4.45	57.39
11	4.19	39.38
12	3.87	49.50
13	4.28	53.64
14	4.10	54.98
15	4.74	59.32
16	4.23	53.36
17	4.22	54.20
18	4.15	58.10
19	4.30	57.58
20	4.13	40.25
21	4.54	39.59
22	4.33	44.04
23	4.68	51.36

2.3 Ecological zoning and spatial modelling

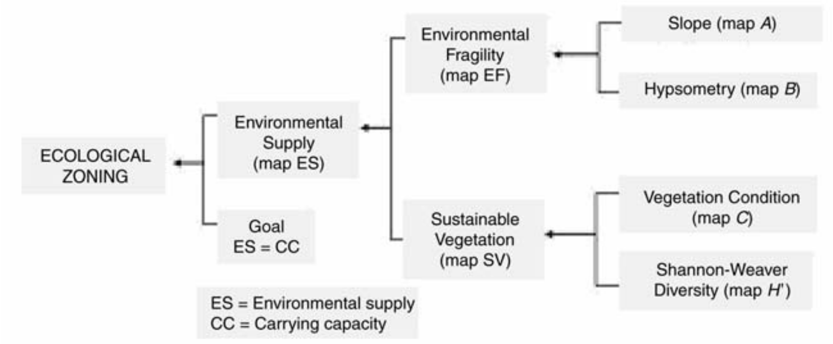
The methodology used to achieve the ecological zoning of the study area was spatial modelling, using IDRISI for windows 2.1 and TOSCA 2.12, which allowed for digitalising, storing, processing and analysing the whole set of data between maps, and between maps and database.

Spatial modelling was used to create simplified representations of spatial structure of grassland landscapes by means of GIS. To represent these grassland landscapes, a set of map layers was related using map algebra to identify layer relationships.

To achieve our goal, a cross-classification operation was used. The cross-classification can be described as a multiple overlay or logical AND operation. The result is a new image that shows the location of the combined categories of the original maps. The summary of our spatial modelling can be seen in Figure 3, which shows the flow chart of all layer combinations using 'cross-classification' operations.

In this study, EF, SV and ES concepts were defined as follows:

Figure 3 Spatial modelling flow chart to determine the ecological zoning of the Andean region of the MNP – Peru, using cross-classification operations



2.3.1 Environmental fragility

EF is a criterion that is defined as a vulnerability index of the physical environment of the grassland. EF is computed by the cross-classification of the hypsometry and soil slope of the landscape. According to this index, grassland areas above 3550 m.a.s.l. are considered the best areas to livestock raising, because the better environmental condition to the development of herbs, grasses and sedges, all of them, utilised for the livestock feeding. On the other hand, lands below 3550 m are closer to the tree-line and are made up of patch of dwarf forest, scrub and grasses. This ecotone, transition between elfin forest and montane grassland (*puna*), is considered as worst areas to livestock raising, because the lack or not enough quantity and quality of livestock food.

In addition to hypsometry, slope plays an important role on the stability of grassland. Steep slopes are more sensitive to soil erosion and runoff than gentle slopes. So, steep slope often results in very shallow soils an little horizon development. According to the topographic characteristics of the study area, soil slope are related to vegetation condition of the grassland, according to the follow sequence:

1. flat and moderate gentle slope (from 0% to 20%) are related to palatable grasses for the livestock
2. soil from moderate gentle to steep slope (20–40%) are related to less palatable grasses
3. soils with more than steep slope (>40%) area related to undesirable species for the livestock feeding.

EF results from the combination of hypsometry (map *B*) and slope (map *A*) maps with classes and respective identifiers (id) as follows:

- the best hypsometric class for pasture is (id = 1) $\geq$ 3550 m
- the worst hypsometric class is (id = 2) < 3550 m
- the best slope class for pasture is (id = 1) < 20% inclination
- the medium class for pasture is (id = 2) 20% < inclination $\leq$ 40%
- the worst class for pasture is (id = 3) > 40% inclination.

2.3.2 Sustainable vegetation

SV is a criterion that is defined as a quality index of the vegetation condition of the grassland. SV is computed by the cross-classification of the vegetation condition and Shannon-Weaver plant diversity of the vegetal communities of the grassland. According to this index, grassland areas with high plant diversity ($H' > 4.5$) indicate moderate pressure of livestock over this kind of grassland, while grassland areas with moderate or low plant diversity ($H' < 4.5$) are related with high pressure of livestock or grassland under an overgrazing condition (Bustamante, 2006).

Vegetation condition follows the same reasoning than plant diversity. Thus, the following sequence is expect:

1 grassland areas with high vegetation condition (VC > 54) indicate grassland vegetation communities with high number or palatable species (35–50% of the community)

2 grassland areas with moderate vegetation condition (45 < VC < 54) indicate grassland vegetation communities with moderate number or palatable species (12.5–34.5% of the community)

3 grassland areas with low vegetation condition (VC < 45) indicate grassland vegetation communities with low number or palatable species (0–12% of the community).

To obtain the vegetation conditions (map *C*), values resulting from the combination of several indices (Table 2) were related to a sampling units map. This sampling units map was obtained from the interpretation of a set of aerial photographs, satellite images and controlled radar images, based on texture patterns. Each index (from I to IV) received a specific punctuation as can be seen on Table 2.

SV results from the combination of Shannon-Weaver Diversity (map *H'*) and Vegetation Condition (map *C*) maps, with classes and identifiers (id) as follows:

- the best diversity for pasture is (id = 1) ≥ 4.5
- the worst diversity for pasture is (id = 2) < 4.5
- the best vegetation condition for pasture is (id = 1) ≥ 54
- the medium vegetation condition for pasture is (id = 2) 45 < condition < 54
- the worst vegetation condition for pasture is (id = 3) < 45.

2.3.3 Environmental supply

ES is defined as the capacity of the grassland ecosystem to supply the necessary amount of grasses, sedges and herbs for livestock feeding, without degrading the grassland soils nor vegetation composition of the grasslands. This means that the livestock density must be adjusted to the carrying capacity of grassland allowing the stability of the soils and the maintenance of the grassland vegetation community. ES is computed by the cross-classification of EF and SV.

According to this index, the ES classes related to EF and SV show the following sequence:

1 grassland areas with best EF characteristic and best SV are classified as grassland with good ES

2 grassland areas with moderate EF characteristic and best SV are classified as grassland with moderate ES

3 grassland areas with worst EF characteristic and worst SV are classified as grassland with worst ES.

3 Results

To produce the EF Map, both Map *A* and Map *B* were multiplied, this resulting in an EF Map ($A \times B$ = EF). Afterwards, a reclassification of the EF took place by analysing the five new classes and reclassifying them into 3 classes as follows:

- Class 1 represents an altitude >3550 m and inclination <20%, representing the lowest EF. This class occupies 28.45% of the study area.
- Class 2 represents two types of areas:
  - with an altitude >3550 m and an inclination between 20 and 40
  - an altitude < 3550 m and inclination < 20%.

  In this case both areas became class 2, with medium EF. This class occupies 26.13%.
- Class 3 represents both areas:
  - with an altitude <3550 m and an inclination between 20% and 40%
  - with <3550 m and an inclination > 40%. In this case both became class 3, the greatest EF.

  This class occupies 45% of the study area.

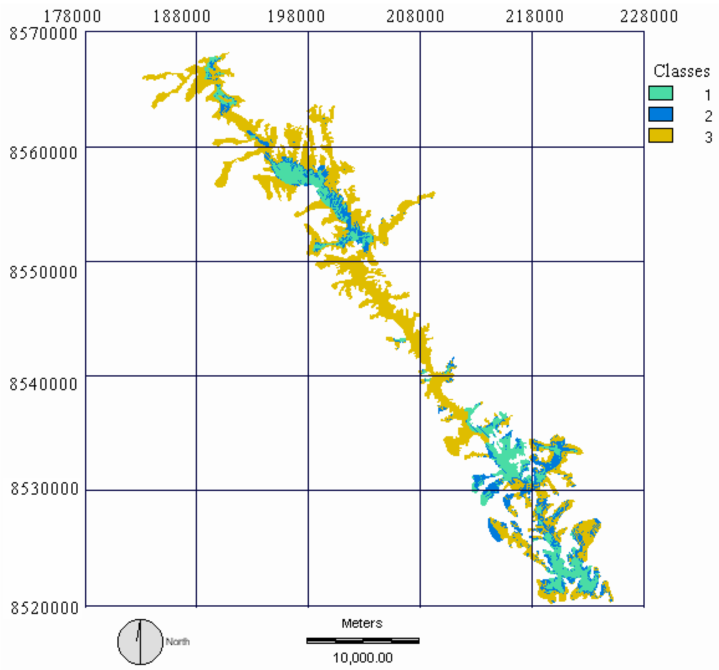
To produce the SV Map, both Map *C* and Map *H'* were multiplied resulting in the SV Map ($C \times H'$ = SV). Afterwards, a reclassification of the SV took place by analysing the five new classes and reclassifying them into 3 classes as follows:

- Class 1 represents the area with vegetation conditions $\geq$54 points and diversity >4.5 and vegetation conditions between 45 and 54 points, with diversity >4.5. In this case they were both considered to be in a good vegetation conditions. This class occupies 8.91% of the study area.
- Class 2 represents areas with vegetation conditions $\geq$54 and diversity <4.5 and areas with vegetation conditions <45 points and diversity <4.5. In this case both were considered to be in a fair to good condition. This class occupies 49.01% of the study area.
- Class 3 represents the areas with vegetation conditions between 45 and 54 points and diversity <4.5. In this case this is considered to be in a fair to poor condition. This class occupies 42.14% of the study area.

The ES Map (Figure 4) was obtained from a cross-classification of EF and SV. The outcome was nine combinations which were reclassified into three new classes as follows:

- Class 1 represents the areas with both – minor EF and good SV, and with minor EF and fair to good SV
- Class 2 represents the areas with both – medium EF and fair to poor SV, and high EF and good SV
- Class 3 represents the areas with – minor EF and fair to good SV, medium EF and fair to poor SV and high EF and fair to poor SV.

Figure 4 Final ecological zoning for the studied portion of the Mapacho-Yavero catchment basin, located in the MNP-Peru. Map ES. Environmental supply = Ecological Zoning Map (for colours see online version)



Due to its characteristics Class 1 is an ecological zone which presents a good ES, Class 2 presents a fair ES and Class 3 presents a fair to poor ES. According to Flórez et al. (1992), ES may be related to carrying capacity for CU/ha as follows: Good ES = 0.75 CU/ha; Fair ES = 0.56 CU/ha and Fair to poor ES = 0.38 CU/ha. Therefore, the ecological zoning classes were redefined as follows (Figure 4):

1. Class 1 covering 2997.50 ha, zone of continuous use, with animal consumption = 0.75 CU/ha
2. Class 2 covering 2792.25 ha, zone of continuous use, with animal consumption = 0.56 CU/ha
3. Class 3 covering 10,434.75 ha, zone of temporary use, with animal consumption = 0.38 CU/ha.

The reason for a zone of temporary use is due to the fact that:

1 sustainability requires consumption ≤ carrying capacity

2 because class 3 showed the areas with the highest instability all.

4 Discussion

4.1 Spatial modelling

In the Andean range, especially in the study area, variables such as altitude and slope are the main factors that influence spatial heterogeneity of the natural pasture units (Bustamante, 2002). Similar results had been obtained by Del Barrio (1997), also in mountain ecosystems.

The use of natural pasture in the Andean region is generalised. However, specialised literature about the sustainable use of this kind of ecosystem, usually estimates carrying capacity, taking into account presence, density and eatable plant species, as well as some abiotic factors. In the present study, abiotic (altitude and slope) and biotic (diversity and vegetation condition) variables had been integrated using spatial modelling in a GIS environment. The outcome was ecological zoning which was associated to a specific objective. This objective was to achieve the sustainable use of natural pasture, while trying to keep the following relationship: ES has to be equal or less than their carrying capacity.

4.2 Environmental fragility

In the study area, 45% (7368.25 ha) of the region possesses high EF due to irregular relief, steep slopes and a slope larger than 40% that predominates in the Andean region (Gentry, 1990; Young, 1997). These areas in some cases are used for livestocking and agriculture (Bustamante, 2006; Flórez et al., 1992).

The other areas with medium and low EF represent 26.13% and 28.45% of the region, respectively. The altitude (3600 m) of most of this surface is outside the limit of cultivation or is marginal for some crops, such as potatoes, barley and corn (Bustamante, 1994). Much of the high level surface is used mainly as pasture for livestocking (Bustamante, 1994).

4.3 Sustainable vegetation

In the Andean mountains region, where herbaceous vegetation forms the natural grasslands, the main criterion of sustainability takes into account vegetation conditions or forage potential (Antezana, 1972; Bustamante, 1994; Contreras, 1967; Farfan, 1981; ONERN, 1986; Oscanoa, 1988; Peña, 1970; Sanches, 1966). In the present work, beyond vegetation conditions, the Shannon-Weaver diversity (H') was included as another important criterion to determine SV.

In the study area, only 8.91% of the region (1445.25 ha) possesses good SV. On the other hand, a fair-good and fair-poor SV represent 49.01% and 42.14% of the region, respectively. This criterion (SV) could be interpreted as an indirect measure of the degree of overgrazing that occurs in the Andean region, covering most of the territory (Antezana, 1972; Bustamante, 1994; Contreras, 1967; Farfan, 1981; ONERN, 1986; Oscanoa, 1988; Peña, 1970; Sanches, 1966).

5 Conclusion

- One of the most important criteria to conserve the Andean grassland of the MBR is the applying of a management plan that take into account both abiotic and biotic variables of the grassland within an ecological zoning in a GIS environment.
- The vegetation conditions that incorporate the proportion of eatable species and erosive soil potential allowed for quantifying the destination use of ecological zoning.
- The Shannon-Weaver specific diversity helped to incorporate the conservation state of the available eatable species and to fit the destination use of ecological zoning.
- The biotic variables, transformed into maps within a GIS environment, gave a new dimension to the results and allowed for quantifying the area of each ecological zone.
- Within the abiotic variables, the use of aerial photographs, radar images, satellite images and DEM, amplified the reliability of the data, especially in an area so poor in cartographic information.
- The relation of these ecological zones with cattle carrying capacity gave them ecological significance.

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