Soil, Vegetation and Vicunas in Apolobamba (Bolivia): Conservation of Biodiversity

Muñoz, M. Ángeles[1] and Faz, Ángel [1]

(1) Sustainable Use, Management and Reclamation Soil and Water Research Group. Agrarian and Science Technology Department, Technical University of Cartagena, Paseo Alfonso XIII, 52. 30203-Cartagena. Murcia. Spain.

E-mail: mangeles.munoz@upct.es/ Tel. 0034.968.32.57.52/ Fax. 0034.968.32. 70.46

ABSTRACT

High-grasslands in the Andes Mountain Range are the natural habitat of many species such as vicuna (*Vicugna vicugna*), endangered specie recognized by The World Conservation Union. These ecosystems are especially weak and suffer, in many cases, over-exploitation processes due to the cattle raising. The National Area of Apolobamba Integrated Management (ANMIN-A) is located northwest of Bolivia and there, government and indigenous people carry out a vicuna sustainable management programme in the aim of the conservation of this specie and its natural habitat. The objectives of this work were to study different zones with diverse vicuna and other domestic camelid populations in Apolobamba in order to evaluate: (i) soil conservation degree through the analysis of physical and chemical properties, (ii) vegetation characterization and (iii) the relationship soil-plant system. Some soil and plant samples were taken in different sampling plots according to vicuna and domestic camelid population densities. Moreover, it was taken into account the geo-morphological and landscape characterization. Results showed differences between soil characteristics and fertility qualities, and plant covert, vegetation species identification and palatability. Results discussion exhibited that the studied zones had different degradation processes, mainly, due to the vegetation modification. In conclusion, in Apolobamba there were differences in the study zones with diverse vicuna and domestic camelid population densities, related to soil and vegetation conservation degree. On the other hand, some zones need specially protection measures associated to the cattle raising impacts and the soil-plant system degradation.

Keywords: soil conservation, camelid population, soil-plant system

INTRODUCTION

Grazing intensity and grassland degradation problems have been studied around the world; ecosystem degradation is commonly assessed, based on soil and vegetation conditions (Chunli et al., 2008). Grazing reduces soil water-holding capacity (Pietola *et al*., 2005) which increases surface runoff (Heathwaite et al., 1990), decreases soil macro-porosity (Singleton *et al*., 2000) and increases the risk of soil nutrients loss (Kurz et al., 2005). On the other hand, an intensive grazing may lead to the destruction of vegetation and incorporation of plant residues into the soil (Bilotta *et al*., 2007), which alter carbon storage and nitrogen levels in rangeland ecosystems (Derner *et al*., 2006; McNauughton *et al*., 1997; Frank and Groffman, 1998; Milchunas and Lauenroth, 1993). Some researchs show that soil and vegetation degradation on grassland is caused mainly by livestock grazing (Keya, 1998). However, the effect of overgrazing on vegetation and soil properties is not well understood (Chunli *et al*., 2008).

In many cases, ecosystems in the *puna* or grasslands in the Altiplane are degraded as a consequence of anthropogenic activities (Rocha and Saenz, 2003), in addition to excessive grazing. Vicuna is an endangered species recognized by The International Union for Conservation of Nature (IUCN, 2008) The National Apolobamba Integrated Management Area (ANMIN-A) in Bolivia is a high altitude grassland (above 4,000 m.a.s.l.), located in the Northwest of La Paz (Fig. 1). ANMIN-A provides a natural habitat for a high number of camelids. Aymara and Quechua indigenous communities live in Apolobamba and their main economical activity is to raise camelids. These ethnic groups present a poverty index of about 98% (Instituto Nacional de Estadística, 2001). According to the Servicio Nacional de Áreas Protegidas (SERNAP), Apolobamba area hosts more than 10,000 vicunas (*Vicugna vicugna*) and 130,000 alpacas (*Lama pacos*), approximately 34% of the total alpacas in Bolivia and other domestic camelids; they are distributed in about 120,000 ha (SERNAP, 2005). Vicuna management in the Apolobamba area is an example of sustainable management in indigenous communities (Agencia Española de Cooperación Internacional, 2004). The objectives of this study were to determine: (i) soil conservation degree through the analysis of physical and chemical properties, (ii) the vegetation characterization and (iii) the relationship soil-plant system.

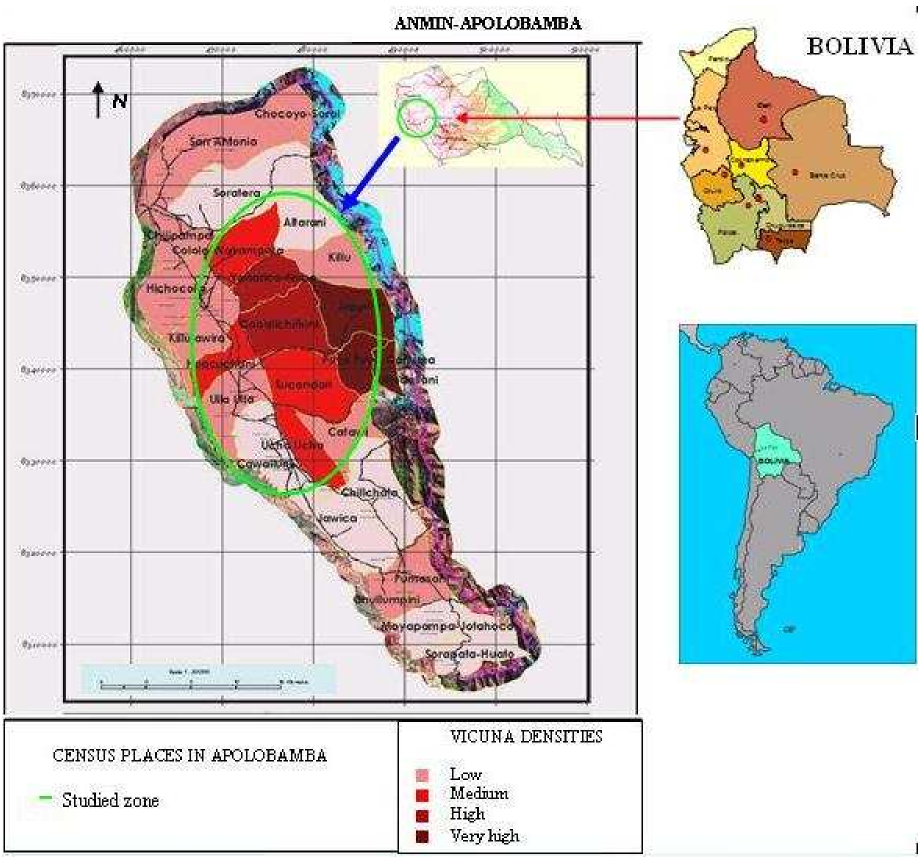

Figure 1. Location map of the ANIMN-Apolobamba and the studied zone.

MATERIALS and METHODS

The research was carried out in the *puna* of Apolobamba, the vicuna habitat. The study zone is characterized by udic and frigid soil moisture and temperature regimes (Soil Survey Staff, 2003) with an annual average temperature of 4.5 ºC and total precipitation of 505 mm which is concentrated in five months, between November and March (SERNAP, 2006). Considering Rivas-Martinez (2004) bioclimatic model and Navarro and Maldonado (2002) bioclimatic map of Bolivia, the study area would be classified as orotropical. It could be also identified by two vegetation units (altoandine and *puna*), according to Beck et al. (2002) classification. García et al. (2002) recognize three sub-units grasslands; with altitude ranges between 4,000 and 5,200 m.a.s.l., and some variations described by several investigators (Ribera, 1992; Kessler and Beck, 2001; Beck et al., 2002; Navarro and Maldonado, 2002).

Soil quality and conservation degree was evaluated through a physical-chemical characterization. Vicuna population density was the main reason to select studied zones (Fig.1). Other characteristics that were determined include: (i) alpaca densities, (ii) vegetation species, (iii) geo-morphological, and (iv) hydrological landscape elements. Eight census places, or areas with stable vicuna populations separated by geographic accidents, were selected (Tables 1, 2 and Fig. 1).

Table 1. Vicuna and alpaca densities in the Apolobamba area.

Vicunas			Alpacas	
Density	**Nº**	**Nº/ km^2**	**Density**	**Nº**
Low	139-412	2.1-9.4	Low	1569-2542
Medium	413-691	9.4-16.5	Medium	2543-4004
High	692-1383	16.5-23.1	High	4005-6641
Very High	1384-2119	23.1-58.1	Very High	6642-15300

(Catari and Fernandez, 2003)

Table 2. Vicuna and alpaca densities in selected census places.

Census places	Vicuna density 2003 (1)	Vicuna density 2004	Vicuna density 2005 (3)	Alpaca density (3)
Ulla-Ulla	Low	Low	Low	High
Killu	Low	Low	Low	Medium
Ucha-Ucha	Medium	Medium	Medium	Very high
Wakampata	Medium	Medium	Medium	Medium
Caballchiñuni	High	High	High	Medium
Sucondori	Medium	High	High	
Puyo-Puyo	Very high	Very high	High	Medium
Japu	Very high	Very high	Very high	

(1) Catari and Fernández (2003); (2) SERNAP (2004);(3) SERNAP (2005).*In 2006 and 2007, the census was not carried out.

Soil Sampling

Three representative plots of 5 x 5 m were selected in each census location or studied area. Since most of the soil organic matter is located in the surface layer (Ganjegunte et al., 2005), three replicates, surface and sub-surface soil samples, were collected per plot: 0-5 cm and 5-15 cm. Samples were placed in plastics bags, which were sealed and then transported to the laboratory. Soil samples were air-dried and passed through a 2 mm sieve to remove gravels, plant remains and root fragments.

The following soil analysis were carried out: organic carbon was analysed on TOC Analyser (Shimadzu 5000, Kyoto, Japan); total nitrogen was determined using Duchafour (1970) method; pH (Peech, 1965), electrical conductivity in 1:5 (w/v) aqueous solution, texture (pipette Robinson) using FAO-ISRIC (1990).

Statistical analyses were determined using mean values and the standard error of means (n=9) was calculated taking into account three replicates per plot. Through the analysis of residuals distribution (normal probability plot) data normally distributed was studied. Variance-ANOVA (Fisher, 1935) and Tukey´s Test were used to determine significant differences in physico-chemical variables in studied zones.

Sampling of Vegetation

Plant covert percentages were determined in each plot according Huss et al. (1986) method, modified using a sampling grid (50 x 50 cm) and needles inserted with 90 º. This way 72 sampling points were located per plot and the mean value was determined for each census place. In addition, vegetation samples of the most representative species were collected on each plot (UNESCO, 1973); they were identified in the Herbario Nacional de Bolivia. Flora samples were taken from around the plots in order to prevent these plots from any disturbance (Yager et al., 2007). The vicuna and alpaca palatability degree of plants was also studied (Catari and Fernandez, 2003). Soil and vegetation samples were collected in the dry season (June-November).

RESULTS

Soil

According to surface and sub-surface samples data, Tables 3 and 4 show different physico-chemical variables mean values analysed in each studied zone. Normal probability plot analyses showed normal data distributions and ANOVA ($p<0.001$) exhibit significant differences in surface and sub-surface results in all physico-chemical variables in the studied zones.

Table 3. Physico-chemical variables. Mean and standard error (n=9) in surface samples (0-5 cm) in studied zones (different letter indicates significant differences).

Variable	Ulla-Ulla	Killu	Ucha-Ucha	Wakampata	Caballchiñuni	Sucondori	Puyo-Puyo	Japu
O.C. (g kg^{-1})	51.5 ± 6.4	58.9 ± 5.2	55.0 ± 3.1	91.7a ± 5.6	45.9 ± 2.3	37.3d ± 2,0	72.7 ± 3.8	61.1 ± 5.9
TN (g kg^{-1})	4.3 ± 0.4	5.0b ± 0.2	4.6 ± 0.3	7.2a ± 0.4	3.9 ± 0.1	3.3d ± 0.2	5.2b ± 0.3	5.2b ± 0.4
C/N	11.9 ± 0.6	11.7 ± 0.8	12.1 ± 0.5	12.7 ± 0.2	11.9 ± 0.4	11.7 ± 1.0	14.3 ± 0.9	11.5 ± 0.3
CEC ($cmol_+$ kg^{-1})	13.9 ± 0.6	20.9 ± 0.4	16.3 ± 0.8	23.5a ± 1.5	12.3e ± 0.6	14.2 ± 1.1	18.3 ± 0.9	17.2 ± 1.4
pH H_2O	5.0c ± 0.1	5.9a ± 0.1	5.6a ± 0.2	4.9c ± 0.2	4.9c ± 0.1	5.4b ± 0.1	4.9 ± 0.0	4.2d ± 0.1
pH KCl	4.0c ± 0.1	4.9a ± 0.1	4.8a ± 0.1	4.0c ± 0.0	4.0c ± 0.0	4.4b ± 0.1	4.2 ± 0.0	3.7d ± 0.0
EC (µS cm^{-1})	22.1d ± 1.6	66.5 ± 4.1	227.0a ± 73.6	192.5 ± 78.0	28.4d ± 5.4	56.6 ± 14.2	184.2a ± 16.5	99.8 ± 16.2
Sand (%)	69a ± 2	40d ± 4	61 ± 3	45 ± 1	66a ± 1	63 ± 4	52 ± 2	50 ± 3
Silt (%)	20c ± 2	42a ± 3	23 ± 3	41a ± 1	23c ± 1	26c ± 3	34 ± 1	36a ± 2
Clay (%)	11 ± 0	18a ± 2	16 ± 1	14b ± 1	11d ± 1	11 ± 2	14 ± 1	14b ± 1

The highest organic carbon contents (O.C.) in surface samples was observed in the Wakampata area (91.7±5.6 g kg^{-1}) and the lowest in Sucondori (37.3±2.0 g kg^{-1}). Related to total nitrogen (TN), Table 3 show the highest value in Wakampata (7.2±0.4 g kg^{-1}) while Sucondori presented 3.3±0.2 g kg^{-1}, the lowest TN content in studied zones, and Killu, Puyo-Puyo and Japu exhibited similar contents. Carbon-nitrogen relation (C/N) presents maximum value in Puyo-Puyo (14.3±0.9). Wakampata showed highest Cation Exchange Capacity (CEC) value (23.5±1.5 cmol+ kg^{-1}) in front of Caballchiñuni (12.3±0.6 cmol+ kg^{-1}). Soil acidity conditions in surface samples are showed in Table 3: Killu and Ucha-Ucha exhibit uppermost pH H_2O and KCl values (5.9±0.1 and 4.9±0.1 in Killu, and 5.6±0.2 and 4.8±0.1, respectively, in Ucha-Ucha); least values were observed in Japu (4.2±0.1 and 3.7±0.0, respectively). Ulla-Ulla, Wakampata and Caballchiñuni areas present similar soil acidity conditions. Electrical conductivity (EC) results indicated low soil salinity in surface; highest value was detected in Ucha-Ucha (227.0±73.6 µS cm^{-1}). Texture data presented the maximum clay percentage in Killu (18±27%) and the least sand percentage (40±4%). Ulla-Ulla presented highest sand percentage (69±2%).

Table 4. Physico-chemical variables. Mean and standard error (n=9) in sub-surface samples (5-15 cm) in studied zones (different letter indicates significant differences).

Variable	Ulla-Ulla	Killu	Ucha-Ucha	Wakampata	Caballchiñuni	Sucondori	Puyo-Puyo	Japu
O.C. (g kg^{-1})	44.5 ± 4,0	47.8c ± 2.0	38.8 ± 2.2	56.2 ± 2.0	57.3a ± 2.7	30.0d ± 2.1	50.4 ± 2.5	43.9 ± 4.0
TN (g kg^{-1})	3.3c ± 0.2	4.7 ± 0.1	3.4c ± 0.1	5.3a ± 0.2	4.4 ± 0.2	2.3d ± 0.2	3.8 ± 0.2	3.9 ± 0.4
C/N	13.5a ± 0.9	10.0c ± 0.2	11.4 ± 0.7	10.6 ± 0.1	13.1a ± 0.7	12.3 ± 0.6	13.1a ± 0.3	11.3 ± 0.2
CEC ($cmol_+$ kg^{-1})	12.0b ± 0.8	19.2a ± 1.0	10.6b ± 0.6	17.7a ± 0.6	12.4b ± 0.7	10.5b ± 1,0	11.8b ± 0.7	13.5b ± 1.5
pH H_2O	4.7d ± 0.1	6.0a ± 0.1	5.7 ± 0.1	5.5 ± 0.0	4.7d ± 0.1	5.5 ± 0.1	5.1c ± 0.1	4.3d ± 0.1
pH KCl	4.0 ± 0.0	4.7a ± 0.1	4.6a ± 0.1	4.1 ± 0.0	4.0 ± 0.1	4.5 ± 0.1	4.3 ± 0.0	3.8e ± 0.1
EC (µS cm^{-1})	32.3c ± 1.9	35.5c ± 3.6	78.1a ± 12.6	47.5 ± 2.8	38.8c ± 2.9	33.9c ± 3.5	63.5 ± 3.1	48.5 ± 5.8
Sand (%)	78 ± 2	40 ± 5	67 ± 3	45 ± 2	72 ± 2	69 ± 3	67 ± 3	58 ± 4
Silt (%)	14d ± 2	40a ± 3	18 ± 3	41a ± 2	18 ± 1	22 ± 2	23 ± 2	29 ± 3
Clay (%)	8e ± 1	20a ± 2	15 ± 0	14 ± 1	10 ± 1	9 ± 1	10 ± 1	13 ± 1

Table 4 shows sub-surface samples data. Maximum OC content was presented in Caballchuñuni (57.3±2.7 g kg^{-1}) conversely to Sucondori with 30.0±2.1 g kg^{-1}. Total nitrogen exhibited the same situation than OC in the Caballchiñuni and Sucondori area, showing the highest and lowest values (5.3±0.2 and 2.3±0.2 g kg^{-1}, respectively). Ulla-Ulla and Ucha-Ucha exhibited similar TN contents. Carbon-nitrogen relation was the maximum in Ulla-Ulla (13.5±0.9) and Caballchiñuni (13.1±0.7). In sub-surface samples CEC data were homogeneous in studied zones: Killu presented the highest CEC value (19.2±1.0 µS cm^{-1}) followed by Wakampata (17.7±0.6 µS cm^{-1}); however, Ulla-Ulla, Ucha-Ucha, Caballchiñuni, Sucondori, Puyo-Puyo y Japu exhibited similar values. In addition, pH H_2O and KCl results showed highest values in Killu (6.0±0.1 and 4.7±0.1, respectively) and the lowest in Japu (4.3±0.1 and 3.8±0.1, respectively). Ucha-Ucha presented maximum EC value (78.1±12.6 µS cm^{-1}) and Ulla-Ulla, Killu, Caballchiñuni and Sucondori areas exhibited low and similar values (Table 4). The highest sand percentage in sub-surface samples was detected in Ulla-Ulla (78±2%) corresponding to the least clay percentage (8±1%); conversely, Killu presented maximum clay percentage (20±2%) and the lowest sand content (40±5%).

Vegetation

Fig. 2 reports mean values of the plant cover in the studied zones (n=3). The highest percentage was observed in the Puyo-Puyo (78.7±1.8%) area, whereas Japu presented the second highest density (68.1±11.9)%. The lowest one was in the Caballchiñuni (41.2±2.3%) and it was related to the low number of species identified (6). About 10 species were identified in the Sucondori and 9 in the Ucha-Ucha zone (Fig. 4), corresponding with low plant cover percentages (50.5±6.0 and 49.6±8.2%, respectively). Most of the identified plant species showed that studied census places presented *Pycnophyllum* grassland. However, in Ulla-Ulla and Killu, census places with low vicuna density and high and medium alpaca density, respectively, there were some species such as *Senecio spinosus*, which were related to vegetation community changes due to environment alterations (García et al., 2002).

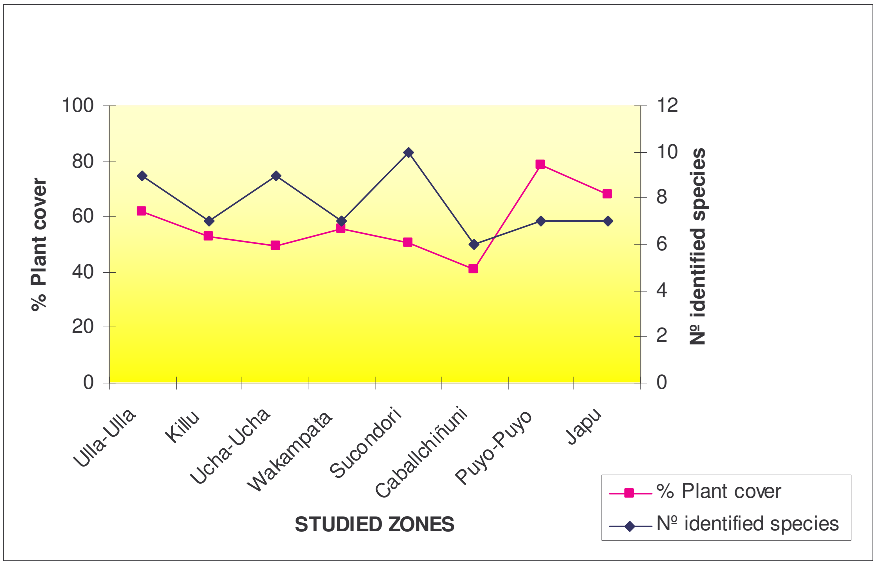

Figure 2. Mean values of plant cover percentage and identified species in studied zones

Species palatability to vicuna and alpaca was studied as well. It was identified one species (*Aciachne acicularis*) with low alpaca palatability, although it was not described for vicuna. Ulla-Ulla exhibited 4 vicuna and alpaca unpalatable species while 2 species were identified in Puyo-Puyo and Wakampata. Puyo-Puyo and Sucondori showed the highest number of identified vicuna palatable species, 5 in each studied zone, while the Sucondori presented highest number of identified alpaca palatable species (5), and 4 for Puyo-Puyo, Wakampata, Ucha-Ucha, and Ulla-Ulla.

DISCUSSION

Soil study reports wide range of OC contents in the studied zones. Wakampata area presented maximum OC values and having medium alpaca and vicuna densities while Sucondori exhibited least OC contents with high vicuna and medium alpaca density. Areas with high and very high vicuna density and medium alpaca density (Puyo-Puyo and Japu) showed high OC contents and similar TN values. Studies on the effect of grazing on semiarid grasslands have shown inconsistent results with soil OC variations; it could be due to the large fraction of highly stable humic substances in soil that are not very responsive to grazing (Galantini and Rosell, 2006; Ganjegunte et al., 2005; Chunli et al., 2008). Carbon-nitrogen relation is similar in most of the studied zones and indicates mineralization and humification equilibrium, apart from Puyo-Puyo, which reported intensive humification processes (Cobertera, 1993). Cation Exchange Capacity presents maximum values in Wakampata and Killu, above 20 $cmol_+ kg^{-1}$; some natural soils can exhibit humic horizons with CEC average of around 30-40 mEq 100 g^{-1} (Cobertera, 1993). These areas reports medium and low vicuna densities and medium alpaca densities, respectively. pH values indicated that soils are strongly acid in H_2O and extremely acid in KCl (Soils Survey Division Staff, 1993) and no saline (USDA, 2005). Texture analyses showed sandy-loam and loam soils (FAO-ISRIC, 1990) and it is no related to vicuna and alpaca densities in each zone.

The study of vegetation showed more plant cover percentage in very high vicuna density census areas, Puyo-Puyo and Japu, with medium alpaca density; Caballchiñuni, Sucondori and Ucha-Ucha areas presented the lowest plant cover: Caballchiñuni had high vicuna and medium alpaca densities, as well as Sucondori, whereas Ucha-Ucha presented medium vicuna density and very high alpaca density. Sucondori and Ucha-Ucha areas exhibited the highest number of identified plant species. Some plant species indicated that there was degradation in the *Pycnophyllum* grasslands (García et al., 2002). Palatability data pointed out that the vicuna and alpaca palatability, in the studied species, were very similar.

CONCLUSIONS

In conclusion camelid density in these areas is not correlated to physico-chemical studied soil properties. There is a balance between mineralization and humification processes and texture conditions. Results show that, nowadays, soil conservation degree is suitable to camelid grazing in studied areas. On the other hand, the vegetation studies have shown a loss in the plant cover and grassland degradation in some zones, which they could be due to an excessive grazing. Areas with high-quality plant cover are matched with those with high soil organic carbon and cation exchange capacity and loam texture. However, other zones exhibited low plant cover and little soil organic carbon; consequently it is necessary to carry out soil and plant protection actions in order to preserve soil quality and biodiversity in Apolobamba.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the Servicio Nacional de Areas Protegidas and the Agencia Española de Cooperación Internacional in Bolivia for cooperation in samplings, both Ministerio de Educación y Ciencia of Spain (Project CTM2006-02812: Natural resources and biodiversity assessment in Apolobamba (Bolivia): Risk assessment by mining activities and remediation of affected areas).

REFERENCES

Agencia Española de Cooperación Internacional-Programa Araucaria. 2004. Manejo sostenible de la vicuña en Apolobamba. La Paz.

Beck, S., Garcia, E. and Zenteno F. 2002. Flora del Parque Nacional y Área Natural de Manejo Integrado Madidi. Proyecto de Apoyo al Parque Nacional Madidi, SERNAP-CARE-HNBCE-WCS. La Paz.

Bilotta GS, Brazier RE and Haygarth, PM. 2007. The impacts of grazing animals on the quality of soils, vegetation, and surface waters in intensively managed grasslands, Adv. Agron. 94: 237-280.

Catari, H. and Fernández, R. 2003. SERNAP-PROGRAMA ARAUCARIA. Caracterización espacial y propuesta de sistema de monitoreo del uso de la vegetación por camélidos en el ANMIN Apolobamba. La Paz.

Cobertera E. 1993. Edafología Aplicada. Eugenio Cobertera Laguna. Madrid, pp. 165-258.

Chunli Li, Xyying Hao, Mengli Zhao, Guodong Han and Walter Willms. 2008. Influence of historic sheep grazing on vegetation and soil properties of a Deser Steppe in Inner Mongolia. Agriculture, Ecosystems & Environment. Vol 128. 1-2, pp 109-116.

Derner JD, Boutton TW and Briske DD. 2006. Grazing and ecosystem carbon storage in the North American Great Plains, Plant Soil 280: 77-90.

Duchaufour, P. 1970. Precis de Pedologie. Masson. Paris.

FAO-ISRIC. 1990. Guidelines for Soil Description. 3 rd. Edition. Soil Resources Managemente ando Conservation Service Land and Water Development Division. Rome.

Frank DA. and Groffrnan PM. 1998. Ungulate vs. landscape control of soil O and N processes in grasslands of Yellowstone National Park, Ecology 79: 2229- 2241.

Fisher R.A. 1935. The Design of Experiments. Oliver & Boyd. Edinburg.
García, E., Beck, S. and Zenteno-Ruiz, F.S. 2002. Plan de Manejo Madidi. Capítulo Botanica. Herbario Nacional de Bolivia. La Paz.
Galantini J. and RoselI R. 2006. Long-term fertilization effects on soil organic matter quality and dynamics under different production system in semiarid Pampean soils, Soil Till 87: 72-79
Ganjegunte, G. K., Vance, G.F., Preston, C.M., Shuman, G.E., Lachlan, J.I., Stahl, P.D. and Welter J.M. 2005. Soil Organic Carbon Composition in Northern Mixed-Grass Prairie. Soil Sci. Soc. Am. J. 69:1746-1756.
Heathwaite AL, Burt TP and Trudgill ST. 1990. The effect of land use on nitrogen, phosphorus and suspended sedment delivery to streams in a small catchment in southwest England. In: J.B. Thornes, Editor, Vegetation and Erosion, Jhon Wiley & Sons Ltd., Chichester, England , pp. 161-177.
Huss, D., Bernardon, A., Anderson, D. and Brun, J. 1986. Principios de manejo de praderas naturales. Instituto Nacional de Tecnología Agropecuaria y Oficina Regional de la FAO para América Latina y el Caribe. Santiago de Chile.
Instituto Nacional de Estadística. 2001. In: www.ine.gov.bo/
IUCN. 2008. In: www.iucnredlist.org/
Kessler, M. and Beck, S. 2001. Bolivia. In: Kapelle M. & AD. Brown (eds.). Bosques nublados del geotrópico. Editorial InBio. San José de Costa Rica, pp. 581-623.
Keya GA. 1998., Herbaceous layer production and utilization by herbivores under different ecological conditions in an arid savanna of Kenya, Agric. Ecosyst. Environ. 69: pp. 55-67.
Kurz I., Coxon O., Tunney H and Ryan D. 2005. Effects of grassland management practices and environmental conditions on nutrient concentrations in overland flow, J. Hydrol. 304: pp. 35-50.
McNaughton S.J., Banyikwa F.F. and McNaughton M.M. 1997. Promotion of the cycling of diet-enhancing nutrients by African grazers, Science 278: pp. 1798-1800
Milchunas DG and Lauenroth WK. 1993. Quantitative effects of grazing on vegetation and soils over a global range of environments, Ecol. Monoyr. 63: 327-366.
Navarro, G. and Maldonado, M. 2002. Geografía Ecológica de Bolivia. Vegetación y Ambientes Acuáticos. Editorial Fundación Simón I. Patiño. Cochabamba, Bolivia.
Peech, M. 1965. Hidrogen-ion activity. In C.A. Black (ed.). Methods or Soil Analisis. American Society of Agronomy. Madison. Wisconsin, USA , pp. 914-916.
Pietola L., Horn r. and M.Y. Halla. 2005. Effects of trampling by cattle on the hydraulic and mechanical properties of soil, Soil Till. 82: pp. 99-108.
Ribera, M.O. 1992. Regiones Ecológicas. En: MARCONI (ed.): Conservación de la diversidad biológica en Bolivia. Centro de Datos para la Conservación - Bolivia, United States Aid Mission to Bolivia, USAID/ Bolivia. La Paz. Capítulo II, pp. 9-71.
Rivas-Martínez, S. 2004. Clasificación bioclimática de la Tierra. In: www.globalbioclimatics.org

Rocha, O. and Sáez, C. 2003. Ministerio de Desarrollo Sostenible y Planificación. 2003. Uso pastoril en humedales altoandinos. La Paz.

SERNAP. 2004. Informe final del censo de vicuña de 2004. La Paz.

SERNAP. 2005. Informe final del censo de vicuña de 2005. La Paz.

SERNAP. 2006. Plan de Manejo. Área Natural de Manejo Integrado Nacional Apolobamba. La Paz.

Singleton, M. Boyes and B. Addison. 2000. Effect of treading by dairy cattle on topsoil physical conditions for six contrasting soil types in Waikato and Northland, New Zealand, with irnplications for monitoring, N. Z. J. Agric. 43: pp. 559-567.

Soil Survey Division Staff. 1993. Soil Survey Manual. USDA Handbook 18, U.S.Government Printing Office, Washington, DC.

UNESCO. 1973. Clasificación Internacional y Cartografía de la Vegetación. Ecology and Conservation. UNESCO. París.

U.S.D.A. 2005. U.S. Department of Agriculture, Natural Resources Conservation Service. National Soil Survey Handbook, Title 430 - VI. http://soils.usda.gov/technical/handbook/

Yager, K., Resnikowski, H. and Halloy, S. 2007. Pastoreo y variabilidad climática en el Parque Nacional Sajama, Bolivia. II Congreso Latinoamericano de Parques Nacionales y otras Áreas Protegidas. San Carlos de Bariloche, Argentina.

.