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# Agriculture adjustment, land-use transition and protected areas in Northwestern Argentina

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ABSTRACT

Land-use change is the main component of regional environmental change, while protected areas represent a direct land use policy to prevent its potentially negative effects on biodiversity and environmental services. We combined an analysis of trends in land use and human demography with trends in creation of protected areas during the last three decades in northwestern Argentina, a subtropical region including a wide range of environments. The eighty nine administrative analysis units of the region were classified into four ecological groups based on their percentage of cover by the six eco-regions of the study area: (1) "Dry valleys"; dominated by Middle-elevation deserts; (2) "Highlands", dominated by High-elevation alpine zones and plateaus; (3) "Humid ecosystems", dominated by Foggy grasslands and Humid forests, and (4) "Dry forests". Between 1970 and 2002, human population became concentrated in urban areas and land use trends varied greatly among the four ecological groups. Agricultural area decreased in the Highlands and increased in the other regions, particularly in the Dry forests. Domestic animals decreased in Humid ecosystems, Highlands and the Dry valleys; and remained constant in the Dry forests. Several protected areas were created, but most of them were established in regions undergoing a decreasing intensity of land use. Overall, the analysis shows that agricultural production is becoming concentrated in the areas more suitable for modern agriculture while marginal agriculture areas and, particularly, extensive grazing are decreasing. The creation of protected areas reflects the decreasing opportunity costs of marginal areas and is failing to protect the eco-regions most threatened by current land-use trends.



## 1. Introduction

Land use change is probably the single most important factor influencing the conservation of natural environments (Vitousek et al., 1997). Patterns of land-use change can be broadly classified into two main categories: 1) expansion of the agriculture frontier, which is a major driver of deforestation and destruction of natural habitats, particularly in tropical and subtropical lowlands where productive soils and growing global demand for food and other agriculture products provide incentives for transforming areas into agriculture; and 2) ecosystems recovery associated to decreasing of intensification of land use in marginal agriculture lands is associated to industrialization and population urbanization. Most conservation science in the neotropics largely assumes that the former trend is the dominant pattern (e.g. Geist and Lambin, 2002; Laurence et al., 2002). However, ecosystems recovery (or "forest transition") is a common pattern in Europe, North America and other developed regions (Mather, 1992; Rudel et al., 2005), and recent publications have reported its occurrence in different neotropical ecosystems (e.g. Rudel et al., 2002; Klooster, 2003; Grau et al., 2003, 2008; Hecht et al., 2006). Since ecosystems recovery may include non-forested eco-regions, the change in land-use trends towards ecosystems recovery maybe broadly called "land-use transition". Current socioeconomic trends including rural-urban migration, the growing importance in the economy of the industrial and service sectors, and the intensification of modern agriculture suggest that land-use transitions leading to ecosystems recovery may become more widespread, having important implications for conservation theory and practice (Aide and Grau, 2004; Wright and Muller-Landau, 2006).

Creation of protected areas is the most straightforward policy aiming to protect biodiversity, watershed quality or recreation landscapes from the threats originated in land use changes.

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Protected areas have expanded worldwide during the last decades (Brooks et al., 2004) in response to perceived current or potential environmental crises. Gap Analysis is a common method for prioritizing the locations of protected areas (Scott, 1993). Gap analysis essentially consists of overlapping maps of protected areas with maps of ecological regions to identify which eco-regions are less represented in the conservation system and thus deserve stronger conservation efforts. Similarly, assessments of the level at which each eco-region is protected are mostly based on the percent of protected area of this eco-region and in the status of these protected areas (Dietz and Czech, 2005).

Generally, these approaches are temporally static (Margules and Pressey, 2000) and do not consider trends in land-use change. But, a region may have few protected areas and might not be a high conservation priority if the threats due to land-use change are decreasing. In addition, the overall assumption that all eco-regions are threatened by a similar trend of increasing land use leads to assessments of levels of conservation at jurisdictional levels (e.g. states or provinces) without reference to regional zonation. Hence, a country or province with a large proportion of its territory under protection may perceive that it needs no new protected areas without considering the level of threat of different eco-regions, even when some of its most threatened ecosystems are not protected.

In this paper we combined an analysis of trends in land use and human demography with an analysis of trends in creation of protected areas during the last three decades in northwestern Argentina. The region includes a diversity of land-use and demographic patterns that vary geographically; and a variety of eco-regions representative of important neotropical biomes: lowland subtropical dry forests, humid mountain forests, middle elevation deserts, high elevation dry plateaus and alpine zones. By combining trends in land use and protection, we provide an example of a dynamic assessment of conservation priorities based on trends in land-use change.

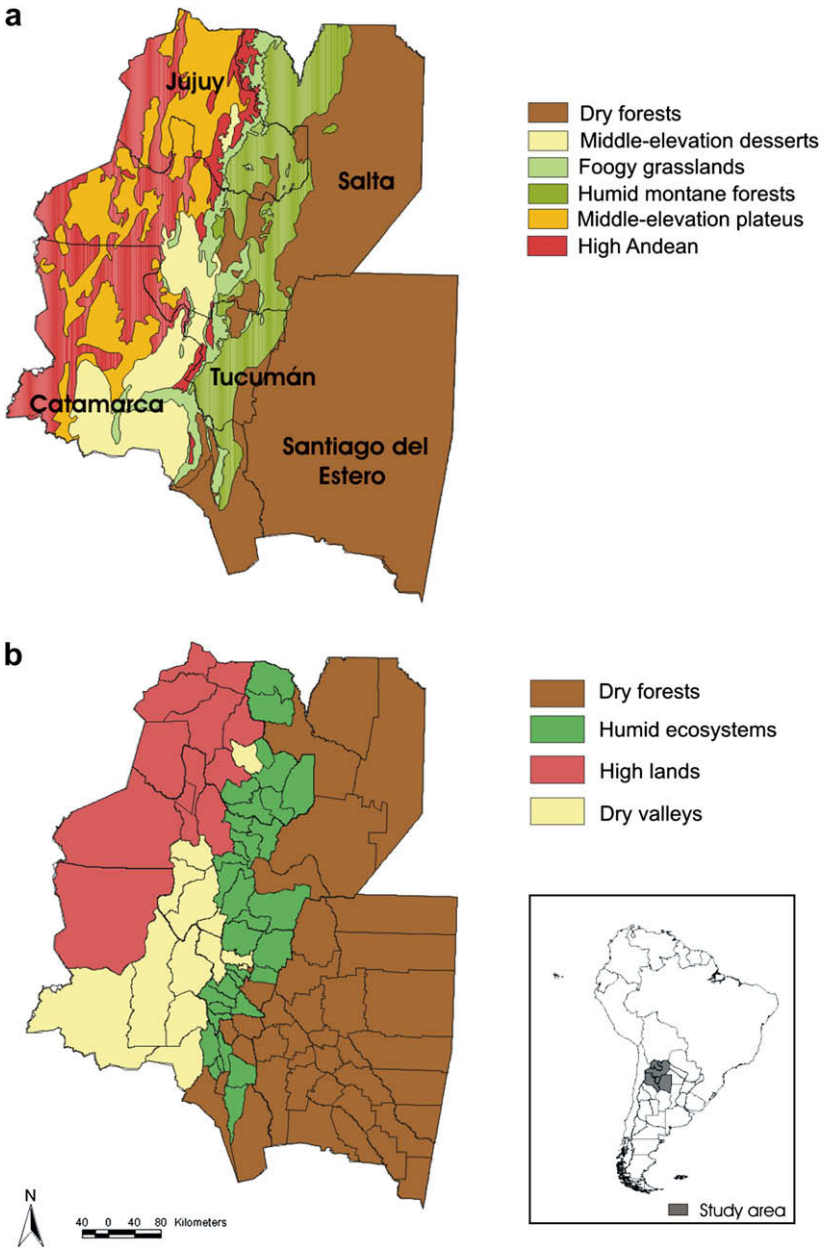


**Fig. 1.** (a) Map of the study area indicating the eco-regions (based on Brown and Pacheco, 2006). (b) Map of the study area indicating the grouping of administrative units based on the Cluster Analysis (ecological groups).

## 2. Materials and methods

### 2.1. Study area

This study focused on the five provinces of northwestern Argentina: Jujuy, Salta, Santiago del Estero, Tucumán, and Catamarca. The area is located between 22°–30° S, and 62°–69° W, and covers 466 362 Km$^2$ (Fig. 1). Argentine provinces are divided into departments, which are the lowest hierarchy administrative units (second order) for which statistical information on population and land use is available. In the present, the five provinces include a total of 96 departments.

The entire region shares the same climatic seasonality (dry winters, rainy summers) but topography, including an elevational range from 300 to almost 7000 m, creates strong gradients in temperature and rainfall (Minetti, 1999). This climatic diversity is reflected in the existence of six eco-regions (Burkart et al., 1999; Brown and Pacheco, 2006):

1) High Andean (*Altoandino*, 73 145 Km$^2$) extends above 4000 m and is characterized by cold temperatures, mesic humidity, and shallow or rocky soils. Vegetation is dominated by bunch grasses and cushion plant communities and it includes barren areas above the vegetation line. This eco-region does not include urban settlements, and human land use is marginal, characterized by extensive grazing.
2) High-elevation plateaus (*Puna*, 54 596 Km$^2$) are dominated by shrubby vegetation in a cold and dry climate (rainfall less than 300 mm/yr), ranging between 3000 and 4000 m of elevation. It has several small towns (less than 3000 inhabitants) and one middle size town with up to 10 000 inhabitants (*La Quiaca*; INDEC, 2001). Land use is characterized by extensive grazing and small family-managed agriculture fields.
3) Middle-elevation deserts (*Monte de sierras y bolsones*, 37 155 Km$^2$) are mostly located between 1000 and 3000 m elevation, with intermediate temperatures and low rainfall (below 300 mm/yr). Vegetation is dominated by xerophytic shrubs and succulent plants, and water-table dependent woodlands in valley bottoms. This eco-region includes several middle-size cities (up to 10 000; INDEC, 2001); land use includes extensive grazing and irrigated modern agriculture (e.g. vineyards, olives, fruit and vegetable orchards).
4) Foggy grasslands (*Pastizales de neblina*, 21 001 Km$^2$) are dominated by grasslands in humid slopes between 2000 and 4000 m of elevation. It includes only minor (less than 2000 inhabitants) townships and land use is largely dominated by extensive grazing with some horticultural development in the valleys (e.g. potatoes, strawberries, garlic).
5) Humid forests (*Yungas*, 54 997 Km$^2$) are dominated by semi-evergreen forests on humid slopes and foothills (above 900 mm of annual rainfall, and below 3000 m elevation). On the slopes, population is scarce, land use is dominated by extensive grazing and selective logging; in the foothills, fertile soils and warm temperatures allow the main agriculture development of the region (citrus, sugar cane, tobacco, horticulture) and the largest urban centers, including three capital cities of more than 100 000 inhabitants and 19 cities of more than 10 000 (INDEC, 2001).
6) Dry forests (*Chaco*, 225 468 Km$^2$) are dominated by deciduous forests over extensive lowland plains and mountains (below

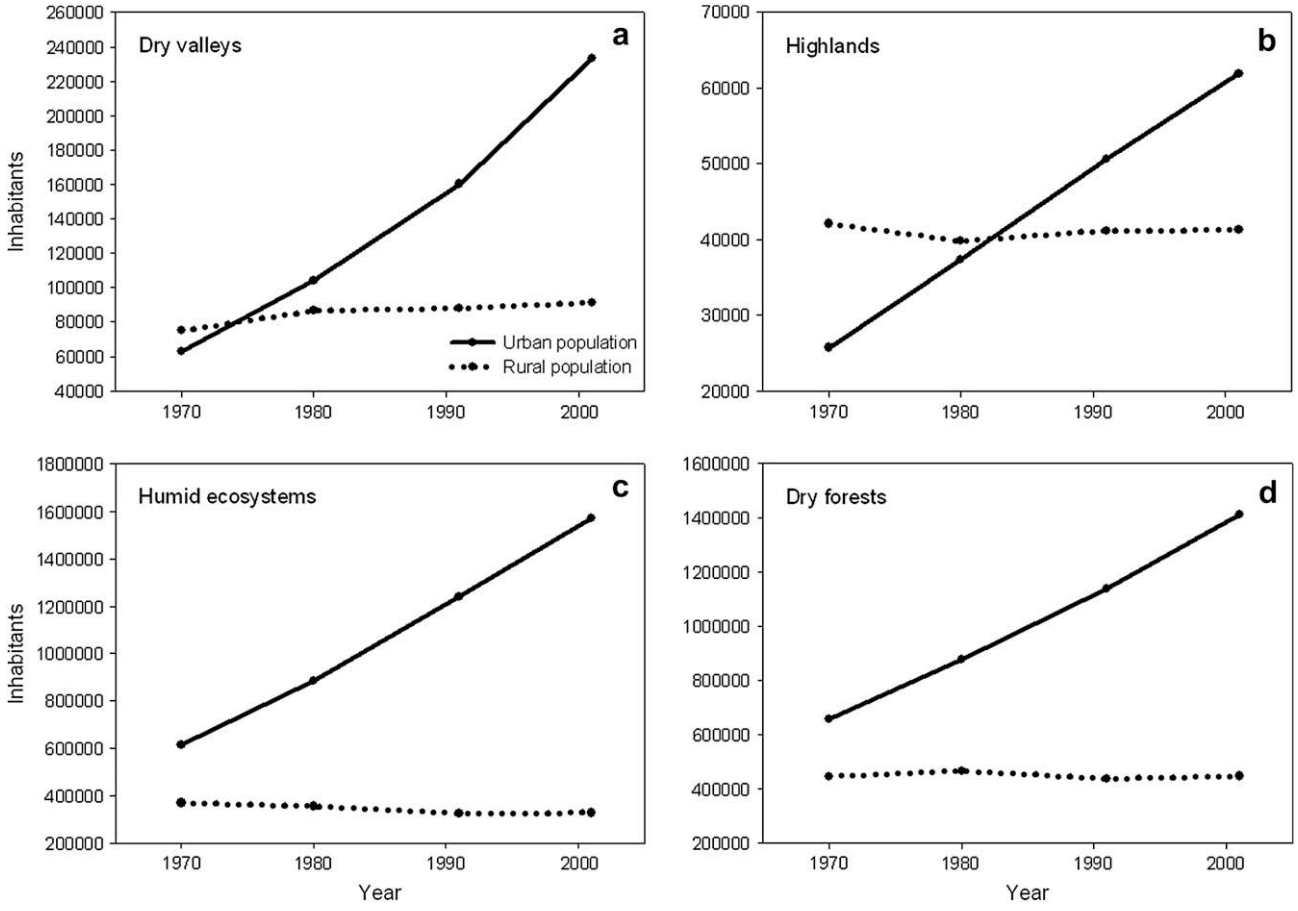


**Fig. 2.** Changes in urban and rural population between 1970 and 2001 in the different ecological groups of administrative units.

1600 m) with arid and semi-arid climates (less than 900 mm of annual rainfall). The eco-region includes two capital cities with more than 100 000 inhabitants and 12 cities with more than 10 000 (INDEC, 2001). Land use includes grazing, some irrigated agriculture, and expanding rain fed agriculture.

### 2.2. Methods

Our analysis combines an assessment of demographic and land-use trends with a description of the trends in protected areas. For land uses analyses we considered agriculture and livestock. Urbanization and water bodies were not included in the analyses since their combined area represents less than 1% of the region. Socioeconomic and ecological data are available and mapped at different spatial resolution, ecological and political boundaries do not coincide, and political boundaries have changed through time. To avoid the later problem we combined the data from the subdivided departments into the original one; the regrouping of the jurisdictions of whole region produced a set of 89 analysis units.

To make the socio-economic data comparable with the eco-regions data, we conducted a Cluster Analysis of the 89 analysis units, based on the percent of area occupied by each eco-region. We used a Hierarchical Cluster Analysis based on Ward's method and distance measure euclidean (Pythagorean), performed by PcOrd, version 4.5, to produce a classification of the department into four "ecological groups". This multivariate approach reflected the degree of similarity between analysis units in terms of their eco-region composition. The areas of eco-regions in each analysis units were calculated based on the eco-regional map of Argentina (Brown and Pacheco, 2006). This map combines historical classifications of biogeographic units (mostly Cabrera, 1976) with recent and more precise satellite-based delimitation of boundaries.

The resulting groups of the cluster analysis were characterized based on their human demography and land use based in the official statistics of the National Censuses. In Argentina, the Censuses are universal and they are made by direct interview. The population censuses collect and compile information on demographic and social aspects of all the inhabitants of the country. Rural and urban populations are divided by the threshold of 2000 inhabitants at any locality. The Farming National Censuses release data on the basic characteristics of the agricultural, cattle and forest activity of the country and use as statistical unit to the "farming operation unit" ("*explotación agropecuaria*") defined as a management unit larger than 500 $m^2$. For the characterization of the ecological groups of the cluster analysis we analyzed the changes in the distribution of population (rural *vs* urban) on the base of National Censuses of Population (INDEC, 1970, 1980, 1991, 2001); and the changes in domestic animals and agriculture area based on Farming National Censuses (INDEC, 1969, 1974, 1988, 2002).

The area under protection was calculated based on the information compiled in Brown and Pacheco (2006) on the location of reserves in Argentina. Protected areas were classified into two categories following IUCN (1994) and Primack et al. (2001): 1) strictly protected areas; and 2) managed areas. Strictly protected areas correspond to IUCN categories I ("Strict Nature Reserve/Wilderness Areas"); II (National Parks); III (Natural Monuments), and IV (Habitat/Species Management Area) and V (Protected Landscape/Seascapes).

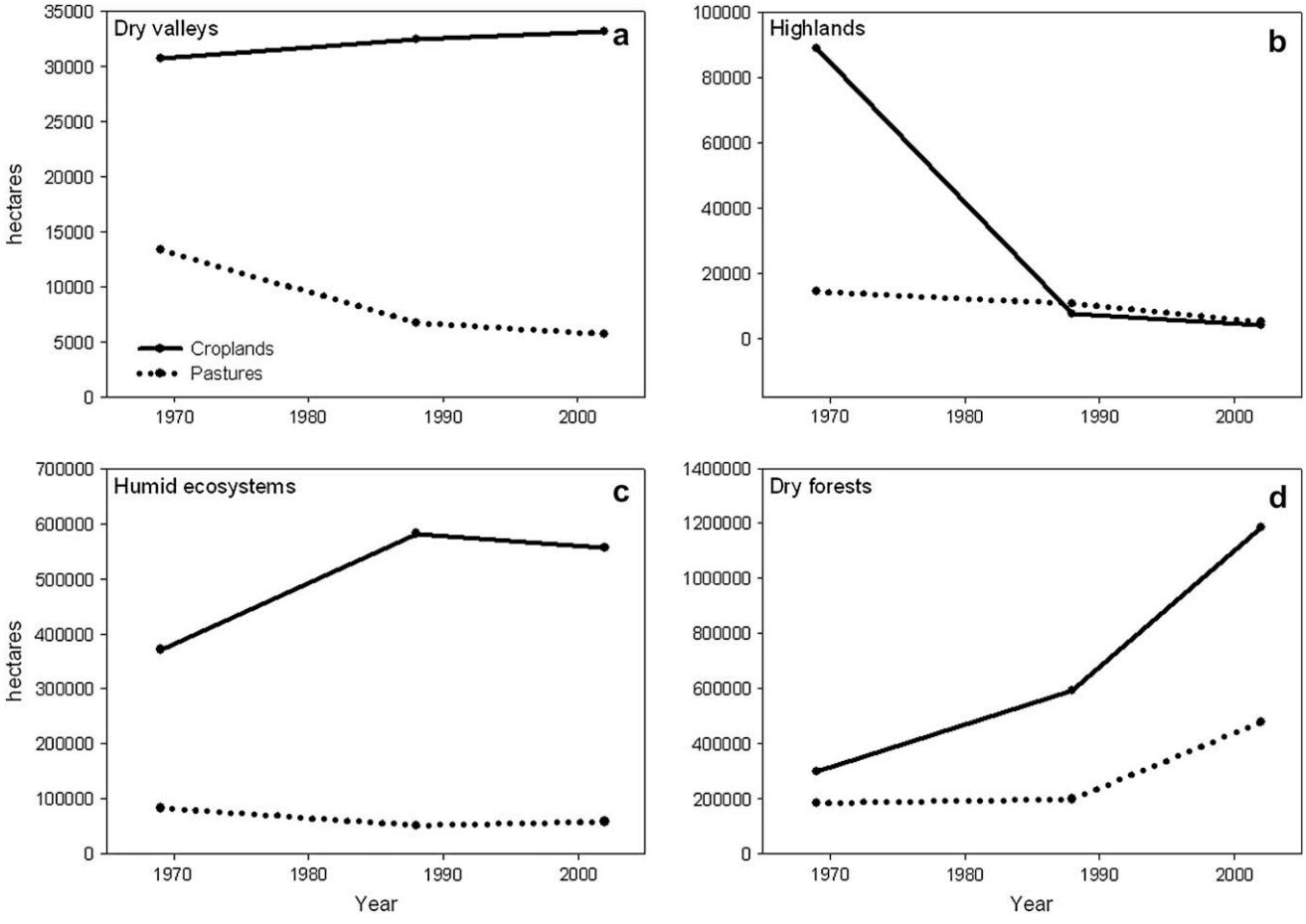


**Fig. 3.** Changes in the area of croplands and pastures between 1969 and 2002 in the different ecological groups of administrative units.

Managed areas correspond to IUCN category VI (Managed Resource Protected Area), which includes, for example Biosphere reserves (IUCN, 1994). We calculated the total area and the area under strictly protected areas and managed areas; including areas of national and provincial jurisdiction for each one of the six eco-regions (i.e. this analysis does not use the ecological groups of administrative units).

To assess the relationship between level of protection and land use trends we combined the analyses conducted for the four ecological groups of administrative units and for the six eco-regions: we analyzed the relationship between the variation in agricultural lands and livestock in ecological groups and the percent of protected area in the dominant eco-regions of each ecological group.

## 3. Results

Between 1970 and 2001, the region experienced a population increase of 1 899 277 inhabitants (83%), which occurred almost exclusively in the cities. Urban population increased by 142% (1 923 609 inhabitants) while rural population decreased by 3% (24 362 inhabitants).

The cluster analysis classified the 89 administrative units into four homogenous "ecological groups" based on their environmental characteristics: (1) "Dry valleys"; include the departments dominated by Middle elevation deserts; (2) "Highlands", include the departments dominated by High Andean and High elevation plateaus; (3) "Humid ecosystems", include the departments dominated by Humid forests and Foggy grasslands; and (4) "Dry forests" include the departments dominated by Dry forests (Fig. 1).

The four ecological groups experienced a strong pattern of increasing urban population (Fig. 2) and decreasing percent of rural population during the study period. In Highlands and Humid ecosystems, the rural population decreased not only in relative terms but also in absolute numbers (Fig. 2b,c).

The changes in agriculture differed among groups (Fig. 3). In the Dry valleys there was an increase in agriculture (Fig. 3a) but it only represents around 0.4% of the total area. The agriculture area increased significantly in the Humid ecosystems, and Dry forest, but in the later only represents 1.26% in 1969 and 5.06% in 2002 of the total area (Fig. 3d). However, while in the Humid ecosystems the agriculture area has remained relatively stable between 1988 and 2001 (Fig. 3c), in the Dry forests agriculture expansion has accelerated through time (Fig. 3d). In contrast, in the Highlands there was a strong decrease in the agriculture area (Fig. 3b). The area of pastures doubled in the Dry forests (Fig. 3d), and decreased in the other three regions (Fig. 3a–c). By the end of the study period the total area under crops and artificial pastures represented approximately 5% of the total area of the region.

The species composition of livestock differed among groups; cattle is the more abundant in the Humid ecosystems and Dry forest; goats in the Dry valleys and sheep in the Highlands. In the Humid ecosystems all the domestic animals decreased during the study period (Fig. 4c) and both the Highlands (Fig. 4b) and the Dry Valleys (Fig. 4a) experienced a net decrease in their dominant domestic animals (sheep and goats respectively). In consequence, in these three regions, the total domestic grazers showed a net decrease. In the Dry forests, livestock decreased between 1974 and

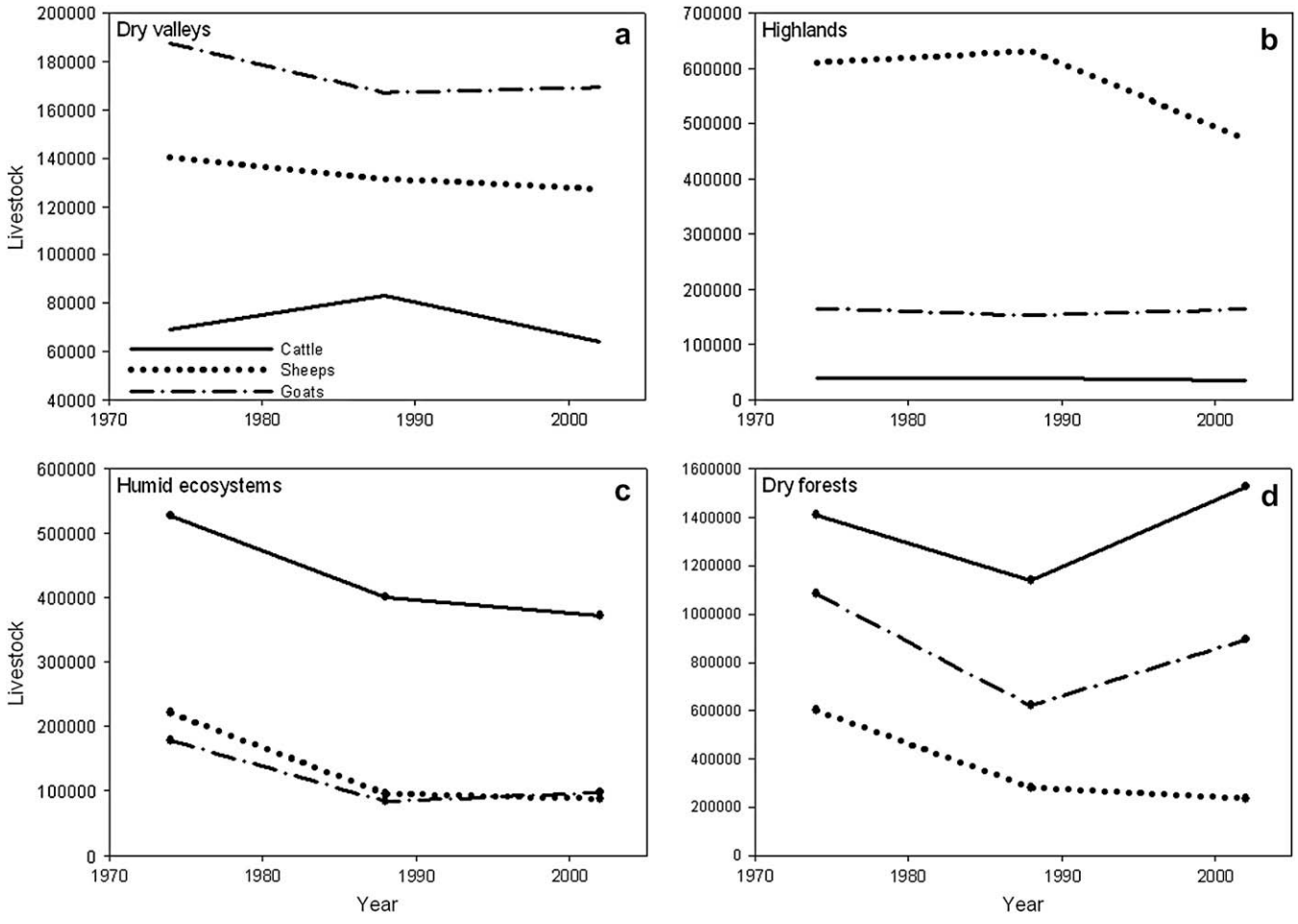


**Fig. 4.** Changes in main livestock between 1969 and 2002 in the different ecological groups of administrative units.

1988, but recovered during the last decade to a similar total number in 2001 as in 1974 (Fig. 4d).

The different eco-regions of the Northwest of Argentina differ in the percentage of protected area, although the entire region experienced a steep increase in protected areas since the early 1970s (Fig. 5). Total protected areas expanded in the High Andean and High-elevation plateaus, the Humid forests and Foggy grasslands; that is, in the eco-regions that dominate the ecological groups Highlands and Humid ecosystems. In contrast, in the Dry forests, the level of protection remained minimal and in the Middle-elevation deserts, despite an increase in protected areas at the end of the period, they never reached 2% of eco-region area (Fig. 5a). Strictly protected areas (categories I–V of IUCN) were concentrated in the Humid forests; and were less than 1.5% in the other eco-regions (Fig. 5b).

There is a generally negative relationship between the degree of protection of the eco-regions and the level of threat due to changes in land use intensity in the corresponding ecological units (Fig. 6). Highlands have the lowest levels of threat; since they have decreasing agriculture and livestock, and its dominant eco-regions (High-elevation plateaus and High Andean) have the highest percent of managed protected areas (Fig. 6b,d). Middle-elevation deserts, Humid forests and Foggy grasslands showed increases in strictly protected areas, while density of domestic animals decreased in Dry valleys and Humid ecosystems, the ecological groups that are dominated by these eco-regions (Fig. 6a,c). In contrast, Dry forests, that experienced the largest threat due to increasing agriculture and constant livestock, are the ecological group with the lowest level of protection (Fig. 6).

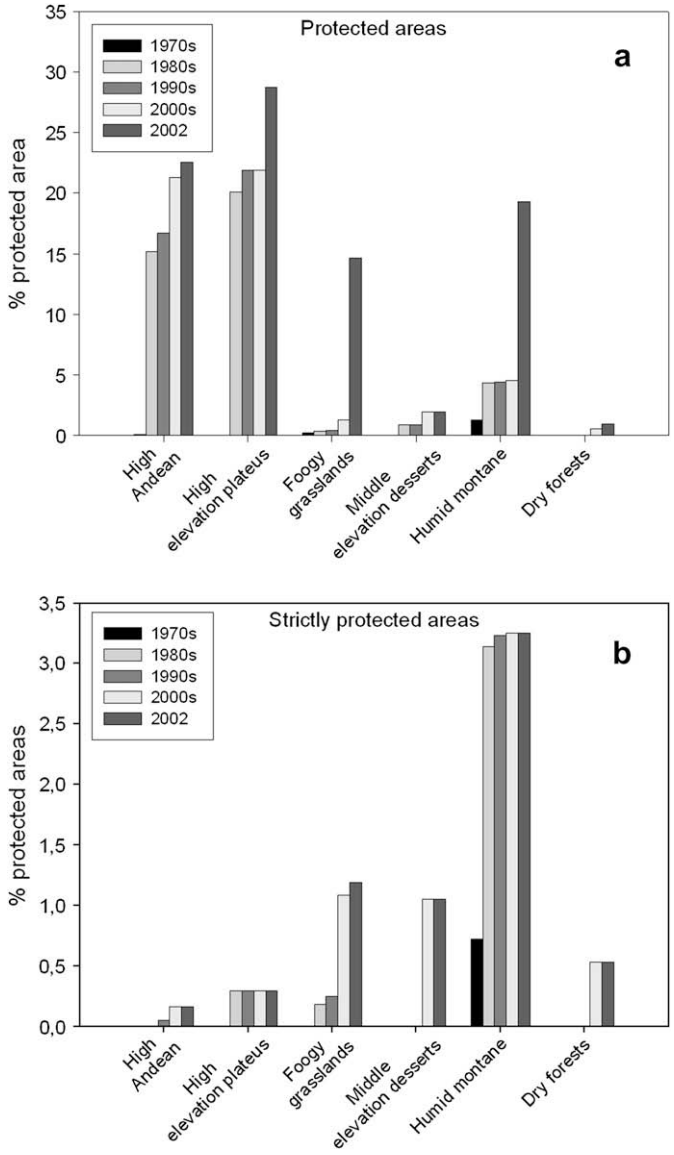


**Fig. 5.** Percentage of total protected areas (a) and strictly protected areas (b) in the different eco-regions.

## 4. Discussion

The analysis of the land-use patterns in northwestern Argentina reflects two contrasting trends in land-use change: land use disintensification and expansion of modern agriculture frontier. These different trends are related to the environmental heterogeneity of the region.

High elevation ecosystems (*Puna* and *Altoandino*) are experiencing a decrease in both grazing (Fig. 4b) and agriculture (Fig. 3b), associated with a reduction in rural population (Fig. 2). This pattern is consistent with the trend toward land abandonment associated with globalization observed in other mountain regions in Latin American (Aide and Grau, 2004; Grau and Aide, 2007), where marginal agricultural practices cannot compete with large-scale modern agriculture and rural job opportunities cannot compete with the off-farm job market; thus favoring the rural-urban migration. In consequence, these ecosystems are hardly threatened by land use, and native wildlife populations such as the once severely endangered vicugnas, now show clear signs of recovery (Vila, 2006).

In contrast, land use appear to be a growing threat to natural ecosystems in the Dry forest (*Chaco*), where the expansion of agriculture frontier (Fig. 3d) is the main cause of increasing deforestation (Grau et al., 2005; Boletta et al., 2006), and domestic animals populations have remained high (Fig. 4d). This process is similar to patterns described in other seasonally dry forests of South America (e.g. Fearnside, 2001; Steininger et al., 2001); making dry forests the most threatened mayor neotropical biome (Janzen, 1988).

The Humid ecosystems and High-elevation deserts show a combination of both patterns: intensification of land use in the fertile lowlands and decreasing land use intensity in the steep marginal areas. In the Humid ecosystems (*Yungas*), agriculture production expanded almost exclusively in the lowland premontane sector, associated with modern technologies in a process that began with the conversion of forest into sugar cane and citrus crops; and is currently reflected in the expansion of soybean (Grau and Brown, 2000). In the Middle-elevation deserts (*Monte*), modern agriculture showed some minor expansion in valley bottoms, in association with modern irrigation systems. In both ecological groups according to our results, domestic animals, the dominant type of marginal land use is decreasing (Fig. 4a,c) likely reducing human impact on montane forests, foggy grasslands, and non-irrigated deserts.

These patterns imply that the whole region is undergoing a land-use transition, including a process agriculture adjustment (*sensu* Mather and Needle, 1998), in which agriculture production is becoming concentrated in areas with productive soils in flat areas which are highly suitable for modern technology; and a reduction in land use intensity in marginal agricultural lands due to topographic and climatic factors, potentially allowing ecosystems recovery (Aide and Grau, 2004).

The trends in protected areas indicate there has been a rapid increase in the number and area covered by reserves during the last decades (Fig. 2), which is consistent with the global trend (Brooks et al., 2004; WDPA, 2003). However, the majority of these protected

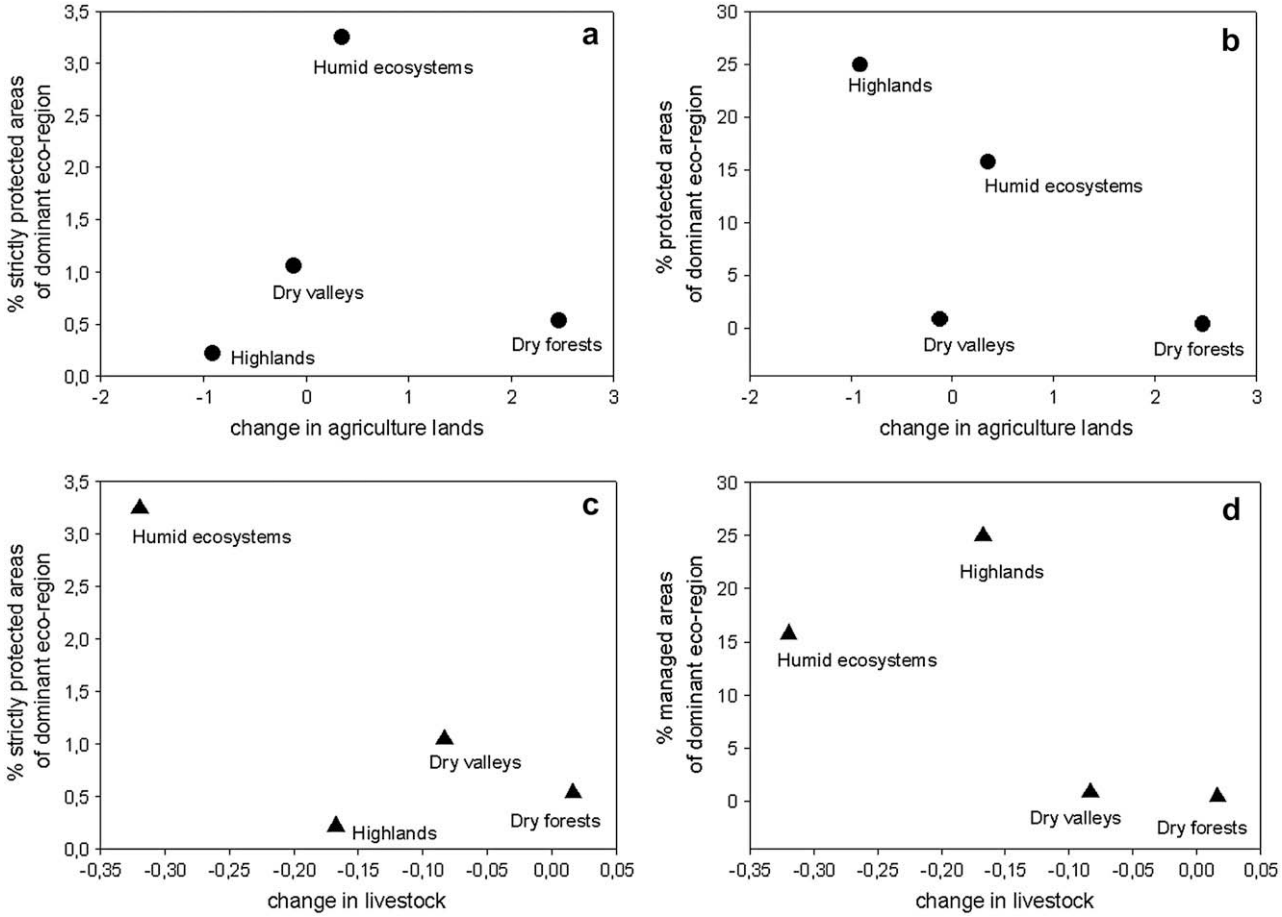


**Fig. 6.** Relationship between change in agriculture lands (a, b) and pasture lands (c, d) in the ecological administrative units vs. percentage of total protected areas (a, c) and percentage of management protected areas (b, d) in the dominant eco-regions of each ecological administrative units.

areas have been established in mountainous and high elevation ecosystems, which are not undergoing an intensification of land use. Hence, the substantial increase in protected areas in the region has failed to protect the eco-regions more severely threatened by land use change such as the Dry forests.

Great efforts have been put into the development of methods to identify areas of high conservation interest. Reserve selection algorithms, gap analysis and other computed approaches have much potential to influence conservation planning (Prendergast et al., 1999). Of these approaches, gap analysis appears to offer most practical guidance for designing protected areas. However, the use of any methods for the selection of protected areas is commonly subordinated to other factors. Protected areas are typically located in remote place and other areas that are unsuitable for commercial activities (Margules and Pressey, 2000), and the eco-regions with highest level of conversion to agriculture tend to have lower levels of protection (Hoekstra et al., 2005). Both patterns are consistent with the trends in NW of Argentina, where conservation efforts have been stimulated for the perceived need to preserve landscape with high scenic value (in the case of high elevation ecosystems) and to preserve biodiversity and watershed quality (e.g. in humid montane forests and foggy grasslands); but part of their success may be due to the reduced level of conflict with other land uses, since they are located in areas where there is a spontaneous trend toward decreasing land uses.

Previous studies using a Gap-analysis approach in the region have identified dry forests and foothills as the priority areas for conservation (Vides-Almonacid et al., 1998). Dry forests have the lowest level of protection and in the Humid ecosystems, although the percentage of area under protection is the largest of the eco-regions considered in this study (Fig. 5), the creation of protected areas has occurred mostly in the sectors montane forests and foggy grasslands, while in the flat foothills where agriculture has expanded, there is almost no area under protection (Brown et al., 2002). In the high elevation deserts, newly created protected areas have also failed to protect the ecosystems threatened by irrigation agriculture, mostly located in the valley bottoms.

## 5. Conclusions

The patterns of land-use change in northwestern Argentina show a process of agricultural adjustment, characterized by a concentration and expansion of agriculture in fertile flat areas suitable for modern agriculture, while marginal areas are undergoing a reduction in land-use intensity associated to decreasing rural population. There has been a trend of increasing protected areas during the last decades, but the new protected areas are in the eco-regions least threatened by land-use change. Our analysis show that the analysis of trends in land-use change provides important additional information to classic gap analysis, and that these trends should be used to prioritize conservation efforts.

The diversity of environments that characterize much of the tropical regions where mountains generate strong climatic gradients, imply that current socioeconomic trends may lead to different and contrasting pathways in the threats to the environment. The example of NW Argentina is likely to be representative of regions that combine environments that are suitable for modern intense agriculture (and therefore are likely to become increasingly

threatened) with environments that are marginal for modern agriculture, and therefore they may tend to be abandoned as rural inhabitants migrate to urban areas (Aide and Grau, 2004). The discrimination between these trends, as in this case study in NW Argentina, should play a role in prioritizing conservation efforts and designing regional conservation policies.

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