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KEY AREAS FOR CONSERVING THE AVIFAUNA OF *POLYLEPIS* FORESTS

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Resumo. Áreas claves para la conservación de avifauna de los bosques de *Polylepis*. El articulo analiza las prioridades para minimizar la perdida global de biodiversidad utilizando una base de datos con distribuciones de 670 especies de aves que habitan las zonas elevadas andinas, donde el *Polylepis* puede crecer. El análisis esta basado en el ordenamiento total de las especies y de las 51 especies que son particularmente especialistas de bosques de *Polylepis*. Los especialistas muestran un patrón geográfico distintivo de agregación, con dos picos principales de endemismo en la Cordillera Blanca/Lima y Cuzco/Apurímac en el Perú, y un pico algo menos marcado al borde norte de la cuenca de Cochabamba en Bolivia. Basado en la complementariedad de las distribuciones de especies, el plan mas eficiente en términos de área para la reducción del riesgo de extinción global, deberá enfocarse en estas áreas (las quales conjuntamente contienen poblaciones del 48% de todas las especies de aves altoandinas amenazadas o cercanamente amenazadas que habitan entre 0 y 30°S). Con el fin de cubrir todas las especies de aves adaptadas a los bosques de *Polylepis*, se necesitan acciones en cuatro áreas adicionales de la región Andina. También se presenta un plan de conservación mas realista para múltiples representaciones de cada una de las especies. La Cordillera Blanca se encuentra formalmente protegida, pero es una seria limitación para la implementación del plan completo de conservación, que las áreas biológicamente mas únicas soporten densas poblaciones rurales. Es por lo tanto dificultoso prevenir la extinción de especies sin suplementar las reservaciones tradicionales con incentivos para majorar el uso de tierras.

Abstract. The paper analyzes priorities for minimizing global loss of biodiversity using a database with distributions of 670 species of Andean birds inhabiting the elevational zones where *Polylepis* can grow. The analyses are based on the total species assortment and 51 species that are particularly characteristic of *Polylepis*. The *Polylepis* specialists show distinctive geographic patterns with a high degree of nestedness, with two principal peaks of endemism in Cordillera Blanca/Lima and Cuzco/Apurímac in Peru, and a somewhat less marked peak along the northern edge of the Cochabamba basin in Bolivia. Based on the complementarity of species distributions, the most area-efficient plan for reducing risks of global extinction should focus on these areas, which altogether contain populations of 48% of all threatened and near-threatened highland birds living at 0–30°S. In order to cover all *Polylepis*-adapted birds, actions are needed in four additional areas in the Andes. Also, a more realistic conservation plan for multiple representations of all species is presented. Cordillera Blanca is formally protected, but it is a serious constraint on implementing a full conservation plan that the biologically most unique areas support dense rural populations. It is therefore difficult to prevent species extinctions without supplementing traditional reserving with incentives to better land-use. *Accepted 03 June 2002.*

Key words: Polylepis *forest, conservation, birds, South America.*

INTRODUCTION

Polylepis forests represent oases of life in the monotonous Andean grasslands and semi-deserts (Fjeldså & Kessler 1996). However, as a consequence of the chronic overgrazing and burning of most highlands, this habitat is now extremely patchy, as is the distribution of the associated species of animals and plants. This land degradation significantly reduces species richness in large parts of central Peru (montane basins of the upper Huallaga Basin and from Junín to Apurímac and in the humid parts of the *puna*) and in Bolivia on the transition between the southern *valles* and the *altiplano* (Fjeldså 2002a, b). Species that are narrowly associated with *Polylepis* forests may have an unfavourable conservation status, in general, and a number of these species are formally listed as endangered or vulnerable (Stattersfield & Capper 2000).

With reference to the Convention on Biological Diversity, many national and global conservation strategies focus strongly on areas that are exceptionally rich in species. Unfortunately, identification of relatively broad zones ("ecoregions," "hotspots") with high biodiversity means that areas with much higher

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extinction risks are often neglected. Within climatically favorable zones, high species richness is often a simple consequence of high landscape complexity and dynamism. Thus the exceptional species richness of the humid slopes of the tropical Andes region reflects a combination of humidity, relief, and high landslide activity, where local patch-dynamics and high species turnover in time and space translates into high beta and gamma diversity. This region was identified as a target area for massive conservation efforts (Olson & Dinerstein 1998, Myers *et al.* 2000), which is good *per se*, but bad if it leads to lack of interest in some of the most threatened biological communities, which are found in montane basins with dry forest or more or less isolated cloud-forest patches, just outside the humid zone. The problem is that these areas are very localized, and difficult to identify and precisely define unless a large effort is made to compile species data. It is argued that the focus on large areas with specific characteristics may help us to maintain important processes. However, these processes are defined in very vague terms, or *ad hoc*, to justify decisions that were actually political. Qualitatively unique biological communities that lie outside the target ecoregions also relate to important processes (discussed by Fjeldså *et al.* 1999a, b). The validity of the argument is therefore unclear (Goldstein 1999).

The core of the problem is whether we want to maintain the biologically richest areas relatively intact, or whether we want to minimize the risks of global extinctions. I will adopt the view here that conservation strategies must first of all consider how global extinctions can be minimized with limited resources; that is, how all species, including those at risk, can be conserved at the lowest cost.

Computer-based techniques for effective area selection, based on patterns of between-site complementarity, are now well developed and may greatly boost the efficient representation of all mapped species, and not just endemics targeted in preselected sites (Williams 1998). The methodology also allows planners to identify sites which most efficiently fill in gaps in the existing reserve network, to justify the choice of particular sites, to determine the flexibility of site selection, and to balance conservation efficiency against development plans, human population, etc. (Balmford *et al.* 2001).

The present analysis is based on birds as a highly valued part of the biodiversity. Priority sites for conservation of *Polylepis*-adapted birds were already suggested by Fjeldså (1993), but this attempt was based on manual data handling. I will now refine these analyses using computerized distribution data of birds, which is the only group mapped in sufficient detail for this purpose. Plant data certainly give more complex patterns (sensitive to, for instance, local soil type variation). Also mammal data suggest considerable local endemism (Yensen & Tarifa 2002), but this could to some extent be an effect of incomplete sampling (as would the bird data that were available few decades ago). For the sake of this analysis I assume that the bird data represent a suitable proxy for describing large-scale patterns of biodiversity in a wider sense.

MATERIAL AND METHODS

The datasets used in this study have been compiled as part of a comprehensive effort to map bird distributions in the Andes (Fjeldså & Rahbek 1998, Fjeldså *et al.* 1999b, Fjeldså 2000). The data are particularly well suited for the present analysis because of the special efforts made (especially in 1987, 1989, 1991, 1997) to document the biodiversity of *Polylepis* forests. Primary data sources are reviewed in Fjeldså & Krabbe (1990) and Fjeldså & Kessler (1996), but new data are being incorporated as an ongoing process through contact with numerous birders. The most relevant new data sources are compiled by Stattersfield & Capper (2000) and in reports from several national parks along the eastern Andean ridge, and from Cordillera Huayhuash, Ancash/Lima boundary (Maynard & Waterton 1998), the Cotacajes Basin on the La Paz/Cochabamba boundary (Fjeldså *et al.* 1999a), Cuzco area (T. Aucca, pers. comm.), and southern Peru (T.E. Høgås, in litt.).

All distributional data (altogether 80,000 confirmed records) have been computerized using the WORLDMAP software (Williams 1992), a PC-based graphical tool designed for fast, interactive handling of distribution data for large numbers of taxa. This provides us with more powerful analytical tools, making it possible to rapidly explore the consequences of various area selections, as well as information about existing protected areas and conflicts with other interests, where such can be obtained.

The primary database was trimmed to include only 670 species that are well established, at least locally, at altitudes where *Polylepis* may grow. This is above approximately 2500 m in most parts of the tropical Andes region, but considerably higher in the northern Andes, falling to 2000 m at the southern end of the study area. In this database I tagged, for separate analysis, (1) all 214 species known to visit *Polylepis* zones, at least locally or sporadically, (2) 51 species which typically inhabit *Polylepis* zones, and (3) 14 genuine specialists, which are only rarely recorded away from *Polylepis* (*Chalcostigma stanleyi*, *Upucerthia serrana*, *Cinclodes aricomae**, *Leptasthenura pileata*, *L. xenothorax**, and *L. yanacensis**, *Asthenes (dorbignyi) arequipae*, *Grallaria andicola*, *Anairetes alpinus**, *Poospiza alticola**, and *P. garleppi**, *Xenodacnis parina*, *Oreomanes fraseri**, and *Carduelis crassirostris*; asterix shows endangered and vulnerable species, Stattersfield & Capper 2001).

The distributional data were entered in a geographic projection grid of one-quarter degree (15'x15', or 729 km^2 at the equator), a compromise between sampling unevenness and the need for a resolution fine enough for conservation planning. In order to reduce the sampling bias, range maps were made by interpolation within areas of uniform macrohabitat. Assuming uniformity of habitat in many parts of the Andean highlands and the potential for (re)colonization and connectivity of populations, I consider this a realistic approach. The existence of suitable habitat in the individual grid cells was determined using numerous topographic and ecological maps and satellite imagery (e.g., *Mapas Planimetrico de Imagines de Satelite* 1:250000 for Peru, LANDSAT scenes and GIS data available on the internet) and a detailed knowledge of the distribution of *Polylepis* patches (Kessler 1995, Fjeldså & Kessler 1996). The interpolation was conservative and distributional gaps were included where a species was not recorded in well-researched sites with appropriate macrohabitats, and for the least common species only confirmed records were used.

'Near-minimum sets' of target areas for conservation are identified using a heuristic search option for complementarity of areas and a redundancy back-check. Complementarity explicitly describes the degree to which an area contributes otherwise unrepresented taxa to a set of areas (Humphries *et al.* 1996, Pressey *et al.* 1996, Williams *et al.* 1996). A minimum set is the smallest number of grid–cells that covers all taxa – per definition the most area-effective approach for conservation planning.

Additional information, for example on population viability and conflicts with other interests, are needed for making a realistic conservation plan. The planning of actions on the ground must involve detailed mapping and inventories of woodland patches and local land use patterns, but this falls outside the scope of this paper.

I will explicitly examine how well a priority-analysis focused on the *Polylepis*-adapted birds would cover the total avifauna of the region, and on the 57 species (in highlands at 0–30°S) that are currently listed as endangered and vulnerable. Threat risks are now based on standardized criteria of the extent of a species' occurrence or changes in its populations or habitat (Mace 1994). I also examined what are the most important target sites covering taxa that are not already "safe" in national parks and areas of similar status. Here I require that one-third of a grid-cell, or at least the biologically most important part, is formally protected. Altogether 300 15' cells were pre-selected as protected, but most of these are in the lowlands and only 50 have *Polylepis*.

RESULTS

The species richness pattern for Andean birds is described in some detail in Fjeldså *et al.* (1999b) and Fjeldså (2002b), and the richness of *Polylepis*-adapted birds is described by Fjeldså (2002a). It will suffice here to mention that species richness is highest on the humid Andean slopes, especially those towards the Amazon basin, but that these slopes have few species that are specifically adapted to *Polylepis*. Such species are also poorly represented in the northern Andes and in the arid highlands in the far south. *Polylepis*-adapted birds are best represented in Peru, where there are marked peak concentrations around the upper Marañón valley and Cordillera Blanca over to the western slope in Lima, in the montane basins of Apurímac and Cuzco, and somewhat less in the transitions between montane basins and high plains in Bolivia, notably around the Cochabamba Basin (Fjeldså 2002a).

Minimum set of areas. The analysis presented here is based primarily on 51 species that were considered typical of *Polylepis* forests (listed in Fjeldså 1993 and Fjeldså & Kessler 1996). However, all species are taken into account when it comes to measuring the overall efficiency of a conservation plan guided by distributions of *Polylepis*-adapted birds.

A complementary analysis of distributions of the 51 typical birds of *Polylepis* forest shows that these can be covered in seven 15' cells (Fig. 1a). A cell at Tiraque east of Cochabamba town, Bolivia, includes rainshadow areas south of the watershed as well as humid *ceja de monaña* north of it (in P.N. Carrasco, eastern Cochabamba), and therefore has altogether 250 species, six of them goal-essential (otherwise unrepresented in the minimum set), eight threatened and near-threatened. A cell at Abancay in Apurímac, Peru (which includes Bosque Ampay to the west, and the eastern edge of the Runtacocha highland to the east), covers 138 species, eight goal-essential, nine threatened. A cell in Cordillera Blanca (immediately above Chavín de Huantar) covers 118 species, seven goal-essential, nine threatened.

A cell with the city of Arequipa and the Volcán Misti slopes covered 77 species, three otherwise goal-essential. Three other cells (Río Mazán near Cuenca, La Paz and the ridge north of Jujuy; Fig. 1a) were needed to "capture" single species (*Metallura baroni**, *Poospiza baeri**, *Leptasthenura aegithaloides*; here the computer simply chooses the first cell in the numerical sequence of those where these respective species occur). These four areas are rather unimportant in terms of threatened and near-threatened species.

Pre-selecting these areas in the main database can assess the overall value of this minimum set of seven grid-cells. They cover altogether 415 (62%) of the total of 670 species, and 27 (47%) of the threatened and near-threatened species. The first-mentioned three cells cover altogether 380 (57%) species, of which one is Critically Endangered, six are Endangered, five Vulnerable, and eight near-threatened.

The residue of "unprotected" species comprises mainly the waterbirds and birds of the humid montane forest zones (except the Bolivian *yungas* species which are included in the Tiraque-Carrasco cell). Twenty-two *puna* birds, which are "unprotected" are mainly species of the arid highlands in the south.

Multiple representations. It is not likely that seven 15' cells contain viable populations of all 51 *Polylepis*-adapted birds, or of all 415 species that are represented. Renewed analyses were made with 2, 3, 4, and 5 representations of each species, still based on a complementarity algorithm (Fig. 1b).

This shows that there are several almost equally good areas adjacent to the three top-priority cells: in Cordillera Blanca, Abancay over to the adjacent high mountains west and northwest of Cuzco (Cordilleras Vilcabamba and Vilcanota), and along the northern margin of the Cochabamba Basin. The whole Cajas highland (including Río Mazán, Fig. 1a) is identified as important (mainly because of one species, *Metallura baroni**). Areas needed to pick up the remaining species are rather scattered: Huamachuco in La Libertad, upper Sta Eulalia and Cañete Valleys in Lima, Puquio in western Ayacucho, areas near Arequipa and Tacna, Sorata, el Pongo and Inquisivi in La Paz, Azurduy in Chuquisaca, and some escarpments above Jujuy, Salta and Tucumán in northern Argentina. These choices are somewhat unstable, and several sites along the southern edge of the Peruvian highlands, and along the eastern Andean ridge in northwestern Argentina, are almost equally good.

The 42 cells cover altogether 533 (80%) of the total of 670 species in the main database and 34 (60%) of the threatened and near-threatened species found at 0–30°south. The residue of "unprotected" species comprises mainly birds of the humid eastern ridge of the Andes, and some birds of the southern humid *yungas* slopes, and a few waterbirds. Twelve threatened and range-restricted landbirds of less humid slopes and montane basins were not accounted for: *Penelope barbata** and *P. dabbenei*, *Amazona tucumana*, *Myiopsitta (monachus) luchsi*, *Aglaeactis aliciae**, *Loddigesia mirabilis**, *Ochetorhynchus harterti*, *Asthenes huancavelicae**, *Siptornopsis hypochondriacus**, *Scytalopus zimmeri*, *Atlapetes melanops**, and *Lophospingus griseocristatus*. Only five *puna* birds were not accounted for: *Pterocnemia garleppi**, *Geositta saxicolina*, *Cinclodes palliatus**, and *Phrygilus dorsalis*, and *P. gayi*.

Gaps in the protected areas network. Polylepis forests were not given much attention in the national strategies for conservation; although some were incidentally included because they are found in high mountains that are of interest because of their scenic beauty (such as P.N. Huascarán in Cordillera Blanca). In order to identify where extra conservation investments are most urgently needed, areas which are already well protected (mainly as national parks) were pre-selected in the database, which means that all species recorded in one such cell are considered as being protected there. However, cells where the *Polylepis*-adapted birds are definitely restricted to areas outside the park were not pre-selected, and this also applies to some small and poorly functioning reserves which do not today provide effective protection for the birds of that grid-cell, like P.N. Tunari in Bolivia and P.N. Ampay in Peru.

The pre-selected protected areas network does not include populations of *Cranioleuca albiceps*, *Cinclodes aricomae**, *Atlapetes forbesi*, or *Poospiza garleppi**, but the remaining *Polylepis*-adapted species are covered at least once. In order to achieve an adequate protection (e.g., five areas for every species) extra conservation efforts are needed on the Cajas plateau in Cuenca (for *Metallura baroni**), in valleys east of P.N. Huascaran (for *Zaratornis stresemanni**, *Atlapetes rufigenis**, and *Poospiza alticola**), in the mountains around Abancay, and in the adjacent Cordilleras Vilcabamba and Vilcanota in Cuzco (for *Cinclodes aricomae**, *Leptasthenura xenothorax**, *Asthenes virgata*, unnamed *Scytalopus sp.*, *Anairetes alpinus**, and *Atlapetes*

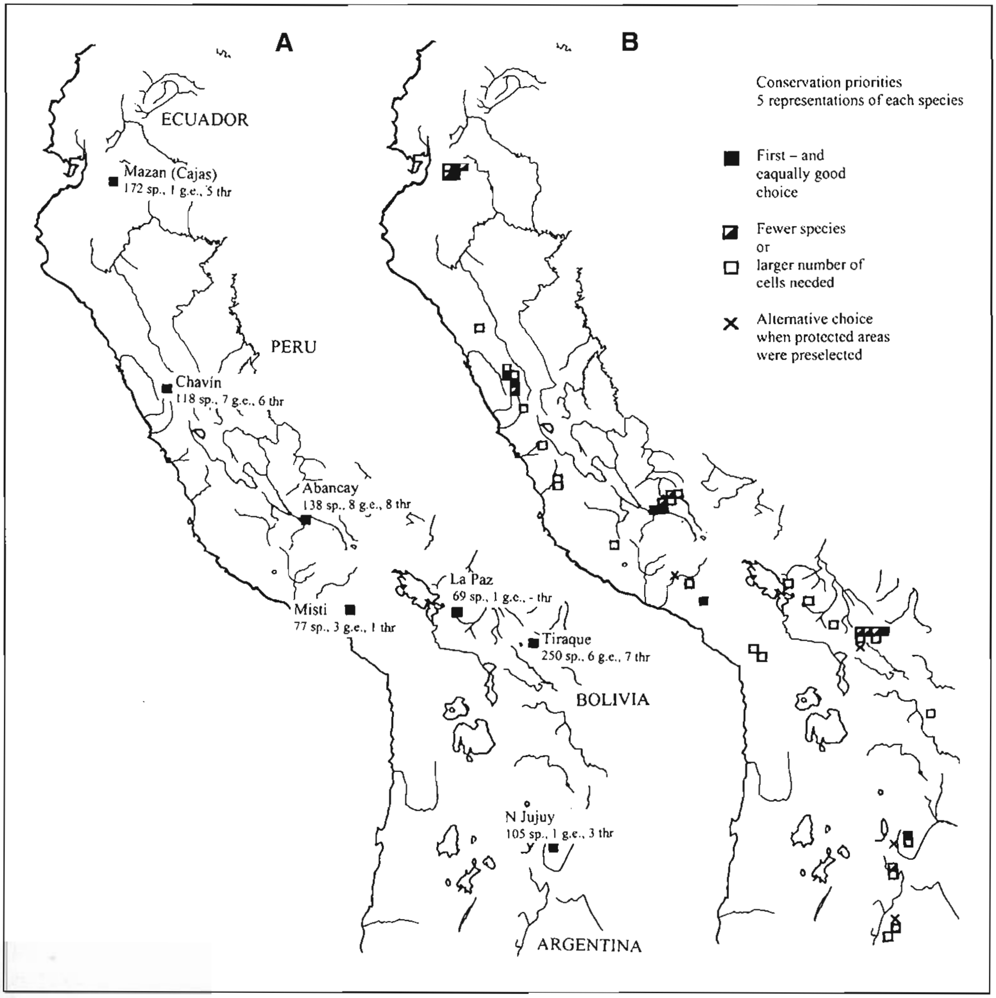

FIG. 1. Near-minimum sets of 15'x15' cells for representing all 51 *Polylepis*-adapted birds. A: a single representation of each species, the figures represent the number of goal-essential species (i.e., those not represented in another cell) and the total representation of the 670 species (sp.) and 61 threatened and near-threatened species (thr) in the regional highland avifauna. B: five representations of each species; here filled symbols are the first choice areas (as in A) and equally good alternatives, half-filled symbols also capture all goal-essential species but a lower total number of species; open symbols are additional areas needed in order to capture all species five times. x marks alternative choices when areas, which are already protected, are pre-selected.

*forbesi**), along the northern edge of Cochabamba Basin (for *Asthenes heterura** and *Poospiza garleppi**) and more areas near Jujuy, Salta and Tucumán (for *Asthenes steinbachi** and *Poospiza baeri**).

DISCUSSION

The uniformity of the Andean highlands, and wide distributions of many highland birds, gives a high autocorrelation in the dataset. In other words, many areas may be more or less equally good conservation targets. So for instance along the western edge of the *puna* zone in southern Peru definite top priority sites are difficult to identify, and conservation decisions should therefore involve criteria other than distribution data, such as access, costs, land-use conflicts, precise location of forest patches which it is feasible to protect, and opportunities for income from tourism, in addition to biological data. In other districts, highly aggregated distributions of endemic and endangered species means low autocorrelation, and a strong possibility of defining precise areas that are essential for reaching the goal of conserving all species. A highly focused conservation strategy is possible here.

The three top priority grid-cells (Fig. 1a) cover 51% of all species in the region, and 47% of those that are now considered threatened and near-threatened (Stattersfield & Capper 2000). A concentration of effort in these areas represents an exceptionally effective means of conserving biodiversity in the Andes. This can be illustrated by considering that a complete plan for all 670 birds included in the present dataset would comprise 35 cells, of which the most important are the three above-mentioned cells plus Cajanuma (western P.N. Podocarpus in Loja, Ecuador, with nine goal-essential species), Cordillera Colán (Amazonas, Peru, six goal-essential), Cocapata (northern Cochabamba, Bolivia, six goal-essential), foothills east of Padilla (Chuquisaca, six goal-essential), and Cerra Aconquija (Tucumán, Argentina, eight goal-essential species). A minimum set for the entire avifauna of the tropical Andes region and adjacent foothills and lowlands would comprise 80 15'-cells (Fjeldså & Hjarsen 1999).

Unfortunately, there are few data for considering how well the above-mentioned top priority sites for *Polylepis*-associated birds represent biodiversity as a whole, including speciose groups of insects and plants. Margules & Pressey (2000) suggest that data for one, or a few, taxonomic groups could be combined with data on representation of different habitats. In this respect we may note that the three top priority sites cover seven of the 15 species of *Polylepis* trees represented in the study region (0–30°S); the minimum set of seven cells covers 10 species, and the suggested conservation plan of 42 cells covers 13 species (missing only *P. crista-galli* and *P. lanuginosa*). This represents a wide range of habitats, from humid to very dry situations. A complementarity analysis based on 6073 georeferenced records of wild potato species (*Solanum*) in a 50 x 50 km grid resulted in a remarkably similar area choice to the present study (Hijmans & Spooner 2001). However, we still lack more complete sets of indicators for analyzing how well different areas contribute key habitats, or key processes. We also lack the means of identifying what the most crucial processes are that must be maintained in order to avoid loss of species.

It is important to note that the idea with minimum sets is that land management and regulations must be sufficient for the biodiversity to persist in all its area units. In some cases it may of course be adequate to survey an area and state that the *Polylepis* habitat is under no particular threat. However, it is clear (from my personal field experience) that significant efforts are needed in Apurímac-Cuzco and around Cochabamba.

One main reason for the efficiency of the concentrated efforts in these places (and continued efforts in the Huascarán National Park) is that the range-restricted (rare and threatened) species show a highly aggregated distribution. This has been related to particular local conditions, which may also have affected the distribution of people and agricultural development (Fjeldså & Rahbek 1998, Fjeldså *et al.* 1999b). The dense rural populations in these areas make conservation work particularly difficult – or challenging (Fjeldså 2002a). The protected areas network does not cover these areas well, since populated areas were generally avoided in the process of establishing a network of protected areas. Formal reserving of areas may be useful as a proactive mechanism, but cannot stand alone as a mechanism to prevent massive biodiversity losses. The national development plan for Bolivia (Bolivia 1994) points in the right direction, but is difficult to implement because of the diverging interests of different ministries and the very low sustainability of the macro-economy. Actions by non-governmental organizations will be strongly needed, as well as support from development agencies abroad.

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