Title:
Thirty Years of Land-Cover Change in Bolivia

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ABSTRACT

Land-cover change in eastern Bolivia was documented using Landsat images from five epochs for all landscapes situated below the montane tree line at approximately 3000 m, including humid forest, inundated forest, seasonally dry forest, and cloud forest, as well as scrublands and grasslands. Deforestation in the eastern Bolivia in 2004 covered 45,735 km2, representing ~9% of the original forest cover, with an additional conversion of 9,050 km2 of scrub and savanna habitats representing 17% of total historical land cover change. Annual rates of land cover change increased from 450 km2 yr-1 in the 1960s to ~2,900 km2 yr-1 in the last epoch spanning 2001 to 2004. This study provides Bolivia with a spatially explicit information resource to monitoring future land cover change, prerequisite for proposed mechanisms to compensate countries for reducing carbon emissions as a result of deforestation. It also shows that policies to limit deforestation had no observable impact on reducing deforestation, that deforestation in protected areas increased in the most recent epoch, and demonstrates that land-cover change is increasing at near exponential levels in some parts of the country due to agricultural expansion in the tropical lowlands.

Key words: *Landsat, remote sensing, deforestation, tropics, land-cover change, protected areas, indigenous reserves, UNFCCC*

INTRODUCTION

Land-cover change in tropical ecosystems is one of the most important ecological challenges facing modern society with potential global-scale impacts that range from catastrophic losses of biodiversity (1), increased global warming (2), and changes in weather patterns that could reduce agricultural production in the world's poorest countries (3). Nonetheless, countries in the developing world continue to experience high levels of deforestation, because economic and social drivers favor the expansion of the agricultural frontier (4, 5, 6, 7). Proposals are now being advanced within the context of the United Nations Framework Convention on Climate Change (UNFCC) to compensate tropical forest countries for conserving tropical forest; most proposals are based on lowering carbon emissions by reducing the current rate of deforestation (8). Whatever mechanism is eventually approved, parties to the agreement(s) will require base line data on historical rates of deforestation at the national level, while information at the sub-national level may be a requisite for individual initiatives. Inevitably, countries will need to conduct a methodologically robust annual survey to document and certify any future reductions in the annual rate of deforestation.

Currently, very few countries have access to reliable statistics on current and historical rates of deforestation. The Forest Resource Assessment (FRA) of the Food and Agriculture Organization (FAO) is the principal source of information that provides summary statistics at the national level (9). The FRA is collected via questionnaires sent to government authorities and represents an assortment of information sources; the FRA statistics are periodically validated at the continental level using a sub sample of satellite images. At the global scale, the scientific community relies on moderate-scale remote sensing instruments such as MODIS and AVHRR (10) or attempts similar to the FRA to estimate trends based on stratified sampling procedures (11).

However, Brazil has demonstrated that compiling wall-to-wall historical base-line data covering multiple decades using high resolution satellite imagery is technologically and economically feasible and similar efforts are underway in Bolivia (this study), Paraguay and Argentina (12)

Bolivia is situated on the southwestern edge of the Amazon Basin and has experienced large-scale deforestation over the past four decades (13, 14, 15). Deforestation in Bolivia is the result of a variety of economic and social forces that are representative of other parts of the developing world. The three major sources of deforestation are: 1) immigrantion of peasants that practice subsistence agriculture; 2) mechanized agriculture for row crops; and 3) pasture establishment for livestock production (15). Bolivia has been the recipient of international assistance to promote the conservation of the country's biological resources. Emphasis has been placed on land-use planning and all of the Bolivian lowlands have been zoned for different types of land-cover according to the principal of "best-use according to soil type;" an effort that has been financed by the World Bank and the Dutch government (16). Large tracts have been designated for forest management and Bolivia recently announced that 2.2 million ha of humid tropical forest had been "certified" as being sustainable managed according to international guidelines established by the Forest Stewardship Council (17). The country has also endeavored to create and manage numerous large protected areas and approximately 17% of the lowlands are currently situated within a protected area (18). Simultaneously, the Bolivian state has initiated a process to review land titles, which incorporates mechanisms to guarantee the ancestral rights of native peoples (19). Rural lowland Bolivia is a culturally diverse region with social groups that range from indigenous peoples, traditional Hispanic residents, recent immigrant farmers, and industrial enterprises backed by foreign capital. Consequently, Bolivia can be viewed as a microcosm of social and economic phenomena characteristic of many parts of the developing world where different social groups compete for access to land and natural resources.

We summarize how land-cover change has evolved over the past thirty years in lowland tropical Bolivia, an analysis that includes data from previous studies (13, 14), as well as new data covering the past fifteen years. We document deforestation rates prior to and after the implementation of policies intended to reduce deforestation and protect biodiversity. In addition, we include data on the conversion of non-forest natural habitats that are necessary for a comprehensive assessment of biodiversity impacts. To our knowledge, this is the first comprehensive and precise assessment of the loss of natural different land cover types at the national level. More importantly, our study has created a spatially accurate data base that provides a methodologically robust base-line for future studies of land cover change. It is increasingly likely that reductions in deforestation or other forms of habitat conversion will be linked to a carbon trading mechanism (8). Although the exact nature of this mechanism is still a matter of discussion, Bolivia and other participating countries will require base-line data to establish historical rates of deforestation as a reference for establishing compensation levels for future reductions at the national scale. In addition, a spatially precise data base will be necessary to enforce land-use regulations or certify compliance for voluntary initiatives at the local scale.

MATERIALS AND METHODS

The land-cover change analysis covers the period between 1975/76 and 2004/05; the first three epochs are adapted from a previous study (9) and the last two epochs are reported here. The fourth epoch compares Landsat images obtained ~1991 (TM) with images acquired in ~ 2000/01 (ETM). The fifth epoch is based on 18 satellite images (TM) from areas that were the most dynamic in terms of land-cover change. Images prior to 2001 were acquired NASA's Geocover project (19, 20). Later images were obtained from the Landsat-5 (TM) receiving station in Cuiabá, Mato Grosso, managed by the Brazilian Space Agency (INPE).

All images were co-registered to orthorectified images and the ~1991 to ~2001 epoch was classified by creating two-date, 12–band composite images, that were subject to an unsupervised classification using the Isodata module of the Leica/Erdas ® software program. The completed images for the ~1991 to ~ 2001 epoch were compiled into a mosaic (termed NKM9101) that was compared with a previous multi-temporal mosaic compiled by the University of Maryland (termed UMD7691) covering three temporal epochs: 1976/75 - 1986/87 - 1991/93 (Steininger et al 2001). The two mosaics differed in spatial resolution, geographic extent and thematic stratification. The UMD7691 mosaic covered humid tropical forest above 20.5°S latitude, whereas the NKM9101 study included all land-cover types to the southern border (~22°S latitude). The UMD7591 mosaic differed due to poor geometric registration of the older Landsat data, as well as from the differences in the classification of natural forest regeneration and anthropogenic secondary forest. Essentially the UMD7591 dataset was used to assign temporal epochs to anthropogenic land cover types identified in the NKM9101 mosaic. The first epoch (pre 1975) covers the period between the onset of modern agriculture and settlement in the lowlands in the mid 1950s and the acquisition of the first satellite imagery. All editorial modifications to the NKM9101 mosaic were validated by comparison to Landsat imagery for the appropriate epoch between 1976 and 2005. A detailed description of common classification errors and the editorial procedure has been described previously (22)

Land-cover change for the last temporal epoch (2000/01 – 2004/05) was added to the composite mosaic to create a new multi-epoch land-cover and land-cover change map covering all of the eastern part of Bolivia termed BOL7604 (Figure 1). This last dataset provides only partial coverage for the last temporal epoch, as it is based on 18 of a total 45 Landsat scenes that cover Bolivia; however, these 18 scenes incorporate 95% of the historical land-cover change prior to 2001. All three data sets (UMD7691, NKM0191, and BOL7604) are available on the Noel Kempff Mercado Museum web portal (23).

The final mosaic (BOL7604) was validated by comparison to aerial videography acquired by over flights made between October and December 2004 (Figure 1); flights were concentrated on dynamic landscapes that have experienced or are currently experiencing land cover change. Individual video frames were georeferenced using a GPS linked to the video camera; the camera was programmed to capture only those video frames that coincided with a fresh GPS datum and the time of acquisition was recorded in the audio channel of the video camera. Land cover within video frames were classified for percent of land cover in three broad classes: 1) forest; 2) all natural habitat, including forest, shrub, savanna, wetland, and water; and 3) anthropogenic cover, including second growth forest, pasture, crop land, bare soil, and urban area. The relative abundance of land cover was summarized for each video frame (~ 7-ha) and this was compared to the relative land cover within a similar 7-ha rectangle around each GPS point from the land cover mosaic. The variance between the tow data sources was calculated by comparing the relative area of each cover class.

RESULTS

Bolivia has experienced steadily increasing rates of land-cover change over the last three decades (Figure 2). In earlier epochs the principal form of land-cover change was deforestation, because mechanized farmers, subsistence agriculturalists and livestock producers all preferentially selected forest landscapes for conversion. However in the more recent epochs, other types of land cover change have become more prevalent, including: 1) conversion of savanna and scrub vegetation to cultivated pasture in the Gran Chaco and Cerrado biomes, 2) conversion of wetlands to mechanized farming by modification of natural drainage patterns, 3) the conversion of wetlands to paddy rice farming, and 4) the conversion of inundated wetlands to native pasture. In spite of the increase of these other types of land cover change, deforestation continues to represent 75% of the total (Table 1).

Seventy five percent of all land-cover change has occurred in the Department of Santa Cruz, where the rate of change has increased exponentially over the last 30 years (Figure 2). The La Paz Department experienced relatively large rates of land cover change in the 1960s when the humid valleys of the Yungas region were colonized by settlers from the Altiplano; however, the rate of change has declined both in real and relative terms since its peak in the 1970s. A similar pattern of migration and deforestation during the 60s and 70s occurred in the Chapare region of the Cochabamba Department. However, the Chapare experienced a surge in deforestation in the period 1986 – 1991, followed by a sharp decline in the 1990s and another increase in the most recent temporal epoch. In the other departments, there have been steady but much smaller increments in land cover change, although both the Pando and Tarija show the greatest relative annual increases after Santa Cruz at 75% and 88% increases respectively (Table 2).

The efficacy of land-use planning recommendations designed to foster appropriate land use and limit deforestation was evaluated by comparing rates of change in the most recent epoch after the implementation of the regulatory system in the late 1990s (Figure 3). The majority of land-cover change continues to occur in areas zoned for agricultural activity; however, deforestation tripled in areas that were zoned for forest management and strict protection. Land-cover change also increased on landscapes that were designated for extensive cattle ranching, a production system that has traditionally depended on native vegetation as grazing lands; unfortunately, landowners are now increasingly converting native savanna to cultivated pastures to improve productivity. In contrast, we show a decrease in land cover change for the Gran Chaco region in the last epoch (Table 1), due largely to a reduction in the conversion of these landscapes to the cultivation of row crops due to recurrent drought.

Protected areas have been successful in conserving large areas of intact natural ecosystems (24). Our results reaffirm the generally positive trend for the 1990s when the rate of deforestation decreased in almost all protected areas. However, our results show a reversal of that trend in the most recent epoch (Figure 3). Three protected area complexes, Amboró, Carrasco and Isiboró-Securé have suffered historically high levels of deforestation and rates of land cover change. All three areas show increased rates of deforestation in the last temporal epoch after showing declines during the 1990s (Table 3). The Amboró protected area has been subdivided into units with differing degrees of protection; areas zones as "national park" have relatively low rates of land cover change, while the multiple use area has higher rates of deforestation. Most protected areas are in relatively remote areas and experience relatively low annual rates of land cover change. The protected areas that experienced the largest total deforestation and the largest increase in deforestation in the most recent epoch were those situated adjacent to peasant colonization zones where the cultivation of illicit crops is widespread.

The validation analysis demonstrated that the land cover mosaic is an accurate map of land cover for lowland Bolivia. The variation between the map and the video frames overestimates the real error rate because over flights were concentrated along major highways and agricultural regions, while almost 75% of lowland Bolivia is covered by expanses of unbroken forest or savanna where the difference between the two information sources approaches zero. In contrast, the validation analysis over dynamic anthropogenic landscapes showed considerable variation between the videography and the land cover mosaic (Figure 4). The source of this variation is in part due to misclassification errors derived of the Landsat images, particularly the confusion of second growth forest with degraded remnant forest patches. However, much of the variance came from the videography due airplane roll, periodic changes in elevation and GPS error that caused the reference video frame to capture slightly different polygons than corresponding polygon extracted from the land cover map.

DISCUSSION

The consequences of tropical deforestation have been an issue of global concern for at least three decades and have lead to multiple initiatives to mitigate the impact and slow the rate of deforestation. Nonetheless, the rate of deforestation remains at near historical levels and according to the FRA, the annual rate of deforestation continues at the "alarming" rate of 130,000 km2 yr-1, of which between 34,000 and 44,000 km2 yr-1 is due to deforestation in Amazonian countries (9). The largest part of the Amazonian deforestation occurs in Brazil, which accounts for approximately 60% of that total. The annual rate of deforestation in Brazil has trended upward since monitoring began in 1988, with peaks in 1995 and 2004. Fortunately, the Brazilian rate has decreased the past two consecutive years falling from a near high of 27,360 km2yr-1 in 2004 to 18,900 km2yr-1 in 2005; and an as yet unvalidated rate of only 13,100 km2yr-1 for 2006 (12). The dramatic recent reduction in deforestation rates in Brazil may be due to a combination of policy initiatives taken by the Brazilian government or, more likely, is the consequence of market forces that have lessoned demand for the commodities drive deforestation (25). Efforts are underway to provide similar information for the Andean countries (26), but data is still deficient for documenting trends in annual deforestation rates and the FRA remains the principal source of information on forest cover and forest loss.

The FRA estimates for deforestation in lowland Bolivia (2,700 km2 yr-1) are close to our results for total land-cover change; however, they exceed our measurements of deforestation; a discrepancy that is largely the result of different criteria for defining forest (Table 1). We define forest as closed canopy evergreen, semi-evergreen and semi-deciduous forests, while the official forest map of Bolivia includes data for Chaco dry forest that is treated separately in our study (27). In addition, the FAO reports refer to "net forest loss", which is a different concept from the "loss of natural forest." The former subtracts the area of plantation and secondary forest from the deforestation area, while the latter is the true measure of deforestation. In lowland Bolivia, there are essentially no large-scale forest plantations in the lowlands, but we measured the amount of second growth forest at ~8,500 km2 in 2001. It is not clear in the FRA report if the net forest loss cited for Bolivia incorporates second growth forest. In addition, the FRA estimate of total forest cover in Bolivia exceeds ours by more than 126,000 km2. Using the broadest definition of forest and including vegetation types from montane areas excluded from our study (~16, 000 km2), there is still a 25,000 km2 difference in total forest cover; this difference represents almost half of the total historical deforestation in Bolivia (Table 1).

The dimensions of the discrepancies between the FRA estimates and these direct measurements strengthen the arguments that the sampling procedures and questionnaires employed by the FRA are inadequate methodologies for monitoring the world's forests. More importantly, the decision to combine statistics on plantation forestry and deforestation conveys a misleading perception about the true fate of the world's forests, particularly regarding the conservation of biodiversity. The feasibility of conducting wall-to-wall surveys that distinguish among natural forests, second growth and tree plantation has been amply demonstrated by Brazil and is further ratified by this study for lowland Bolivia.

Information on land cover and land cover change may eventually be used by authorities to review land tenure, enforce land-use regulations or assess land-use taxes (12, 25). Consequently, the accuracy and precision of land-cover change studies are important attributes that need to be further documented and, if necessary, improved by using higher resolution images, more frequent temporal samples, or by relying on direct field validation. Our results show that at the national scale, classifications based on Landsat images are robust; since overestimates canceled out underestimates of deforestation, our study can be considered to be unbiased and accurate. However, the variance over anthropogenic landscapes shows that caution is necessary when using Landsat imagery at the local scale. This last point is important when considering proposals for using satellite imagery for legal or regulatory purposes related to land-use and land-use change (25).

The high level of deforestation in lowland Bolivia also has important implications for efforts to reduce greenhouse emissions. Bolivia is a signatory to the Kyoto protocol and is eligible to organize projects under the Clean Development mechanism (CDM). Landscapes eligible for CDM projects under the current rules must have been deforested prior to the adoption of the Kyoto Protocol in 1991; however, half of the total area deforested in lowland Bolivia (~ 22,400 km2 yr-1) has been deforested since 1991. Current annual rates of deforestation represent 10% of the area eligible for CDM projects, a rate that has been growing exponentially over several decades (Figure 2). No CDM reforestation projects have been approved in Bolivia and those in the planning stage represent only miniscule portion of the total eligible areas (< 0.01%) and are insignificant when compared to the annual carbon emissions that result from deforestation.

Recent proposals to modify the UNFCCC to include deforestation avoidance would provide Bolivia and other countries with an economic incentive to conserve valuable forest ecosystems (8). However, the political feasibility and economic value of future reductions would vary enormously depending on the base-line used to calculate and certify the reduction in the deforestation rate. If the period 1976 - 1990 was used as the base-line, Bolivia would have to reduce its current rate of deforestation by more than 50%, from almost 2,500 to 1,400 km2 yr-1 to be eligible for compensation; a goal that would be unacceptable to the country's citizens. Similarly, the economic value of an offset would vary by almost 50% depending on whether the epoch 1990 – 2000 or 2001 – 2004 was used as the baseline. The existence of our study provides Bolivia with an important information resource for negotiating potential baseline values within the framework of an expanded Kyoto Protocol. Arguments could be tendered for using the actual trend in the growth of the annual rate of deforestation to establish a base-line.

The future potential for future land cover change is best understood in the context of recent history. The exponential growth rate in land cover change in Santa Cruz was driven by international commodities for sugar and cotton drove in the 1970s during a period that coincided with subsidized credit (15), while policies favoring the private sector and investment in infrastructure coincided with a favorable market conditions for soy in the 1990s (15). The variation in deforestation in the Chapare region of Cochabamba can be attributed to the tolerance of illegal coca cultivation in the 1980s that contrasted with aggressive eradication of coca in the 1990s (28). Government collusion was compounded by the collapse of the mining sector, which led to large scale migration of ex-miners to the region in the 1980s; recent civil unrest and the unwillingness of recent governments to aggressively pursue eradication has led to a new boom in coca cultivation (28), which has led to increased deforestation in the Chapare (Table 2).

These types of internal and external phenomena will continue to push deforestation rates upward. For example, the regional road network is rapidly expanding in Santa Cruz and export corridors are being dramatically improved to both the Pacific and Atlantic coasts. Other lowlands Departments are eager to emulate the economic growth of Santa Cruz and investments in new highway infrastructure will probably result in the expansion of mechanized agriculture on the alluvial plains of La Paz Department, as well as intensive cattle farms on the less fertile landscapes of Pando Department, similar to that predominates in the adjacent Brazilian state of Acre (29).

Our results also demonstrate the need for a broader perspective of land-cover change; most reports focus on deforestation in humid tropical forests and fail to take into account habitat conversion in tropical dry forests, scrubland, and grassland ecosystems; these ecosystems are often more degraded as a percentage of total original cover when compared to tropical evergreen rainforest (30, 31). The conversion of these lands to agriculture also contributes to carbon emissions and may represent a form of leakage if deforestation is displaced to these areas. More importantly, these habitats are biodiversity rich. Most of the savanna and scrubland habitats of eastern Bolivia are part of the Cerrado and Gran Chaco biogeographic regions. More than 50% of the Cerrado region has been converted to agriculture in Brazil and, unless the rate of conversion is dramatically reduced in future years, this biome will be restricted to a few isolated patches in protected areas within a decade (30). The trend reported here indicate that Bolivian land owners have begun to mimic their Brazilian neighbors and are also converting Cerrado habitat to crops and cultivated pastures.

Wetland conversion, one of the most controversial forms of land-cover change in temperate countries, is seldom even mentioned in forums dealing with land-cover change in tropical regions and the loss of wetland habitat is only described in qualitative terms by organizations dedicated to the conservation and management of aquatic systems (32). Our study shows that wetland conversion is becoming increasingly important in Bolivia and is probably also underestimated in tropical countries. Vast areas of lowland Bolivia are characterized by seasonally inundated savannas (Figure 1) and recent reports of paddy rice cultivation provide an ominous warning as to the nature of future land cover change in lowland Bolivia. The conversion of non forest habitat types has important ramifications for conservation planning and should be addressed by the Bolivian state as a signatory to the Convention of Biological Diversity and the RAMSAR Convention.

Bolivia has been the recipient of numerous initiatives designed to manage the environmental and social impacts of development; our results demonstrate that these policy initiatives have not been effective (Figure 3; Table 3). The failure of land-use zoning regulations to protect forest lands is a consequence of creating regulatory mechanisms that lack sufficient economic incentives that favor forest conservation. Some form of a carbon based program may ultimately provide the necessary incentives to make forest conservation competitive with other forms of land use, but until that happens, land-owners will continue to monetize timber resources and then convert land to crops or pastures. Our results from lowland Bolivia highlight the need for a historical perspective of deforestation to evaluate the efficacy of policies designed to reduce deforestation. Development in the western Amazon will increase due to regional efforts to physically integrate economies across the continent (28) and our study shows that deforestation is not slowing but increasing at consistently greater rates of change.

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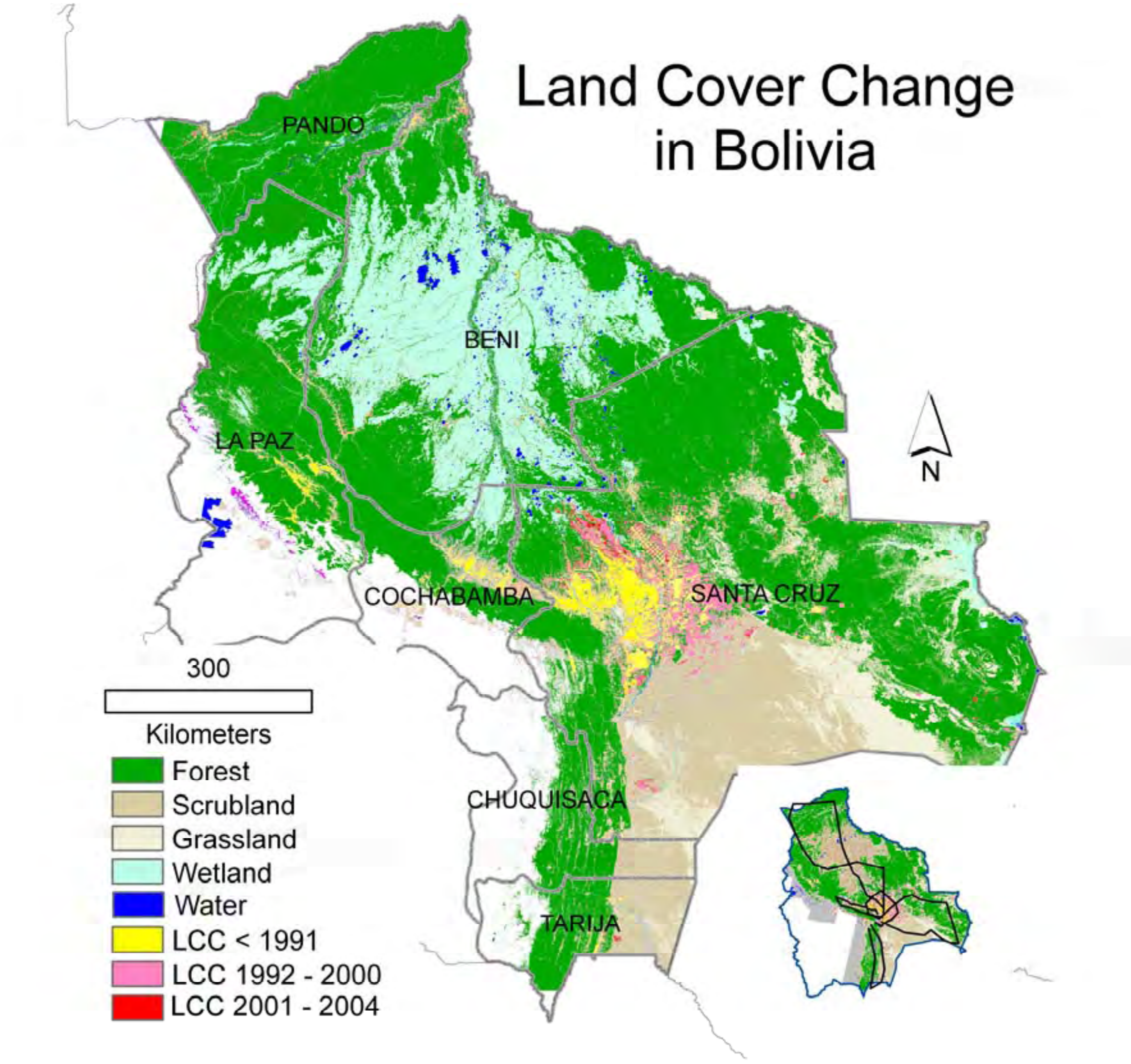

Figure 1. Map of land-cover change (LCC) in Bolivia; the inset shows the approximate route of the validation over flights.

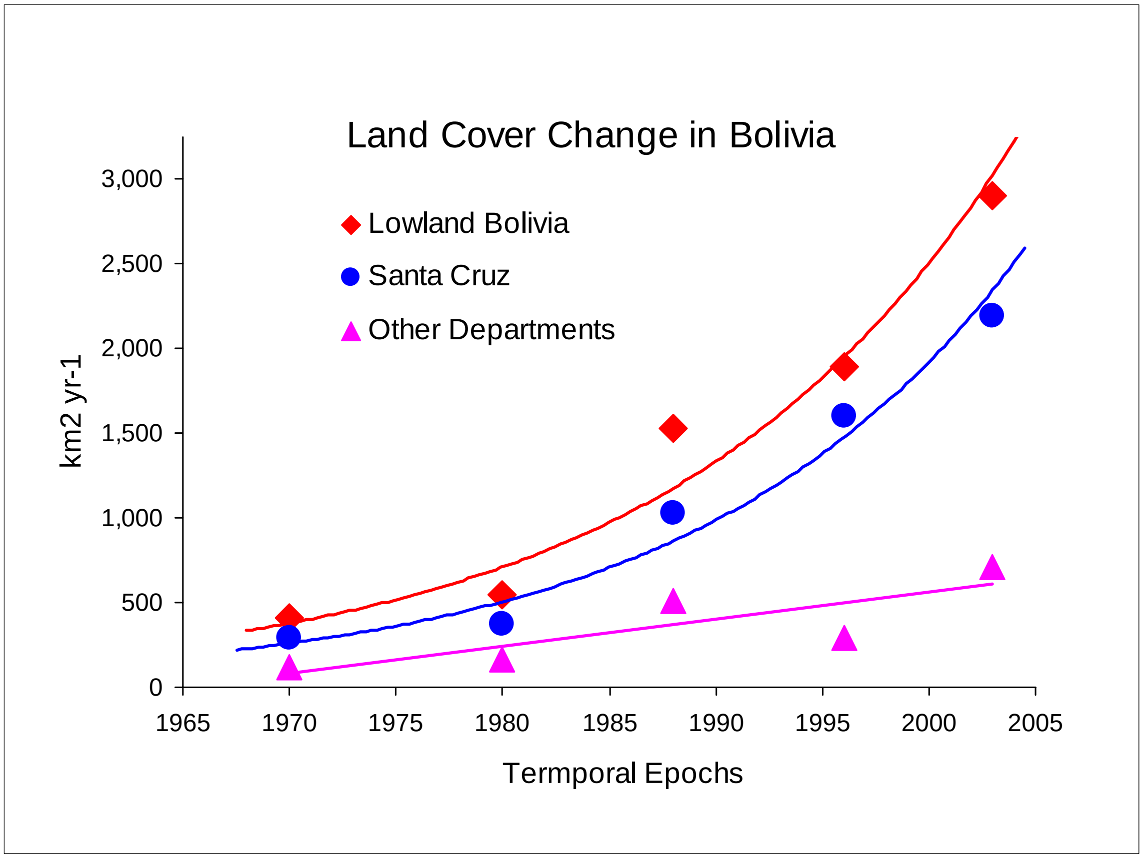

Figure 2. Rate of change in lowland Bolivia; other departments include the lowland regions of Cochabamba, La Paz, Beni, Pando, Chuquisaca and Tarija; the first epoch is based on a 20 year period starting in 1955 at the start of modern settlement in lowland Bolivia.

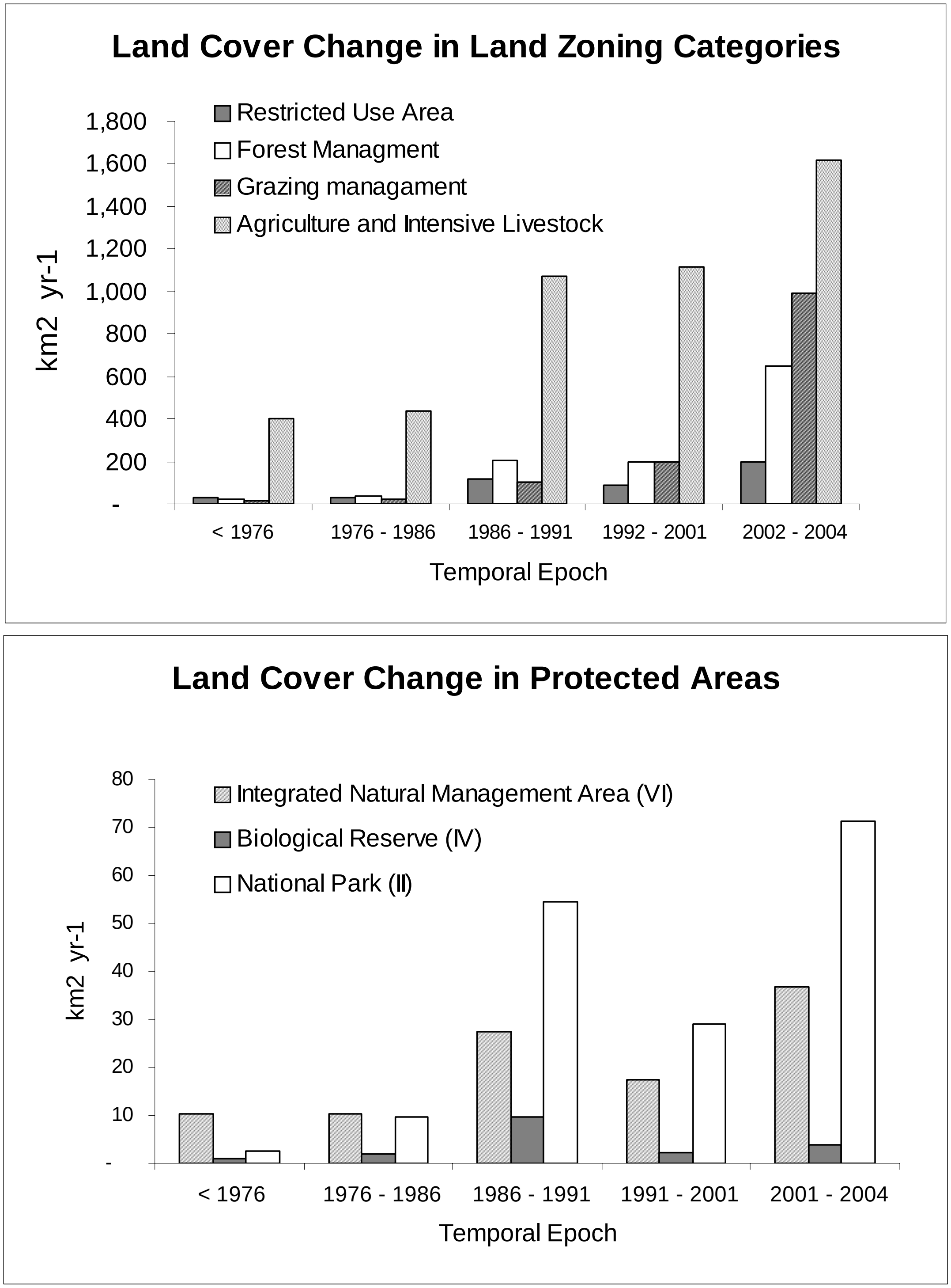

Figure 3. A). Rate of land cover change for four categories of land use zoning recognized by the Bolivian government; B) Land-cover change in three categories of the Bolivian system of national protected areas. (IUCN Categories in parenthesis); both graphics cover all of lowland Bolivia.

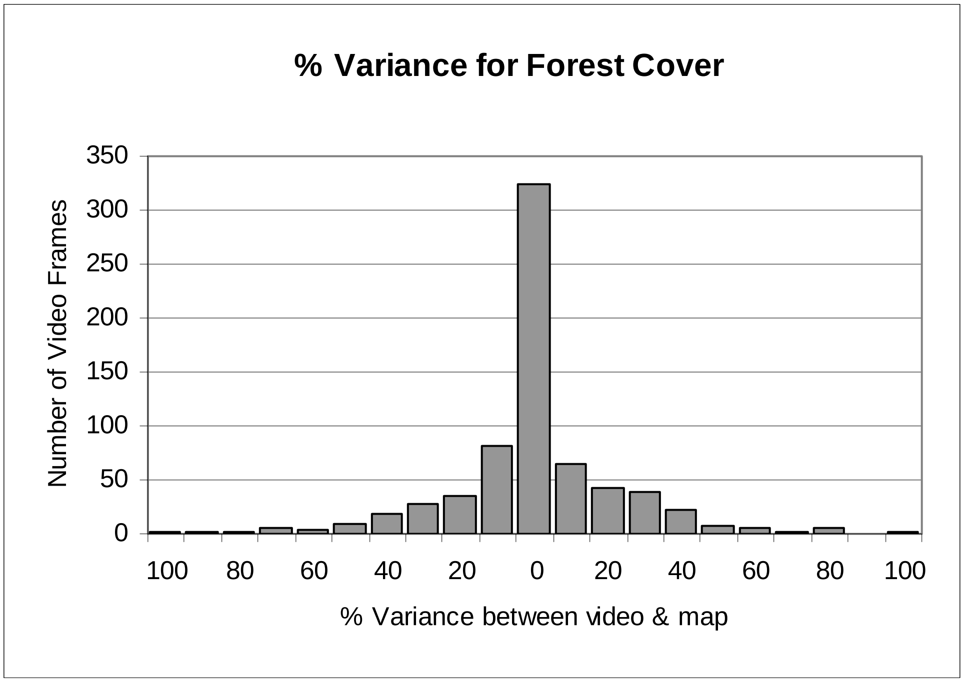

Figure 4. The variance for forest cover when comparing equivalent areas (~ 7 ha) from the land cover mosaic derived from classified Landsat images with video frames captured on validation over flights.

Table 1. Land-cover change (LCC) and rates of land-cover change for different land cover types.

	Total remnant habitat (km^2)	Total LCC (km^2)	LCC as % of total area	(km^2 yr^{-1})					Annual LCC as % of total remnant habitat
				<1976	1976 – 1986	1987 - 1991	1992 - 2001	2002 - 2004	
Forest	460,726	45,735	8.90%	404	516	1,386	1,506	2,247	0.49%
Chaco, scrubland*	72,929	4,918	6.30%	31	49	72	254	187	0.26%
Cerrado, upland savanna	58,193	3,407	5.50%	15	20	115	115	317	0.54%
Llanos, savanna wetland	129,115	721	0.60%	0.1	0.1	6	12	153	0.12%
Total	720,963	54,781	7.00%	450	586	1,579	1,887	2,905	0.40%

* sometimes treated as dry forest

Table 2. (A) Total land cover change (LCC) and (B) Deforestation in the lowland sectors of the six Bolivian Departments included in the study.

A.	Total Remnant Habitat (km^2)	(km^2 yr^{-1})					Rate of Total LCC (%)***
		> 1976*	1976 - 1986	1987 - 1991	1992 - 2001	2002 – 2004 **	
Beni	201,384	13	25	138	85	227	0.11%
Chuquisaca	21,882	0	0	1	13	16	0.07%
Cochabamba	24,176	31	50	218	101	240	0.96%
La Paz	73,322	56	67	40	51	44	0.06%
Pando	58,770	6	12	97	30	90	0.15%
Santa Cruz	316,070	290	375	1,028	1,598	2,192	0.69%
Tarjia	25,311	11	13	12	15	95	0.38%
Total		407	543	1,534	1,893	2,905	0.40%

B	Total Remnant Forest (km^2)	(km^2 yr^{-1})					Rate of deforestation (%)***
		> 1976*	1976 - 1986	1987 - 1991	1992 - 2001	2002 – 2004 **	
Beni	98,028	13	25	134	80	208	0.21%
Chuquisaca	15,161	0	0	0	9	4	0.03%
Cochabamba	20,745	31	50	218	101	238	1.15%
La Paz	62,258	56	67	38	51	41	0.07%
Pando	58,213	6	12	96	30	88	0.15%
Santa Cruz	192,612	269	329	870	1,229	1,608	0.84%
Tarjia	13,683	10	13	8	7	59	0.43%
Total	460,700	384	496	1,365	1,506	2,247	0.49%

* based on a 24 year period starting in 1952.

** data for 18 Landsat scenes with historically high levels of land-cover change representing more than 95% of land-cover change in previous

*** annual rate calculated based on existing remnant habitat in 2004

3. Land cover change and rates of land cover change for the three most threatened areas of the Bolivian Protected Areas Network.

	Total remnant habitat (km^2)	Total LCC (km^2)	LCC as % of total area	(km^2 yr^{-1})					Annual LCC as % of total remnant habitat
				<1976	1976 – 1986	1987 - 1991	1992 - 2001	2002 - 2004	
Isiboro Securé National Park & Indigenous Area	11,819	406	3.3%	0.1	3.8	28.4	9.0	33.1	0.28%
Carrasco National Park	5,472	493	8%	1.7	2.0	22.9	18.1	35.3	0.64%
Amboró Integrated Natural Management Area	1,078	445	29%	7.1	7.6	17.7	8.9	14.3	1.33%
Amboró National Park	4,338	24	0.6%	0.1	0.5	1.4	0.5	1.8	0.04%
20 Other Protected Areas	127,355	497	0.4%	4.1	9.0	19.9	12.1	32.4	0.03%
Total	150,061	1,865	1.2%	13.0	22.9	90.2	48.7	116.9	0.08%