Article

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Linking National Agrarian Policy to Deforestation in the Peruvian Amazon: A Case Study of Tambopata, 1986–1997

Amazonian deforestation rates vary regionally, and ebb and flow according to macroeconomic policy and local social factors. We used remote sensing and field interviews to investigate deforestation patterns and drivers at a Peruvian frontier during 1986–1991, when rural credit and guaranteed markets were available; and 1991–1997, when structural adjustment measures were imposed. The highest rate of clearing (1.5% gross) was observed along roads during 1986–1991. Roadside deforestation slowed in 1991–1997 (0.7% gross) and extensive regrowth yielded a net increase in forest cover (0.5%). Deforestation along rivers was relatively constant. Riverside farms today retain more land in both crops and forest than do roadside farms where pasture and successional growth predominate. Long-term residents maintain more forest on their farms than do recent colonists, but proximity to urban markets is the strongest predictor of forest cover. Future credit programs must reflect spatial patterns of development and ecological vulnerability, and support the recuperation of fallow lands and secondary forest.

INTRODUCTION

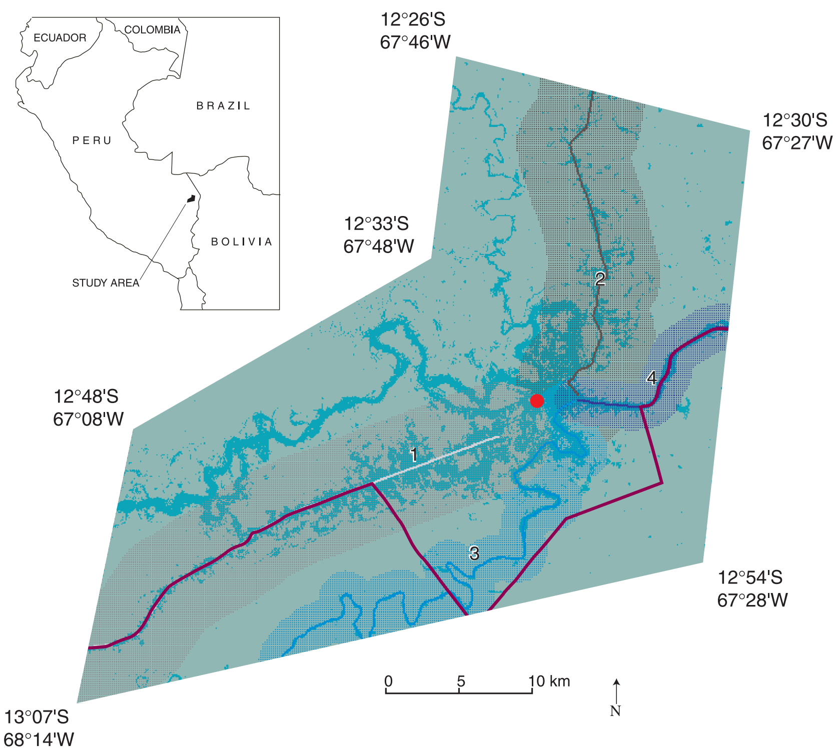
Every year, more than 2 million ha of Amazonian forest is cleared as road networks expand into remote areas (1). Current projections suggest that deforestation rates will continue until half of the Amazon's closed canopy forest is eliminated by 2020 (1). Environmentalists decry the loss of this immense tract of rainforest due its global significance as a storehouse of biodiversity and carbon, and a renewable resource base for local citizens (2–4). Concern over the loss of Amazonian forest has launched an array of research aimed at better understanding patterns and drivers of deforestation (5–9). These studies indicate that Amazonian forest is not being cleared in a steady sweep across the landscape. Rather, deforestation rates vary dramatically between regions, and ebb and flow over time according to shifts in national policy (10–12). Understanding this variation enables conservationists to identify forests vulnerable to clearing as well as promising sites for forest regeneration. Recent research also shows that regional socioeconomic context shapes the impact of broadly recognized drivers of deforestation, such as roads, markets, credit and settlement schemes (9, 13, 14). For this reason, explanatory models and policy recommendations cannot be readily transplanted between Amazonian countries or regions (9, 10).

This paper examines the patterns of land-cover change and deforestation in the Province of Tambopata in southeastern Peru, a development frontier whose forests have great biodiversity importance (15, 16). While concern about deforestation drives a number of projects (17), there has not yet been an accurate estimate of the rates of forest clearing in the area. This study documents patterns of deforestation along roads and rivers in Tambopata during an 11-yr period when Peru's national agrarian policy shifted drastically, from macroeconomic populism under the Garcia regime (1985–1990), to neoliberal austerity under Fujimori (1990–2000). Results from remote sensing analysis and field interviews indicate a direct link between shifts in national policy and land-use change in this remote area. In Tambopata, as elsewhere in the Peruvian Amazon, changes in agrarian policy alter deforestation rates and relocate forest-clearing activities, leaving some areas newly vulnerable and others to regenerate (10, 11). In describing and explaining these shifts, this study aims to guide local conservation interventions and contribute to more sophisticated explanatory models of deforestation in the Amazon basin. This project also underscores the importance of combining remote sensing with field interviews to explain patterns and processes of deforestation at the regional and household level (7, 8).

STUDY REGION

Physical setting: The study region covers 414 759 ha within the Tambopata Province of the Department of Madre de Dios in southeastern Peru (Fig. 1). Two major rivers pass through the region (Tambopata and Madre de Dios) and join at the city of Puerto Maldonado. The Transoceanic highway bisects the region and connects Puerto Maldonado to the Peruvian highlands and Acre, Brazil. This low lying (< 350 m a.s.l.) region receives 1600–2400 mm of rainfall per year and is covered predominantly in evergreen forest (18). Tambopata holds world records for diversity in butterflies and birds, and retains intact populations of threatened Amazonian species, e.g. giant river otters, wooly and

Figure 1. Location of study site in Peru, showing the entire study region and the sub-regions used in detailed analysis. Bajo Madre de Dios and Tambopata Rivers, Road to Brazil, and Road to Cuzco.



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spider monkeys, jaguars, river turtles and white-lipped peccaries (18). The region also includes old-growth riparian forest, a habitat type endangered elsewhere in the Amazon (18). Environmentalists aim to protect Tambopata's diverse forest ecosystems by establishing protected areas and promoting sustainable forest use in inhabited areas (13, 17, 19).

Land-use history: Tambopata has long been isolated by high mountains to the west, and fast-flowing rivers and vast forests to the east (20). The region was buffered from the international economy until the rubber boom of 1890–1920, when companies imported > 6000 workers from neighboring countries and other parts of Peru (20). This population influx gave rise to *ribereño* society (Amazonian residents of mixed ancestry), while enslavement and epidemics decimated indigenous populations (20). Rubber tappers altered forests along the rivers by clearing agricultural fields and opening thousands of paths to access the wild rubber trees (*Hevea* spp.). When global rubber prices crashed in the early 1900s, Tambopata's residents turned to other activities, including gold mining, selective logging and collection of Brazil nuts (*Bertholletia excelsa*) (21). A second wave of immigration began in the mid-1960s, when a new road connected Tambopata to the Peruvian highlands. For the next 20 years, newcomers from the highlands settled along the new road or in the capital city of Puerto Maldonado (Table 1).

The agricultural frontier in Tambopata expanded rapidly during the 1980s under the macroeconomic populist policies of president Alan Garcia (1985–1990). Garcia's regime aimed to raise the welfare of the rural poor by providing easy access to agricultural credit and land titles, promoting farmers' cooperatives, and offering guaranteed markets for products like rice (Table 2) (10). These incentives were also part of a broader geopolitical strategy to assert control over the Amazon territory. During this period, approximately 40% of the total land area worked under state credit in Peru was located in the Amazonian frontier region (10). Immigrants came by the thousands in response to these opportunities and also to escape political violence in the highlands (20) (Table 1). Upon arrival, settlers cleared forest and planted rice, plantains, maize, cassava, and beans. They took advantage of government credit to employ *rozeros* (forest clearing crews armed with chainsaws) to open up land for fields. During this period (1985–1990), rice production in Madre de Dios increased 30%, maize 72%, and cattle 29% (20). As elsewhere in the Peruvian Amazon, after two or three planting seasons, many agriculturalists abandoned farming for livestock production, a more profitable activity given Peru's hyperinflation during this period (10).

Agrarian and economic policies changed drastically when Alberto Fujimori was voted into office in 1990. Fujimori's neoliberal administration set about imposing a radical austerity program based on structural adjustments. Agricultural credit dried up, Agrarian Associations were dismantled, subsidies were removed and taxes imposed, all resulting in a decline in agricultural production, as well as forest extraction activities in Tambopata. Without credit, agriculture became less profitable, and in many cases, the activity was abandoned. Despite slowed economic activity, influx of Andean peasants to the area continued and Tambopata's population grew by 5–6% yr^{-1}, reaching 76 610 in 1997, with roughly half the population residing in the capital city of Puerto Maldonado (17).

In addition to major political and economic change, the 1990s also brought the first major conservation interventions in the Tambopata region. The Peruvian government created the 1.5 million ha Tambopata Candamo Reserve Zone (TCRZ), with a 500 000 ha National Park named Bahuaja Sonene at its core. The strictly protected Bahuaja Sonene National Park was later expanded to 1 million ha, while the multiple-use Reserve Zone was reduced and reclassified as a National Reserve. Considerable research was conducted on conservation issues during the 1990s, including nontimber forest use, ecotourism, hunting, agroforestry, and soil quality (15), but there has been no systematic analysis of regional deforestation patterns. This study examines deforestation rates within subregions of Tambopata during 1986–1997, a period encompassing drastic shifts in national agrarian policy and substantive conservation interventions. Specifically, this study compares: *i*) rates of forest clearing and regrowth along roads and rivers during two different agrarian policy regimes: macroeconomic populism (1986–1990) and neoliberal structural adjustment (1991–1997); and *ii*) socioeconomic and geographical determinants of land use at the household level.

METHODS

Remote sensing techniques were used to gather spatial information on forest cover and patterns of deforestation across the entire study region and within subregions along the major roads and rivers. To better understand socioeconomic processes underlying the observed deforestation patterns, additional data were gathered through semistructured field interviews with local agriculturalists and other key informants.

Remote Sensing Analysis

Database development: A time series of three satellite images was acquired for the years 1986, 1991, and 1997 from the Tambopata region. These dates were selected for analysis based on the assumption that land use changes lag policy changes; e.g. to test the impact of the Garcia's regime (1985–1990), images from 1986 and 1991 were employed. The 1986 image came from a 79 m resolution Landsat MSS sensor. The 1991 and 1997 images came from 30 m resolution Landsat TM sensors. The 1997 TM image was geometrically rectified and registered to a UTM coordinate system based on 1:100 000-scale topographic maps of the study region (19S zone, WGS84 datum). The 1986 and 1991 images were georectified using an image-to-image approach with the 1997 image as the reference. The rectification process resulted in 0.7, 0.7, and 0.6 pixel-RMS error for the 1997, 1991, and 1986 images, respectively. All the images were resampled to a 30 m pixel size. Although the use of different resolutions could influence the accuracy of change detection analyses (22), simple forest/nonforest cover change has been successfully conducted elsewhere in the Amazon combining MSS and TM sensors (23).

Groundtruthing: Data on land use

Table 1. Population growth in Tambopata Province, Peru.

Year	Total number residents	Urban population[1] (%)
1972*	14 764	5584 (38%)
1981*	24 590	13 055 (53%)
1993*	46 738	31 249 (67%)
1997**	76 610	38 305 (50%)

Sources: *National Population and Housing Census, Instituto Nacional de Estadística e Informática, Lima, Peru. ** (33).
[1] Urban = settlements > 5000 inhabitants.

Table 2. Land titles in Tambopata Province, Peru.

Year	Number of land titles issued	Average size title (ha)	New land under legal title (ha)
1982	64	59	3776
1984	1	53	53
1985	54	74	3995
1986	40	258	10 336
1987	251	54	13 431
1988	154	47	7302
1989	3	178	533
1990	2	127	254
1991	89	80	7122
1992	108	54	5852
1993	100	104	10 420
1994	206	42	8702
1995	48	33	1595
1996	477	30	14 456
1997	1436	34	48 591
Total	3033	45	136 418

Source: Data compiled in 1999 from office of Proyecto Especial de Titulación de Tierras, Puerto Maldonado, Peru.

and land cover were collected and georeferenced during two field work periods in June–July 1999 and July 2000. Thirty ground-truthing sites were selected along major roads and rivers, along forest trails, and within large blocks of farmland. Land-cover identification was based on local people's classification of landscape features. These include: tall forest (*monte alto*), seasonally flooded forest (*bajíos*), swamp forest (*aguajales*), old successional forest (> 12 yrs), early successional forest (< 12 yrs) (*purmas*), cultivated fields (*chacras*), bamboo forest (*pacales*), pasture (*pastos*), and bare soils (includes newly cleared areas, built-up areas, roads and beaches).

Classifying images: Binary images of forest and non-forest areas for the years 1986, 1991 and 1997 were generated by means of a supervised classification method. The forest category included areas of tall forest, seasonally flooded forest, swamp forest, and areas of old successional forest ~ > 12 yrs old. The nonforested areas included areas of young successional forest $\lesssim$ 12 yrs old, areas of bamboo forest (*Guadua* spp.; an invasive species that colonizes abandoned fields and pasture) (18), pasture, agricultural lands and bare soils. The total area in forest cover in 1986, 1991, and 1997 was calculated for the whole study region and net deforestation rates were derived from these values.

Forest change trajectories: The forest *vs* nonforest areas for 1986, 1991, and 1997 were compared to analyze forest change trajectories related to forest loss and forest regrowth in four subregions along major transportation corridors: 1. Road to Cuzco, 2. Road to Brazil, 3. Tambopata River, and 4. Bajo Madre de Dios River (Fig. 1). For each subregion, a buffer was drawn at 8 km on either side of the road and 3 km on either side of the river. These different size buffers correspond to official land-titling schemes. The buffers were "cookie cut" for each subregion and the area of the polygons related to forest clearing and forest regrowth was calculated for the period 1986–1991 and 1991–1997. The individual forest/non-forest layers were combined using the stack layer function in ERDAS Imagine (24). The final product was a categorical image containing seven different change trajectories related to forest clearing and forest regrowth, e.g. areas going from forest in 1986, to forest in 1991 to non-forest areas in 1997, or areas under forest during all three dates (Fig. 2). Measurement accuracy was assessed for each trajectory based on Jackknife classification method. Forest clearance areas for the 1986–1991 and 1991–1997 periods had an accuracy of 93.6% and 88.7%, while areas of forest regrowth had an accuracy of 70.5% and 82.5%, respectively.

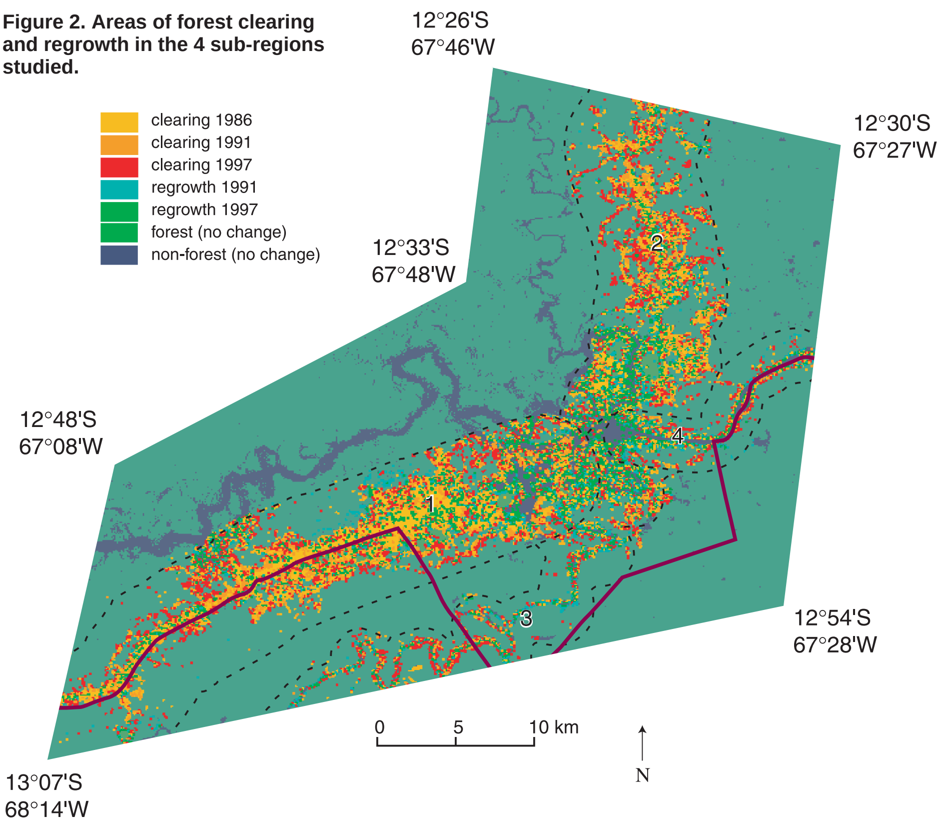
Interviews with Local People

Field interviews with 47 farmers living in 12 communities (13 along roads, 34 along rivers) were conducted during visits to the area in June and July of 1999, 2000, and 2001. The communities were selected to cover the full range of variation across the study area. Individual respondents were selected randomly within each community. In these semistructured interviews, specific quantitative questions on land use and social histories were posed to all respondents (e.g. How many ha of pasture do you have on your farm? and, How long have you resided on this farm?). Information regarding the location of the farm in relation to roads, rivers and the city of Puerto Maldonado was obtained from the interviews and from satellite images, e.g. the distance in km to travel to Puerto Maldonado. Also interviewed were a series of key informants officially involved in land-use planning and forest conservation, e.g. the former head administrator of the Agrarian Bank. Finally, during June 2001, preliminary results from the remote sensing analysis were discussed in a series of meetings with local scientists, farmers, government officials, and university students. This was done to evaluate the interpretation of the remote images, and to better understand local perceptions of land-use changes and causes.

Data analysis: Interview data were statistically analyzed using the individual farm as the unit of analysis. For each farm, the percentage of forest, fallow area, pasture, and cropland, was compared to five predictor variables: *i*) river *vs* road: whether the farm is located near one of the major roads or rivers; *ii*) distance to Puerto Maldonado: measured both in km (mean = 19 ± 11), and in travel time in minutes (mean = 130 ± 99); *iii*) within or outside the Tambopata Candamo Reserve Zone; *iv*) origin of the farmer: whether the farmer's previous residence was in the Andean or Amazonian region; *v*) year of arrival: whether the farmer acquired the land before or after 1985, the year when the APRA government began providing economic subsidies for agriculture.

The relationship between variables was first explored by means of univariate statistical analysis, e.g. origin of the farmer. The Mann Whitney U test (for nominal variables) and the Spearman rank correlation (for continuous variables) were used. A multivariate model was used to further evaluate and rank the more influential predictors of land-use composition. Given the nature of the data (both continuous and categorical data), an ANCOVA test provided the best approach to analyze the multivariate relationship. (See (25) for more details on data and analysis.)

Figure 2. Areas of forest clearing and regrowth in the 4 sub-regions studied.



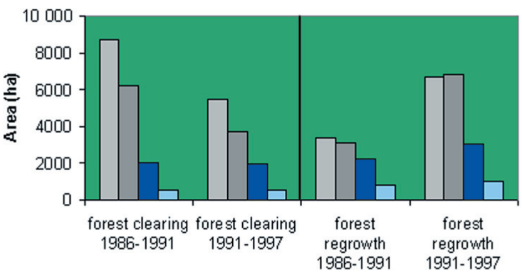
RESULTS

Satellite image interpretation indicated that approximately 29 112 ha of mature forest were cleared during 1986–1997—mature forest cover was reduced from 353 281 ha to 348 394 ha—and 24 225 ha regenerated as secondary forest. These measurements yield a relatively slow annual deforestation rate of 0.7% (gross clearing) and 0.1% (net change in forest cover) across the study period. However, these rates varied considerably over time. Between 1986 and 1991, forest was cleared fairly rapidly (net annual deforestation = 0.5%), but deforestation then slowed and even reversed between 1991 and 1997 (net annual deforestation = – 0.2%). While deforestation was relatively slow for the region as a whole, there was rapid clearing along major roads (Fig. 3). Areas neighboring the Road to Cuzco and Road to Brazil lost more tall forest than did areas along the Tambopata and Madre de Dios Rivers (11.7% *vs* 7.0%; annual gross deforestation 1.1% *vs* 0.6%, 1986–1997; annual net deforestation = 0.2% *vs* – 0.2%) (Fig. 3). And again, deforestation rates varied during the study period. Forest clearing proceeded rapidly along the Highway during 1986–1991, but then slowed significantly during 1991–1997 (Fig. 3). By contrast, deforestation along the river remained fairly constant throughout the study period (Fig. 3). All four subregions experienced significant forest regrowth which accelerated during 1991–1997 (Fig. 3).

Results from field interviews reveal similar land-use patterns at the household level. Univariate analyses revealed that land-use composition at the farm level was correlated with the location of the farm in relation to roads and rivers. Farms along the rivers had a significantly higher percentage of area in cropland and forest than did farms along the road (mean = 16% ± 19% cropland for riverside farms, 5% ± 5% for roadside farms; 63% ± 21% forest for riverside farms, 28% ± 34% for roadside, n = 34) (Table 3). Similarly, riverside farms had a significantly lower percentage of land dedicated to pasture (mean = 3.2% ± 7.4%) than did roadside farms (35% ± 39%) (Table 3). Long-term Amazonian residents tended to have more forest on their farms (mean = 60% ± 23%) than did recent colonists from the Andes (36% ± 38%) (Table 3). But in multivariate analysis only two land-use predictors were significant:

Proximity to urban market and road vs rivers. When tested against the other predictors in the multivariate test, the location of the farm in relation to roads and rivers was the strongest predictor of the percentage of pasture in landholdings ($F_{1,42}$ = 13.66, p = 0.0006). *Roads vs rivers* was also the strongest predictor of the percentage of farm in cropland ($F_{1,44}$ = 6.16, p = 0.017). Furthermore, the univariate analysis suggested that farms inside the TCRZ had more land in forest and croplands and less land in pasture than farms outside of the TCRZ (for TCRZ farms, mean = 73% ± 12% forest, 16% ± 9% cropland, 0% ± 0% pasture; *vs* 43% ± 31% forest, 11% ± 12% cropland, 18% ± 29% pasture for farms outside TCRZ) (Table 3). Nevertheless, the farm's location within or outside the protected area was not a significant predictor in the multivariate analysis.

Figure 3. Forest loss and regrowth in the 4 sub-regions studied. % total buffer area, buffer area = 3 km for river study zones and 8 km for road study zones.



DISCUSSION

Linking Field Interviews to Remote Sensing Analysis

In this study, remote sensing analysis in combination with field interviews revealed regional and temporal variation in deforestation at Tambopata. Both semistructured and unstructured interview data confirm the trends observed in remote sensing analysis, and they offer additional insights on local land use practices. The multivariate test of interview data confirmed the remote sensing observation that areas along the roads contain the largest deforested areas. Riverside farms today have more land in both crops and forest than do roadside farms where pasture and successional growth predominate. The interviews also provided insights on individual land-use strategies during the study period.

Local residents consistently commented that higher rates of deforestation during 1986–1991 were due to rapid clearing of forest areas for cultivation and cattle ranching under state-sponsored agricultural incentives. For example, a key informant described how

"Don Jose (a prosperous local farmer) hired a team to cut 10 ha at a time when he had support from the Agrarian Bank. But when the Bank closed, he abandoned his lands in Isuyama (roadside site) and got land in the community of Baltimore (riverside site) instead, where unclaimed land was available". (Torres, F., 2001, Puerto Maldonado, pers. comm.)

Regrowth during 1991–1997 was mainly attributed to the decrease in forest clearing activity and the abandonment of agricultural lands due to the elimination of agricultural incentives and poor transportation conditions for marketing of agricultural products. A roadside agriculturalist explained the difficulties he faces today.

"We farm because it is our custom; to not abandon the farm, and to feed our chickens. There isn't any profit in it. If we go to market, we have to pay a lot for the transportation, buy a lunch, and they don't even pay you right away". (Villanueva, S., 2000, Comunidad de Castañales, pers. comm.)

Local people also agreed with the patterns of deforestation and regrowth along roads and rivers perceived from the satellite images. People attributed the decrease in forest clearing activities along the roads to the migratory patterns of peasants struggling to cope with the ending of the agricultural credits in the early 1990s. When credits dried up, agriculture was no longer profitable, and many farmers moved to areas along rivers, where more

Table 3. Results for the Univariate analyses (n = 47).

Independent variables and Test	Test	Parameters	Dependent variables: Landuse types % Closed-canopy forest	% Pasture	% Cropland	% Fallow areas
River *vs* road	Mann Whitney U	Z value P value	–2.92 0.0035**	3.05 0.0023**	–3.18 0.0015**	–0.36 0.72
Proximity to urban market	Spearman correlation	r_s value Z value P value	0.52 3.50 0.0005**	0.35 –2.34 0.019*	0.23 1.57 0.12	0.22 –1.48 0.14
Origin of the farmer	Mann Whitney U	Z value P value	–1.79 0.074	–1.48 0.14	–1.27 0.20	0.95 0.34
Time of arrival	Mann Whitney U	Z value P value	–1.27 0.20	–1.42 0.16	0.37 0.71	2.11 0.035*
In or outside the protected area	Mann Whitney U	Z value P value	3.53 0.0004**	–2.96 0.0031**	2.05 0.041*	1.23 0.22

$^*\alpha \leq 0.05$ $^{**}\alpha \leq 0.01$

fertile land was available. Others moved to the city of Puerto Maldonado, attracted by the social support programs implemented by the Fujimori government (17). Although many people described an increase in forest clearing activities along rivers during the Fujimori regime, this pattern was only captured by the satellite images for one of the river areas (Tambopata River). In general, remote sensing analysis shows that forest clearing activities along rivers remained relatively constant from 1986–1997, while forest clearing activities along the road decreased considerably after 1991.

Conservation Implications for Tambopata

The area under secondary forest in Tambopata is expanding significantly, particularly along the road. Although old-growth forest has greater ecological and economic value (26, 27), secondary forest can provide benefits, including medicinal plants, soil recuperation, hunting areas, and environmental services such as carbon sequestration (27, 28). Secondary forests can be managed to provide many of the products that small-farmer households traditionally obtained from primary forests while still maintaining environmental services (26, 27). In Tambopata, local hunters value secondary forest areas as a source of small game (29). Some fast-growing pioneer tree species, e.g. *Iriartea deltoidea*, have commercial value as construction material (30). However, secondary forest can only partly replace the ecological and economic services provided by primary forests (27). For this reason, it is important to map and track not just forest *per se*, but processes of deforestation and regrowth and to incorporate such knowledge into sustainable forest management practices. The observed pattern of deforestation suggests two important areas for conservation interventions in Tambopata: *i*) protect old-growth floodplain forests; and *ii*) enhance the economic value of secondary forest and promote its regrowth where possible. Old-growth riparian forests are one of the most rare and vulnerable forest types in Amazonian ecosystems (18). In Tambopata, these areas contain valuable giant specimens of species that have been removed elsewhere such as *Ceiba pentandra*, and they hold high densities of endemic plants. Floodplain forests also provide important habitat for wildlife, including 50% of the region's bird species (18). Given the high economic value of Tambopata's riparian forests and the fertility of their soil, these areas are hotly contested by agriculturalists, loggers and ecotourism companies (31). Effective conservation will no doubt entail difficult public negotiation and compromises by interested stakeholders.

Comparing Tambopata to Other Amazonian Sites in Peru and Neighboring Countries

The impact of agrarian policy on forest clearing that we measured in Tambopata was also observed elsewhere in the Peruvian Amazon during the same period (10, 11). During 1986–1989, the amount of agricultural credit flowing into the Peruvian Amazon tripled from mean levels for the previous 10 years (10). This expansion in lending allowed local residents and colonists to clear 10 000s ha of primary forest for croplands and pasture (10, 11, 32). Despite this substantial flow of credit, the national program largely failed to increase agricultural productivity or improve the welfare of the Amazon peasantry (20). In Iquitos, in the northern Peruvian Amazon, Coomes (10) concluded that the credit program failed because it suppressed economic competition among local producers, and it was issued with no regard to spatial particularities such as soil conditions, land availability, and access to markets. In Iquitos, as in Tambopata, when agricultural credit was eliminated, deforestation decreased considerably, from an average of 6634.5 ha deforested yr^{-1}, to 1339.0 yr^{-1}, although population continued to increase (11). Roadside agricultural lands were often the first to be abandoned because soil fertility in these areas had been exhausted by intense cultivation of rice and pasture funded by state credit (17). Experts warn that if similar credit projects are implemented in the future, large areas of primary forest will be replaced with pasture, and lands in rural communities will be further degraded (10).

Like Peru, other Amazonian countries have heavily promoted the expansion of agricultural frontiers and occupation of remote territories resulting in major forest clearing (14). In every case, roads and rivers have been essential for providing colonists access to remote areas and linking them with urban markets (11, 13, 33). Considering that the most massive colonization occurs along roads, not rivers, current plans to expand Amazonian highways and secondary road networks represent a serious threat to remaining forests (13, 33, 34). However, the rate and extent of clearing along roads is mediated by socioeconomic factors. In particular, poorly designed credit schemes can greatly accelerate deforestation. In Brazil, for example, state-sponsored incentives for cattle ranching implemented in the 1980s resulted in the conversion of forest to pasture in the Brazilian Amazon at an average rate of 35 000 km^2 yr^{-1} (7). Agricultural credits expedited deforestation by offering easy credit to individuals establishing large ranches (34). Similarly, colonists in Rondonia, Brazil, used state credit to purchase chainsaws and deforestation accelerated accordingly (34). Without these subsidies, forest clearing activities would likely have been much lower, as deforestation rates declined after the removal of the incentives in 1987 (7).

In Bolivia, state financial incentives did not drive deforestation, but private credit funded a massive expansion of agro-industrial activities within the Department of Santa Cruz (9, 35). It is important to note that the same type of neoliberal policies, e.g. private *vs* public credit, and privatization of landholdings, which constrained deforestation in Tambopata facilitated massive clearing for soybeans in Santa Cruz (35). This contrast underscores the need to consider regional context in predicting the impact of agrarian policy. In the future, as Tambopata's highway is improved, and its economy globalized, a flow of private credit could potentially cause similar land-clearing scenarios as occurred in Santa Cruz.

In sum, the flow of both state and private credit has accelerated deforestation across the Amazon, often without significant improvements in rural livelihoods (3). But rather than working against credit schemes altogether, conservationists ought to lobby for programs that support the restoration and cultivation of degraded fields and pastures, or other alternative land-use practices, such as agroforestry systems and natural forest management. Moreover, credit programs must be sensitive to spatial patterns of land use (10), and buffer ecologically vulnerable areas, such as old-growth riparian forests.

CONCLUSIONS

Significant Expansion of Secondary Growth

Analysis of Landsat images revealed an unexpectedly slow rate of deforestation in the 414 759 ha study region of Tambopata in southeastern Peru. Net annual deforestation averaged 0.1% during 1986–1997, a value well below the estimated national rate of 0.4% (1990–2000 (36)), and below the estimated 0.3% rate for the neighboring Brazilian state of Acre (1988–1997 (37)), and ~ 0.2% for neighboring lowland forests in the Bolivian Department of La Paz (1992–1994 (35)). However, while deforestation rates for the entire Tambopata study region were relatively slow, forest clearing was spatially concentrated along roads where 11.7% was cleared (gross deforestation = 1.1%; net deforestation = 0.2%). Time series analysis revealed the dynamic quality of deforestation along these frontiers. During 1986–1991, roadside forests were cleared more rapidly than riparian forests. Then, during 1991–1997, clearing along the road slowed enough that there was a net gain in forest cover due to secondary regrowth. Deforestation in riparian forests remained fairly constant throughout the study period.

The Impact of Boom and Bust Credit Cycles on Deforestation is Clearly Visible in Remote Images

The drivers of deforestation in Tambopata parallel those for other Amazon regions, where most deforestation is traceable to the construction of roads and to the institution of state-promoted agricultural incentives (10, 12), but see Hecht (9) for an example of private credit driving forest conversion. The Tambopata case reveals that the impact of roads on forests is shaped by national economic and agrarian policies. As elsewhere in the Amazon, in Tambopata it was the combined influence of infrastructure and economic policy that dramatically altered land use (25). This is reflected by the fact that roadside deforestation was most rapid in the second half of the 1980s when credit and land title were easily available for colonists. Later, when easy credit was removed, roadside deforestation slowed significantly, even as improvements were made on the road. Many peasants responded to the neoliberal austerity measures of the 1990s by farming along rivers where market access was limited, but soils were better suited for cultivation.

Combining Remote Sensing and Field Interviews Reveals Causal Explanations for Deforestation

Combining remote sensing analysis with field interviews and public discussions offers an effective means for understanding the impact of national policies on land-use and land-cover change in Tambopata. The interview data revealed that the land-use trends observed at the regional scale were also operating at the household level. Moreover, the interviews uncovered influential socioeconomic variables that were not visible in a satellite image, e.g. long-term residents maintained more forest on their land, and brought to light individual strategies for coping with dramatic policy shifts.

Need for Conservation Interventions at Local and National Scale

Conservationists aiming to slow Amazonian deforestation ought not only to implement local projects to protect or restore forests, they must also participate in national discussions and decisions regarding agrarian policy and infrastructure development. Even the best forest management field projects are vulnerable to fluctuations in markets, credit, and access. Conservationists should lobby for programs that support the restoration and cultivation of degraded fields and pastures, or other alternative land-use practices, such as agroforestry systems and natural forest management. Moreover, credit programs must be sensitive to "spatial particularities" and discourage clearing in ecologically vulnerable areas, such as old-growth riparian forests.

References and Notes

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