

Human landscapes have complex trajectories: reconstructing Peruvian Amazon landscape history from 1948 to 2005

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Received: 15 August 2006 / Accepted: 18 June 2007 / Published online: 14 July 2007
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Abstract Long-term landscape history studies can probe the complexity of landscape dynamics that appear linear or determined by a single driver on shorter time scales, and may span variations of both human-initiated and naturally occurring drivers. With a variety of historical sources this study traces the history of landscape change in Amazonian communities that have existed since the early 1900's, in a region comprising both upland and riverine ecosystems. Aerial photography from 1948, 1965 and 1977 and satellite images from 1993 to 2005 are analyzed to reconstruct spatial transformations of the study region. The reconstructed landscape history is analyzed as a result of shifts in economy, policy, local markets and river dynamics. In 1948, the upland region was used for agriculture and farms appeared to be encroaching into primary forest. However by 1965, 49% of the upland farm area had become secondary forest, as farmers left upland farms fallow and moved into the floodplain to farm crops promoted through agricultural credit programs. Between 1965 and 1977 river channel migration affected the riverine landscape, dramatic floods occurred throughout the Amazon River and many farmers migrated to the city. During the 1980's the credit given to small farmers greatly increased, resulting in the highest

density of farms in the landscape by 1993. The disappearance of these credits is reflected in reduced farming activity and increased charcoal production. The results show that agricultural activity and deforestation do not always have a simple trajectory of increment.

Keywords Amazon · Deforestation · Floodplain dynamics · Landscape history · Iquitos

Introduction

The dramatic deforestation rates in Amazonian forests have attracted many researchers to analyze land-cover change patterns and develop new models (Hecht and Cockburn 1990; Skole and Tucker 1993; Pfaff 1999). These Amazonian studies have often focused on upland regions that have recently been colonized by humans. Hence the analysis is confined to a short sequence of events and to a particular class of Amazon forest. However, the Amazon has historically been populated by rural non-indigenous communities that date from the 19th century, and many of these inhabit floodplain regions (San Roman 1975; Stanfield 1998). The few studies that have analyzed land-cover change in these older communities or in riverine areas have mainly relied on recent remote sensing imagery as well (Brondizio et al. 1994; Zarin et al. 2001). Because of this, the current interpretation of Amazonian land-cover change is predominantly

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based on studies of modern dynamics and upland processes. Thus it is important to analyze the patterns and processes of change in floodplain regions and to evaluate what information might be overlooked by focusing exclusively on recent events of Amazonian deforestation.

The Amazonian upland and floodplain are ecologically distinct, and the land use practices (Denslow and Padoch 1988; Hiraoka 1992) and the biophysical composition (Kalliola et al. 1993; Junk 1997) for these systems differ greatly. The floodplain is subject to significant transformations by geophysical processes on directly observable timescales, because of the river channel migration (Salo et al. 1986). The upland forest is significantly transformed by humans through processes which are well documented across the Amazon (Laurance et al. 2004; Nepstad et al. 1999; Uhl and Kauffman 1990). Most Amazonian land use studies to date either analyze the upland or the flooded forests (Pinedo-Vasquez et al. 2002). In this study I consider an area in which both of these ecosystems are present and are being managed by humans. By including a Peruvian floodplain area the study can include the effects of natural events on the landscape through history, and probe the interactions of human and natural disturbances. The analysis can illustrate how changes in the floodplain geography might compare to changes in government policy or market demand in their influence on land use in the combined upland-floodplain ecosystems.

Besides using a setting in which humans and natural events shape the forests on comparable time scales, this study accesses an interesting temporal frame using historical aerial photography. Black and white aerial photography has not been extensively used for reconstructing land-use change in the Amazon, although regions of the Amazon have been photographed in black and white from airplanes since the late 1930's. The technique allows mapping of the landscape over much longer time-spans, permitting an analysis of the effects of a series of transitions in economic, biophysical and political conditions. In some cases it is also useful to analyze image data at a scale appropriate to studies of agricultural land-use: agriculture is traditionally practiced by small-holder farmers who commonly farm units smaller than a hectare. While these plots span a few pixels and can be detected in the satellite images, such fine scale agricultural patches are generally difficult to classify

and hence are often neglected in large-scale analyses such as regional studies. The classification of a series of air photographs is feasible in a study such as this one, but is less practical in broad regional studies, since spatial rectification and analysis of fine scale historical black and white aerial photography is more labor intensive than satellite image analysis.

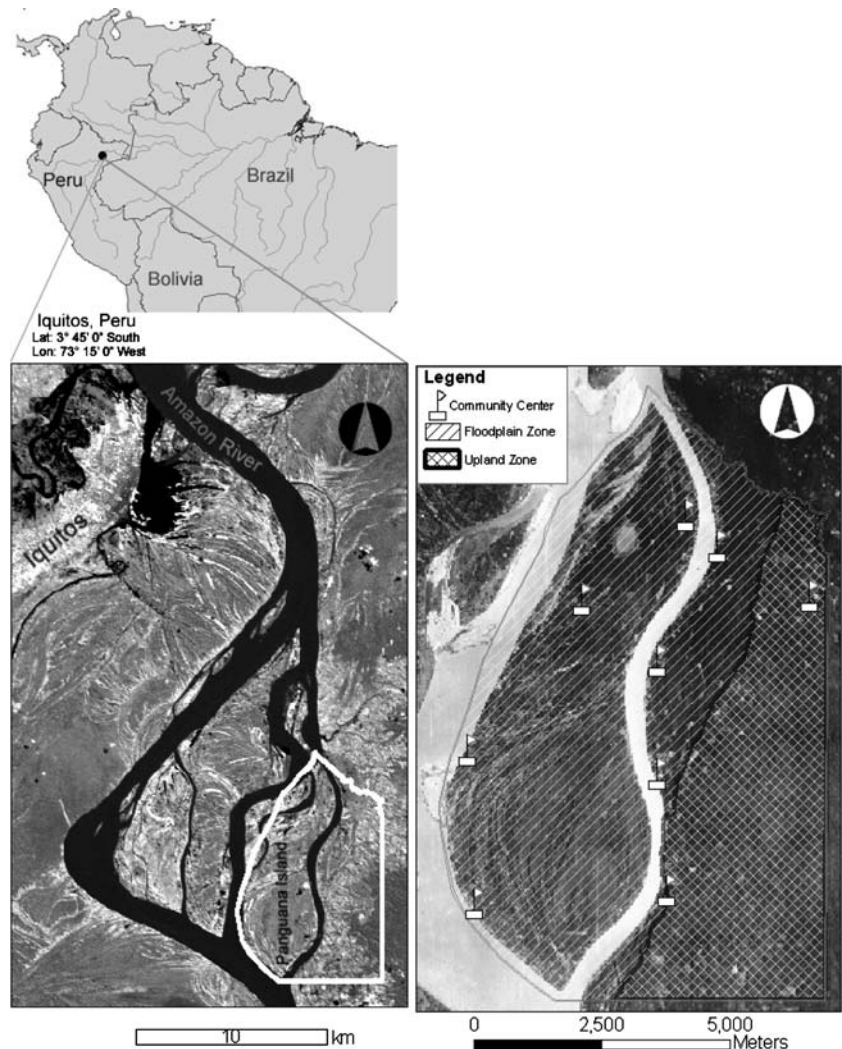
Our current understanding of Amazonian deforestation and change processes is due to studies involving a variety of approaches, the diversity of which reflect the difficulty of tracing both spatial and social processes to explain landscape dynamics. Some researchers in the Peruvian, Ecuadorian and Brazilian Amazon have used satellite image analysis (Maki et al. 2001; Messina and Walsh 2001; Ferraz et al. 2005), and some have correlated the land-cover data derived from images with socio-economic variables (Deadman et al. 2004; Pan et al. 2004). There are also distinct historical studies describing the transitions in land-use and agroextractive markets (Santos-Granero and Barclay 2000; San Roman 1975; Bunker 1984). Outside of the Amazon, some studies have addressed the spatially explicit data together with historical information (Klepeis and Turner 2001).

This study relies on oral histories to augment social and economic statistics and archival data in constructing a detailed description of human interaction with the space. Using remote sensing imagery from 1948 to 2005, and socio-economic historical information from the numerous sources cited below, I attempt to determine how patches within the Peruvian Amazon landscape have changed since the 1940's, which patches have been conserved and which have been in constant transformation, and how the land-cover transitions can be explained by the historical data.

Study site

The study area is located 20 km south of the city of Iquitos in the Peruvian Amazon (Fig. 1). The region can be interpreted as two connected systems, the floodplain (*várzea*) and the upland (*tierra firme*). The floodplain is the region that is exposed to seasonal river floods. The river's water level fluctuates up to 10 m between the low water season (August–October) and the high water season (March–May). The floodplain is mainly composed of alluvial soils

Fig. 1 Location of the study area. The first image locates the region within South America, the second places it within the greater Iquitos region, and the third shows the location of communities in the study area, and the demarcation between the upland and the floodplain



that have been deposited by the Amazon River during the flood pulses. The landscape is characterized by a set of curvilinear levees interspersed with vast swamps, interlevee lakes and other wetland features (Kalliola et al. 1993). The swamps are low drainage areas and exhibit several different kinds of vegetation cover: some are populated by strangler figs, large palms groves and timber species, while less densely vegetated swamps are covered by floating vegetation, *Monthocardia* sp., *Triplaris* sp., *Bactris* sp., thin *Cecropia* sp. and sparse Bombacaceae. In the newly-created floodplain areas, *Gynerium* forests can be observed: these are patches dominated by the grass species *Gynerium sagittatum* which reaches up to 15 m in height (Kalliola et al. 1991; Dekroon and Kalliola 1995). The floodplain (including the lakes

and river, which are not found in the upland) makes up about 66% of the study area.

The upland is the remaining 34% of the region, composed of a set of forested and farmed hills of older sediments, mostly of Tertiary origin (Hiraoka 1986). In the hill valleys there are small creeks mainly surrounded by palm vegetation (Vormisto et al. 2004). This landscape is not exposed to the river floods, and hence demonstrates a different vegetation composition than the floodplain.

The region is inhabited mainly by ribereños, which are the Spanish speaking non-indigenous Amazonian peasants. They are the descendants of Amazonian indigenous groups, Andean indigenous groups and immigrants that mainly arrived during the rubber boom era at the end of the 19th century. The word

riberaño means “river people” in Spanish, and they often live at the edge of river channels. They have historically practiced a variety of agroextractive activities including swidden-fallow agriculture in both the floodplain and upland, maintenance of plantations and orchards, extraction of fruit, timber, charcoal and medicinal plants from the forests, and the raising of livestock such as birds, pigs, and cattle. Many families invest time in more than one agricultural activity, and have developed many strategies to cope with the river dynamics and to manage both the floodplain and upland ecosystems.

To allow a fine scale analysis of change, a 6,948 ha study area was selected based on the available aerial photography and the community boundaries. In 1948 the area was composed of 2,370 ha of land in the upland and 4,578 ha of floodplain, of which 685 ha were river. On the eastern side, the site is bounded by the limits of the 1965 air-photograph coverage. The other limits followed community boundaries: the northern limit was determined by the small tributary Yanayacu, the western borders were defined to include Panguana Island entirely and the southern boundary includes Panguana Island and the limit of Colpa, a town that neighbors the urban town of Tamshiyacu. Clusters of houses and farmlands can be observed in the entire region since the first air photograph in 1948, but most of the current town names were officially established later (Atarama Lonzooy 1992). Presently the region is composed of 10 towns and a population of 1,500 (INEI 1994).

Methods

The image analysis is based on vertical air photographs taken from below military aircraft in 1948,

1965 and 1977, and Landsat satellite images from 1993 and 2005. The air photographs for each year comprise a set of overlapping images, constructed from negatives scanned at 15 micron resolution. The high-resolution scanning produced digital images with pixel sizes less than 1 m in all cases (Table 1). The images were orthorectified using the GPS-measured positions of stable landscape features such as roads, houses or supporting columns, which often remained after a house was abandoned or destroyed. The overlapping images were used to produce orthostereographic (three-dimensional) data according to standard stereo-photography techniques (Wolf and Dewitt 2000). The satellite images were geometrically rectified using ground control points. For both photographs and satellite data, some ground control points were reserved to test the accuracy of rectification. The precision was measured to be better than 3 m for all photographs and 15 m for satellite images.

All images were classified into nine cover type classes (Tables 1 and 2). Although dozens of land-cover and forest types are described for the Amazonian lowland region (Tuomisto 1993), the images were classified in these nine broad classes to increase the accuracy of the air photograph and satellite image classification, and to simplify the interpretation of transitions from one year to another. The nine classes also attempt to reflect how the local population makes land-use decisions. The categories are farm-fallow, secondary forest, mature forest, high-density swamps, low density swamps, lakes, river, sand and Gynerium forest. Since farmers of this region practice intensive management of fallows (Hiraoka 1985; Padoch and de Jong 1991; Pinedo-Vasquez et al. 2002), and because young fallows are spectrally and visually difficult to separate from farms, they have been grouped into one class. Forest patches with a canopy

Table 1 Sources of remote sensing data used in the analysis: Servicio Aerofotográfico Nacional, Instituto Geográfico Nacional, Global Land Cover Facility, and the USGS EarthExplorer

Year	Data type	Original scale	Date	Water level (m)	Source
1948	Aerial photo	1:40,000	Nov 2 1948	–	SAN: 3094
1965	Aerial photo	1:30,000	Jan 27 1965	–	SAN: 132-64-A
1977	Aerial photo	1:60,000	Aug 24 1977	115	IGN/SAN 75-1
1993	Landsat TM	–	Aug 5 1993	112	GLCM
2005	Landsat ETM	–	Aug 14 2005	109	USGS

All aerial photographs were originally scanned with a resolution of 15 microns, digitized, and converted to 30 × 30 m raster format. The two Landsat images also have 30 × 30 m pixels

Table 2 Land-cover categories used in describing and classifying the study region

Class	Description
Agriculture/Fallow	Areas that are actively farmed or that have recently been left fallow, such as areas covered with <i>Heliconia</i> sp., bushes and dispersed plantain trees
Secondary forests	Forests with a canopy height lower than 35 m, or degraded mature forests
Mature forest	Forests with a canopy height higher than 35 m that are dense with a complex canopy stratification
High density swamps	Forests in areas which are (almost) constantly inundated, have trees higher than 25 m, and greater than 50% canopy cover
Low density swamps	Forests in areas with low drainage that have sparse trees or trees shorter than 25 m
Lakes	Interlevee lakes
River	Main channel of the Amazon
Gynerium forest	Forests and fallows dominated by <i>Gynerium</i> sp.. This class is only seen in the floodplain
Sand/Mudflat	Bare land as a result of river meandering soil deposition. This class is only observed in the floodplain.

The choice of classes is discussed in the methods section

higher than 10 m that were deforested at least 30 years ago are considered secondary forest. Mature forests are those forests that have a canopy height higher than 35 m. The swamp categories were introduced earlier: high density swamps include low drainage areas encountered in the lowland with a canopy higher than 25 m, and low density swamps have floating vegetation and smaller tree species.

The aerial photographs were classified into the nine classes using stereo analysis, which allowed the topography of the region and differences in the height of the canopy to be directly observed. The general features of the regional topography, and the boundary between floodplain and upland, were deduced from the stereo photographs and verified using surveys with an engineering level in the field (Arce-Nazario 2006). The classification resulted in polygons that were converted into raster data with 30 m resolution, in order to allow comparison with the satellite images. This conversion did result in reduced accuracy of classification, from an edge-effect when boundaries were rasterized. In addition, data which can be easily detected in air photography but not at the coarser scale of satellite images, such as the types of crops in agricultural plots, was discarded in the statistical analysis of transitions. The satellite images were classified using a prior probability maximum likelihood supervised classification algorithm. The overall classification accuracy for each of the images was above 87%. For the recent satellite images, accuracy was assessed primarily by ground-truthing, supplemented by interview data. The classifications

of older photographs were tested for accuracy using higher-resolution images and spatially referenced interview data. The final set of classifications was used to determine the cumulative index of change, C , which represents the number of class transitions in the 57-year study period. C is calculated for each pixel as the total number of pairs of consecutive images for which the pixel's classes are not equal.

Comparisons of satellite images in the floodplain can be affected by seasonal changes in the water content of the soil. The effect of the 3 m variation in water level between the 1992 and 2005 images (Table 1) was minimized by using training sets for each spectral class from ground-verified areas within the same image. The variation in water level did not affect the classification of air photographs, which was based on the canopy height and texture. Since satellite images were taken during the low-water season, they are comparable to the canopy-based classification. The spatial rectification, classification strategies, collection of spectral signatures and accuracy assessment are described in more detail elsewhere (Arce-Nazario 2006).

The history of land-use for the region was reconstructed through interviews with the community members and by recording individual oral histories. The interview technique for the in-home oral histories was an open-ended question format, with questions focusing on the changes in the landscape and the individual's interaction with it. Interviews generally began with an opening question such as "What was the area like when you were young?" A total of

42 recorded, in-depth individual interviews and seven with couples, as well as nine community meetings and 86 non-recorded informal conversations were collected. Participants were selected based on their willingness to participate and their familiarity with the area. The information on the personal and community level history was augmented through participant observation and walks with farmers through the landscape, synchronizing the recorded interviews with GPS mapping in order to obtain georeferenced historical data. This allowed a better understanding of the general agricultural activities performed through the years. The field interviews were conducted during four field visits between 2003 to 2005, which totaled 1 year and 6 months of research time in the field.

Timelines were created from local interviews and from archival information related to the agricultural economy of the region, which was primarily obtained from the Biblioteca Nacional del Perú and La Biblioteca Amazónica. The timelines also included information on extreme flood events, as these were often mentioned by the interviewees. The exact date of extreme flood occurrences was obtained from the historical record of water level measurements in Iquitos, available from the Servicio de Hidrografía y Navegación de la Amazonía. The history of demographic change was also included in the analysis (Table 3). Understanding the general socio-economic and environmental history of the communities and households was considered essential for evaluating the possible drivers of change.

The historical and interview data were compared to characteristics of each landscape pattern observed in the maps, such as land-cover areas and correlation to geophysical features. Because some of the interviews were geographically explicit, in many cases the

transitions in the mapped data could be directly connected to historical experiences or events. A potential source of error in combining historical data from interviews with the image data arose from interviewees misremembering or misrepresenting boundaries in the landscape, but in general the disparate sources were in remarkable agreement. The correlations between the datasets were analyzed to determine the influence of each socio-economic, environmental and demographic variable on the landscape pattern.

Results and discussion

The 1948 *barbasco* boom landscape

The first air-photograph of the study site shows a set of Amazonian farms in the upland encroaching into the mature forest (Fig. 2). More than half of the farm area was located in the upland. The interviews show that these were farms mainly dedicated to producing *barbasco* (*Lonchocarpus nicou*), a native plant that contains rotenone concentrated in the roots. This natural pesticide is also a compound traditionally used by Amazonians to fish. Interviewees explained that *barbasco* was propagated by cuttings, and was usually harvested 3–4 years after planting by unearthing the roots. Written records describe that *barbasco* was planted in this region since the early 1900's (Hernández 1924). However, it was not until the Second World War that *barbasco* found a large international market, especially from the United States (Santos-Granero and Barclay 2000). During the 1940's the *barbasco* exports had become so profitable that some expected the Amazon to return to rubber-boom prosperity. The market for *barbasco* had an important role in attracting new merchant houses to the nearby city of Iquitos (Santos-Granero and Barclay 2000). Also, as discussed in Padoch and de Jong (1990), the *barbasco* boom promoted extensive demographic displacement. Some of the oral histories of the Panguana region indicate that elders came to the Panguana region either as employees of a trader who would come to collect the *barbasco* from the farms, or as small-scale farmers interested in the business.

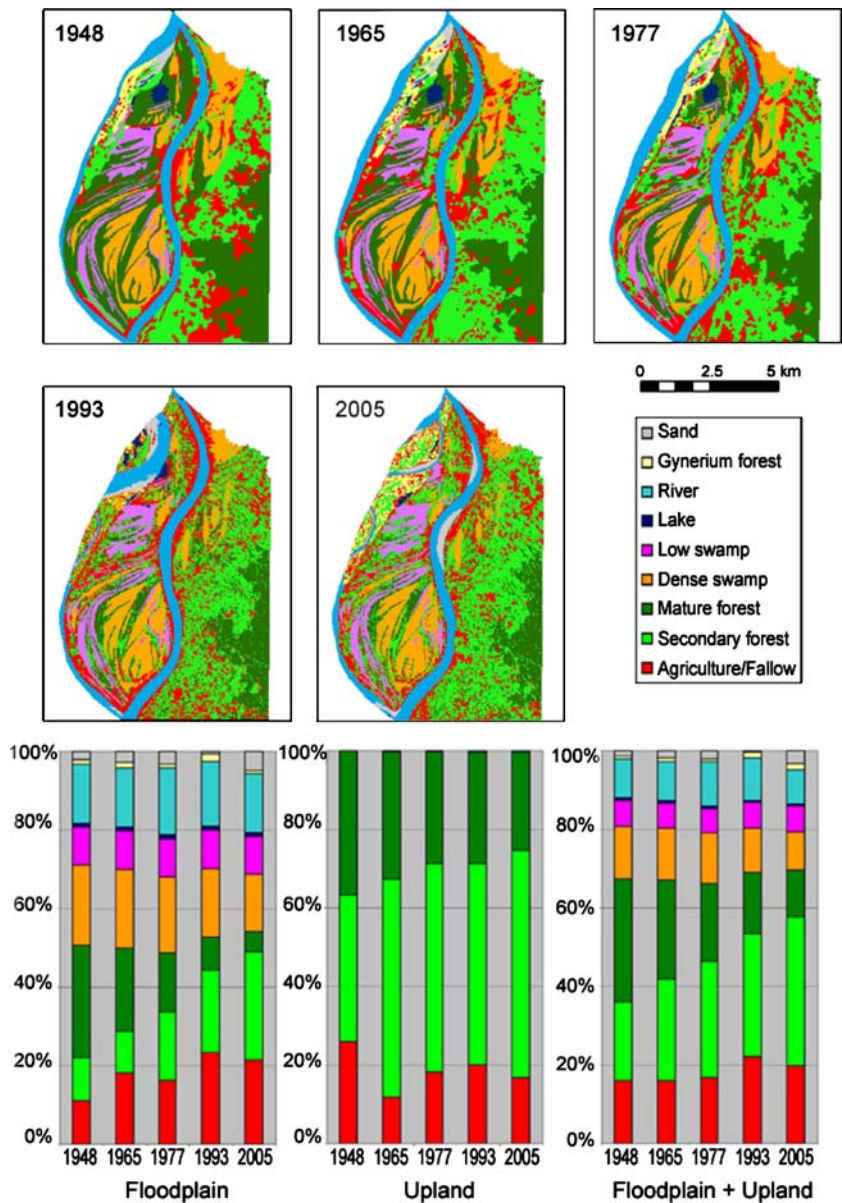
Oral history interviews elaborate details about the farming practices that are hard to distinguish in the

Table 3 Population by year for the study region and the nearby city of Iquitos

Year	Population: study region	Urban population: Iquitos
1940	1,046	31,828
1961	1,673	57,777
1972	1,661	110,242
1981	1,704	173,629
1993	1,548	274,759

Source: Instituto Nacional de Estadística e Informática del Perú (INEI)

Fig. 2 Classified images for each year, and bar graph of cover class percentages for the floodplain, the upland, and the entire region. The resolution of the air photographs has been reduced for comparison with the satellite images. Note that floodplain farms in the study region are characteristically narrow, following the shape of the levees. Upland farms tend to be more rectilinear in shape



images. *Barbasco* farming was performed entirely in the non-flooded forests of the Amazon. However, even during the *barbasco* economy plantations were intermixed with plantain, manioc and other plants and trees. Farmers also kept farms at the river’s edge and in other lowland regions, but most of these lowland farms were relatively smaller and directed toward subsistence farming, with the rare exception of farms maintained as cattle pastures. By 1940, the year that the first census was done in the Peruvian Amazon, 1,046 individuals lived in the Panguana region.

However, historical documents (Hernández 1924) and oral history suggest that in early 1900, before the *barbasco* boom, the region was populated by less than 10 households.

From 1948 to 1965: the jute boom

With the end of the Second World War, which allowed the United States access to Asian regions producing *Derris* sp. (another rotenone producing species), the demand for *barbasco* quickly decreased.

Furthermore, the commercialization of DDT in the 1950's resulted in the virtual disappearance of *barbasco* farming across the entire Amazon by the early 1960's (Santos-Granero and Barclay 2000). Upland farms were left fallow as ribereños moved back to the fertile floodplain soil, where newly accessible government credits supported farming (Fig. 2). The transition resulted in a 49% increase in secondary forest in the upland and the deforestation of 25% of the floodplain mature forest with respect to 1948 (Fig. 2).

In 1931 the Peruvian government created the Agricultural Bank, which had an important role in giving credit and seeds to farmers (Banco Agrícola del Perú 1931). However, it was not until 1943 that credits were given to farmers in the Peruvian Amazon, and not until the 1950's that loans were granted to small scale farmers in the Amazon (Banco de Fomento Agropecuario del Perú 1943, 1954). In the 1960's agricultural credits become popular, as farmers without a land title could apply for agricultural credit for the first time, thanks to the Agrarian Reform of 1962 (Banco de Fomento Agropecuario del Perú 1963).

For the Amazonian region the Agricultural Bank was interested in developing an infrastructure for the production and processing of jute and rice. Jute (*Urena lobata*), a herbaceous crop used for its fiber, was initially introduced into the Brazilian Amazon in the 1930's from Bengal by a group of Japanese immigrants (Winklerprins 2002). Brazilian jute seeds were then traded with the Peruvian government in 1952 (Banco de Fomento Agropecuario del Perú 1953). The production of jute was meant to fulfill the demands for sacks and fiber in Peru. Jute was planted in the lowlands close to interlevee lakes and swamps, because jute fibers must soak and ferment for an average of 15 days after harvesting (Banco Industrial del Perú 1965). Panguana Island was thus a particularly convenient place to plant jute, since it had many interlevee lakes and swamps. After soaking and drying, fibers were shipped to Iquitos (Banco Industrial del Perú 1965). Rice production was also concentrated in the low levees, especially in the mudflats, because as described in several interviews and in the literature these were relatively easy to clear and had good soil quality (Chibnik 1994). Pastures and certain types of plantain farms, visible on the mainland, were also promoted by the Agrarian Bank

(Banco de Fomento Agropecuario del Perú 1963). In the Panguana region of the image other crops are observed such as manioc, corn, and fruit orchards; while available credit clearly influenced the region's agriculture, these programs did not entirely dictate the kinds of farming that took place.

The 1965 to 1977 transitions

In 1948 the international market for *barbasco* resulted in a clear upland farming distribution and the economic shift to jute in 1965 showed an obvious increase in floodplain agriculture and a reduction in upland agriculture (Fig. 2). However, between 1965 and 1977 many variables play a role and do not allow such a simple interpretation of change. In the period from 1965 to 1977 there were dramatic demographic, economic and river changes which affect the resulting landscape patterns in ways difficult to distinguish from one another. The historical information obtained from written documents, oral sources, river level measurements and remote sensing images does not allow a clear separation of the causes of change.

By 1977 the provision of credit for jute had almost ended, but more credit was being given to plant other produce such as plantain, corn and rice, as suggested in informal interviews and the paucity of discussion about jute in the Agrarian Bank literature from those years. From 1965 to 1977 the number of loans given in the Peruvian Amazon region increased 9-fold: 1,463 loans at a total value of \$551,667 were granted in 1965 and 13,310 loans were granted at a total value of \$10,134,097 in 1977 (Santos-Granero and Barclay 2000). The 1970's were especially marked by an increase in funding for rice cultivation in the floodplain (Chibnik 1994). This sponsorship was accompanied by the creation of government supported buying centers that allowed farmers to sell at fixed prices. However, the effects of these programs were dampened by extreme floods and the growing oil economy.

Even though the accessibility of credit for rice cultivation was much greater in the 1970's than in the 1960's, and the floodplain population was virtually the same (Table 3), the farming cover in the floodplain in 1977 was 90 ha smaller than in 1965. The fact that lowland farm cover did not increase can be partially explained by the loss of 25 ha in the northwestern section of Panguana Island as a result of

river migration, a loss which is confirmed in the oral histories and by inspection of the air photographs at high resolution. The area contains most of the mudflats in the region, and as explained above, mudflats are preferred for planting rice. The reduction in floodplain farming can also be explained by the extreme flood events in the previous years that destroyed farmer's produce. Flood peak levels in the years 1971, 1974, and 1976 were 1.30 m higher than average, and May 1976 was the highest monthly average river level ever officially recorded for this region of the Amazon (Arce-Nazario 2006). The memory of devastating floods and losing farm produce may have encouraged the farmers to transfer their farms to the upland regions. This is supported by several interviewees' comments, and the observation that the farming cover in the upland areas was 149 ha (about 40%) higher than in the 1965 image, even when most credit was focused on floodplain agriculture. Another less obvious reason for the reduction in the floodplain farming cover while credit was increased could be the fact that, according to oral sources in the study area and to oral history projects elsewhere in the Amazon (Regan 1983), many male workers left to work in oil exploration and sent money to their rural families. The effects of the oil boom are clearly observed in the urban population of Iquitos, which almost doubled in the 11 year period (Table 3). This economic network could have resulted in reduced dependency on the land, as is suggested by some land use change studies in El Salvador (Hecht et al. 2006).

1977 to 1993: the peak and the end of agricultural credit

By the late 1970's the oil boom collapsed, and very few jobs related to oil exploration existed during the 1980's as described by oral histories. In 1990 Alberto Fujimori became the President of Peru, and a neoliberal policy was instituted in the country. By 1991 the agrarian bank had been dismantled (Santos-Granero and Barclay 2000).

The 1993 image shows the highest area of farm/young fallow coverage for the entire Panguana region, and for all the years considered in this study (Fig. 2). This large difference—an increase of 31%—from the 1977 farming pattern can be explained in part by the declining oil economy, but principally by

the agricultural credits distributed at the end of the 1980's. The late 80's was the peak of agricultural credit grants to small holders: 32,267 loans were given in 1989 (Banco Agrario del Perú, 1990). Many of these farms had recently been abandoned, so the classification categorizes 22.2% of the entire study area as farm/young fallow (Fig. 2).

A radical new pattern is observed in the 1993 image. Swamp areas that had been unchanged for the previous 50 years were suddenly deforested. Geographically referenced oral history interviews reveal that this deforestation is the result of more farmers participating in the market for charcoal. Farmers had been involved in the charcoal market for decades on small scales, often producing charcoal from their fallows or from the forests they cleared to farm (Padoch et al. 1985; Coomes and Burt 2001). In contrast, the new charcoal extraction took place in swampy areas. Oral sources explain that these areas are often uncontested property, that they are close to river transportation, and that trees found there produce high-quality charcoal. From 1977 to 1993, at least 135 ha (15%) of dense swamps were deforested, at a rate more than 4 times higher than the average for the previous periods. These estimates may be systematically low, as charcoal in swamps is in many cases produced from the *tangarana* tree (*Triplaris* sp.), which does not dominate the canopy of dense swamps. Trees like emergent Bomabacaceae and strangler figs, which do dominate the canopy of dense swamps, are not commonly extracted for charcoal. Hence areas where the extraction concentrated on *tangaranas* are not easily recognized as changed by the spectral classification.

2005: The recent dynamics

The satellite image from 2005 suggests that the disappearance of credit influenced the level of farming. The area covered by farm-young fallow is 168 ha (10.8%) less than in 1993. The significance of this measurement is low, but oral histories stress that most fallows currently observed were abandoned after the credit program ended. The concentrated charcoal extraction from the swamps continued. An additional 144 ha of dense swamp (18%) were deforested mainly for charcoal. This trend may increase in the near future, as the oral histories relate that five families in the towns of Gran Perú and

Panguana Primera Zona have changed land use strategies during the period from 2003 to 2005. These families now expend more effort in charcoal production, while agriculture has become a secondary activity continued mainly for household consumption. Even though there is access to farmable land, individuals are opting to extract charcoal from swamps rather than plant new crops.

Most farmers in the oral history interviews acknowledge that charcoal is the fastest way to earn money and has a relatively stable price, compared to other produce. Charcoal can be stored until the market is favorable, unlike other perishable agricultural products. The charcoal market appears to be stabilized by the increasing urban population that relies on charcoal for cooking, and by the popularity of barbecuing restaurants in the city. These types of changes in the local economy go relatively undetected as there is no agency keeping inventories of the agroextractive produce entering local ports. Hence, to obtain information about these local economies it is necessary to interview farmers, merchant boaters and wholesalers (Coomes and Burt 2001). Understanding the underlying processes of change in this region requires more than image analysis or access to official documents.

The overall history of change

A look into the overall history of changes of the Panguana landscape indicates that certain process and drivers of change have varied while others have not. While agricultural land use is a consistent feature of the images during the entire study period, the level and types of agriculture have not been constant but instead driven by networks on different scales (Fig. 3). The response to market drivers can be tempered by responses to biophysical processes, as shown in the rise of upland farming in the 1977

image. The temporal patchiness of farming in the upland and *várzea* has led to nonlinear trajectories, such as the rise and decline of agriculture in the floodplain from 1948 to 1977.

The overall history also demonstrates that the changes are spatially heterogeneous. From the map of the cumulative index of change, C , it is clear that certain regions were more prone to changes than others (Fig. 4). The most dynamic regions are the geometrically convex section of meanders, where most erosion takes place and farmers are forced to move their farms back. The least dynamic regions are the swamps and forests that are far from transportation routes, a common conclusion of most Amazon land-cover change studies (Pfaff 1999; Maki et al. 2001; Pan et al. 2004). Farms in the concave section of the river also show little variability. These are areas that are kept clear for the drying of seeds, or where families have small gardens which are constantly farmed. The regions nearest the river accumulate most of the new sediments brought by the floods (Wittmann et al. 2004), which allows the farmers to more intensively use these areas. The other dynamic regions are those areas that are part of the traditional swidden fallow management of the Amazon. These regions contrast with the areas that I term the boom regions, which changed once as a result of the *barbasco* or jute booms and have been left fallow thereafter. Typically the boom regions are no longer profitable because they are too far from transportation, or because the levee is too low to support any other form of farming. The *barbasco* boom region remnants have well-defined borders since they are found far from the river and close to the unchanged upland forest regions. In contrast, the jute boom remnants are close to swamps and creeks in the floodplain, in areas that are patchy to begin with, so the demarcation is not as clear.

Fig. 3 Timeline showing the history of economic, river, and policy transitions affecting the land-use practices in the study region

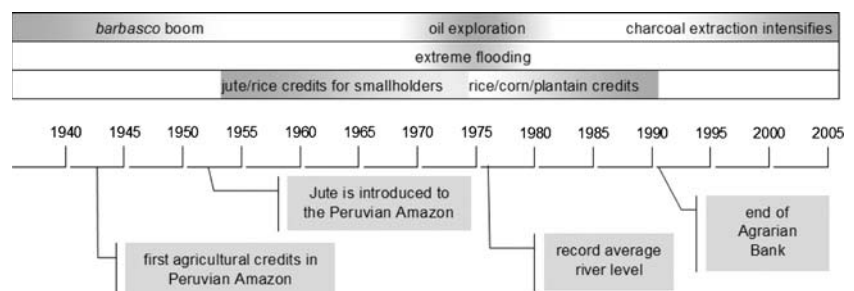
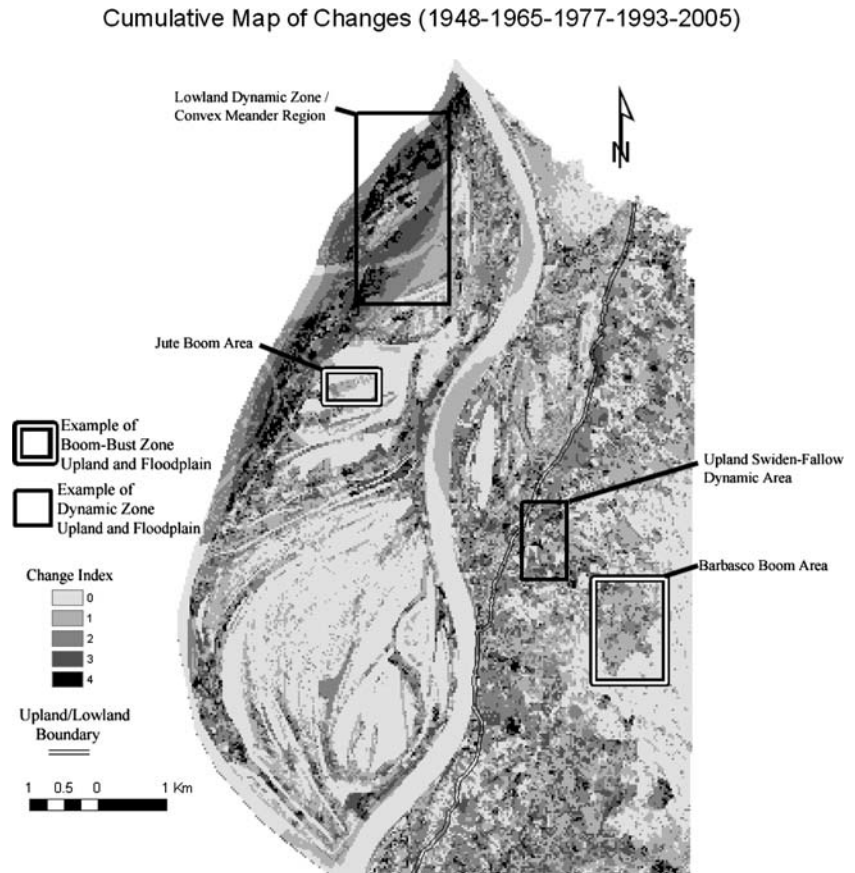


Fig. 4 Cumulative map of change. The change index C represents the number of class transitions in the 57-year study period. It is calculated for each pixel as the total number of pairs of consecutive images for which the pixel's classes are not equal



Conclusion

Authors of previous studies of Amazonian landscapes have insisted that their focus region is neither a unique example of change, nor representative of the entire Amazon. The Panguana region is also not unique or representative, but the heterogeneity of the landscape and temporal scale of the study allows us to observe certain patterns of change common to many tropical regions, such as afforestation as a response to economic and demographic shifts in El Salvador, Puerto Rico and Ecuador (Grau et al. 2003; Hecht et al. 2006; Rudel et al. 2002). The observation of change over this longer time-span reveals how the landscape has been shaped by a variety of economic drivers operating at international, national and local scales. It shows that deforestation trends have changed through history and do not necessarily follow a simple predictable pathway, as is sometimes suggested through conservation or demography research in the Amazon. Furthermore, landscapes

can be greatly transformed by unpredictable natural disturbances, which in turn alter human decisions and their future interactions with the landscape.

Even though a historical approach to the landscape changes of the Peruvian Amazon can not result in a simple predictive model of change, it allows us to reflect on the complex dynamics resulting from the interaction of both society and the environment. This study is a case demonstrating that the Amazon has had a history of change with variable peaks of deforestation rate, but also of forest recovery. Conservation and environmental advocates should consider these entangled processes when prescribing future policies.

Acknowledgements Special thanks to the families of the Panguana–Muyuy region who helped me throughout the project. The paper benefited from the comments of three anonymous reviewers. This study was partially supported by the NSF Dissertation Improvement Grant (# 0327293) and the Fulbright Fellowship. Any opinions, findings, and conclusions or recommendations expressed in this publication are those of

the author and do not necessarily reflect the views of the granting agencies.

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