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Road construction in the Peruvian Amazon: process, causes and consequences

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Summary

In the north-western Peruvian Amazon, a new road has recently been constructed to link the city of Iquitos with the town of Nauta. The road crosses lands that are remarkably heterogeneous in terms of ecological conditions, comprising distinctive soil types from extremely poor to relatively fertile. Although this reality contributes to the land use potential and human carrying capacity of each place, deforestation of road margins appears equally intensive on all types of land. In the mid-1990s, two dead-end roads starting from both urban centres were characterized by distinctive zones of resource exploitation, with a road-free section of primary forest in between. A few years later, the separate road ends were linked by a dirt road that served only occasional traffic, but introduced significant new settlement. Various developmental trends evidence incoherent resource management and momentary public support in the region. By promoting diverse economic activities that reflect environmental conditions in the initial land use planning and land allocation, most sections along this road could be considered economically valuable for purposes such as sustainable forestry, tourism, agroforestry and, in suitable sites, intensive agriculture. To promote the more sustainable uses, thorough environmental legislation, administrative guidelines and follow-up based on an implicit mechanism of learning from previous experiences should be implemented. At the local level, there are some important initiatives to support such development, including ecological and economic zoning. However, these measures might be too late to prevent the destructive practices so common in many parts of Amazonia.

Keywords: road construction, rain forest, deforestation, land use planning, Peru, Amazon

Introduction

Road construction in the Amazon has been internationally condemned as synonymous with negative development. This is not without reason, since there is an obvious causal relationship between road building and loss of forest cover; extensive deforestation beyond river margins only became possible after major road building efforts began in the early 1970s (Goodland 1980; Myers 1993). For example, in the Brazilian Amazon where road construction has been extensive, forests were lost at a rate of 22 000 km year^{-1} over the period 1978–1988 (Fearnside 1993). Since then, deforestation rates have fluctuated considerably, reaching more than 29 000 km year^{-1} in 1994–1995 and remaining relatively high until the present (Marengo 1998). In Peru, deforestation has been less destructive, and the cumulative total was 69 480 km^2 by 1995 (9.2 % of Peruvian lowland Amazon, INRENA [Instituto Nacional de Recursos Naturales] 1996). Road construction in Peru has also been less intensive than in Brazil: in the three lowland Peruvian provinces of Loreto, Ucayali and Madre de Díos, with a total area of 556 445 km^2, the current length of affirmed roads is only about 1000 km (Instituto Nacional de Estadistica e Informatica 1996).

Although road construction in the Amazonian lowlands has induced serious environmental, social and economic problems (Goodland & Irwin 1975; Eden 1990, 1998; Pfaff 1999), improving and intensifying the road network is an important development priority in many Amazonian countries. Therefore, the direct and indirect factors contributing to the road construction process and its environmental and socio-economic effects need to be identified and carefully analysed when striving for more sustainable development associated with road networks. The common attitude of conservation-minded people that road construction should be banned has unfortunately not only been ineffective in preventing repetitions of the destructive history of Amazonian roads, but it has also failed to acknowledge the interest that local people have in finding solutions (Cox & Elmqvist 1997).

Intensifying and maintaining the road network may also have other than negative implications. A well functioning farm-to-market transportation network may have a major impact on the establishment of stable local village economies based on long-term sustainability (Leinbach 2000). However, the distinct environmental variation of the different soil and landscape types to be reached by road building influences the probability of success of different land uses. While increased

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accessibility to new areas opens possibilities for economic development, restrictions of the human carrying capacity should be addressed seriously (see Fearnside 1997). The early establishment of property rights, including a statement defining the land uses allowed, and access to credit for the first settlers, may be a way of stabilizing the local economy and inhibiting the common problems of land speculation and turnover (Schneider 1995).

This paper documents an ongoing road construction process and the various environmental and socio-economic factors related to its outcomes in the north-western Peruvian Amazon. Linking the towns of Iquitos and Nauta with a 100 km long road, and thus occupying and exploiting the areas between, has been an important regional development priority since the early 1970s (Ministerio de la Presidencia 1998). During the first two decades, there was only intermittent progress in the road construction, but since the mid-1990s this has advanced without interruption. Once an all-weather road is established, the economic and social structure of the road's area of influence is likely to change rapidly, with substantial impacts on the surrounding ecosystems. To explore this process, the present paper has the following specific objectives: (1) to provide evidence of the remarkably heterogeneous environmental conditions within the road's area of influence, (2) to document phases of deforestation, road construction and settlement history in the region, and (3) to record the status of land use along the road in the late 1990s. We evaluate our observations in the light of possible future developments in the study region. We also discuss the role of knowledge, planning and legislation in the more general context of Amazonian development associated with road construction.

Study area and methods

Geography and history of the study area

The study area is located near the Peruvian city of Iquitos in the western part of the Amazon Basin at a distance of some 2500 km west of the Atlantic Ocean and 400 km east of the Andes (Fig. 1). Iquitos has no road connection to any other urban centre, but a good number of cars and motorcycles fill its streets. The only existing roads lead from Iquitos to some nearby riparian villages and toward the town of Nauta.

The environmental conditions in the Iquitos region are, in general terms, typical of the Amazon, but they are unique in detail, consisting of a mosaic of varying vegetation and soil types (ONERN [Oficina Nacional de Evaluación de Recursos Naturales] 1976, 1991; Kalliola & Flores Paitán 1998). The climate is humid tropical with annual precipitation close to 3000 mm. The soils are highly variable in terms of both their edaphic conditions and geological origin. The oldest sediments (the *Pebas* formation, see Hoorn 1993; Räsänen *et al.* 1995) represent sedimentation in lacustrine to brackish water conditions and are characterized by fine layered clays and silts that sometimes contain lignite or mollusc fossils. In

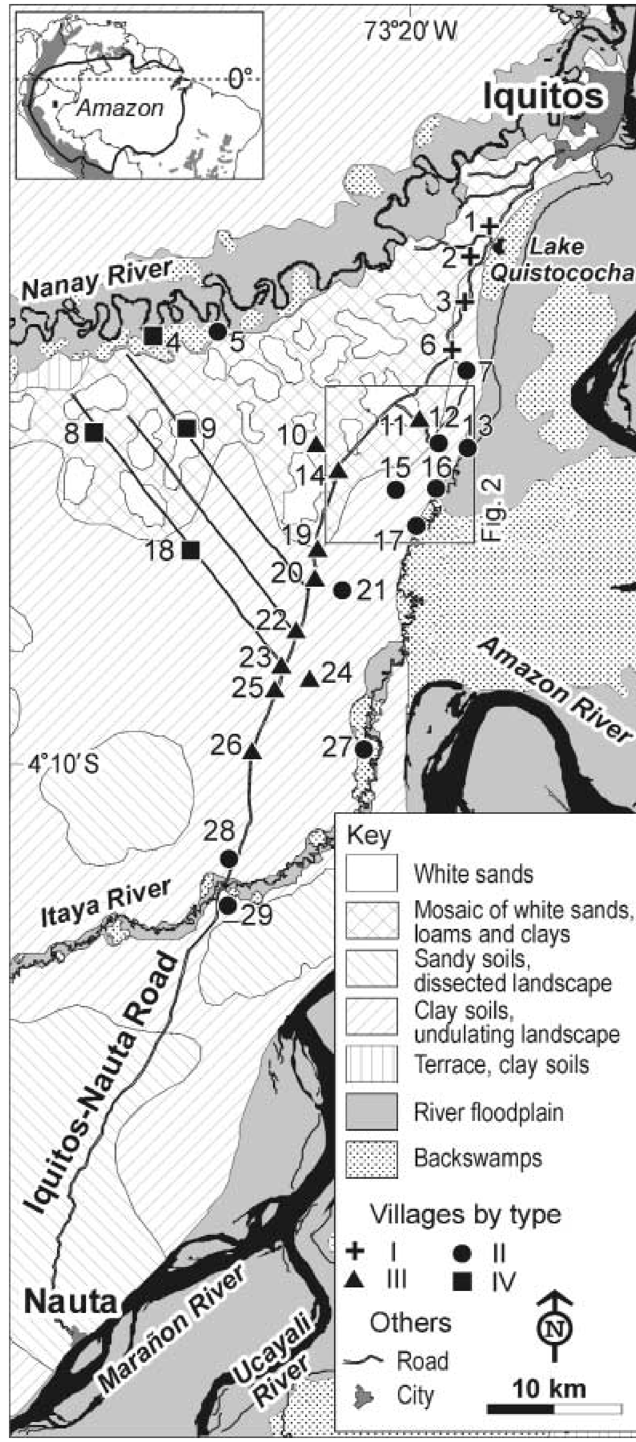

Figure 1 The study road and its vicinities in the western part of the Amazon Basin in Peru. The major geoecological terrain types are shown according to Mäki and Kalliola (1998). Village types and numbers are explained in full in Table 1. The square delineates the area shown in Figure 2.

places, younger deposits of fluvial origin cover this formation (Linna 1993). The dominant natural vegetation is closed canopy lowland rain forest with distinctive structural characteristics and species compositions associated with the local soil types (Gentry 1981; Tuomisto & Ruokolainen 1994; Ruokolainen *et al.* 1997). These forests are internationally renowned for their outstanding biodiversity (Gentry 1988).

The first western settlement in the early 18th century was a missionary post on the lower reaches of the Itaya River. The village of Iquitos was founded in 1757 (Villarejo 1979, p. 243), and gradually it established its position as the leading administrative and commercial centre of the region. Rapid growth did not start until the rubber boom in the latter part of the 19th century. The population was 81 in the year 1808, 1500 in 1876, 14 000 in 1903, 110 000 in 1970 and 351 940 in 1997 (Villarejo 1979, p. 302; Gómez Romero & Tamariz Ortiz 1998). The town of Nauta, founded in the year 1731, is substantially smaller and its growth has been slower: the population was 2063 in 1746 and about 13 700 in the year 1997 (Villarejo 1979, pp. 243, 315; Gomez Romero & Tamariz Ortiz 1998). Nauta is a harbour town and the commercial and administrative centre of the province of Loreto.

The economic history of Iquitos is closely related to the exploitation of natural resources. It shows successive periods of trade prosperity, namely world market integration (1850–1880), the rubber boom (1880–1940), national integration (1940–1970), and the petroleum industry, the coca trade, and the development of regional markets (1970–present) (Coomes 1995; Barham & Coomes 1996). The present cultural and natural landscape retains reminders of these previous resource use practices. Both the river floodplains and their non-inundated margins have been used for the extraction of marketable products, including timber, palm leaves, vegetable ivory, fruits and animals. These extraction activities have influenced those forests that lie within a few days' travel of the city. In addition, the upland margins near the confluence of the Itaya and Amazon Rivers have been used for about 150 years for the market-oriented production of sugar-cane, coffee, fruits and cotton (Villarejo 1979). It is probable that some of these areas are still in use, while others were reforested during the latter part of the 20th century.

Field observations and remote sensing analyses

The environmental documentation of the present study is centred on the multidisciplinary scientific research carried out in the region by the Amazon Research Team of the University of Turku (UTU-ART, see http://www.utu.fi/ml/amazon/) in collaboration with various institutions, including the Peruvian national natural resource institute INRENA, the local university, Universidad Nacional de la Amazonia Peruana (UNAP; see Kalliola & Flores Paitán 1997, 1998) and the Peruvian Amazon research institute, Instituto de Investigaciónes de la Amazonia Peruana (IIAP). The latter institution is responsible for land use planning in the region and maintains important documents and GIS (Geographical Information System) registers concerning the road's area of influence, which have been at our disposal.

Data on road construction and deforestation were collected using remote sensing methods and GIS. An indicative time series of maps was produced to document phases of road construction and deforestation. The oldest available source of spatial information was an aerial photograph index mosaic from the year 1948 (SAN [Servicio Aerofotográfico Nacional, Ministerio de Aeronáutica, Dirección de General de Aerofotografía], Proyecto No. 3094 / 1:30 000 / November 1948) of the immediate vicinity of the city of Iquitos. Aerial photograph mosaics with a wider spatial coverage were used to interpret the situation for the years 1972 and 1980 (SAN, Proyecto No. 3094, and SAN, Proyectos No. 214-72-A / 1:20 000/ July – September 1972 and No. 313-79-A / 1:20 000 / August 1980, Peru). After 1983, data on deforestation were based on the visual interpretation of satellite imagery (Landsat MSS, Path 6, Row 63, 19 September 1983; Landsat TM, Path 6, Row 63, 8 August 1993, 1995), using both hard copies with a scale of 1: 250 000 (including Mapa planimétrico de imágenes de satélite 1983) and digital data (years 1993 and 1995). The interpretations of the remotely sensed images were supplemented by observations collected during a small-plane flight over most of the study area on 31 January 1996.

We collected field data from several explorative surveys in the region between the years 1990 and 2001. We amalgamated environmental data on soils and the primary and secondary vegetation from a number of sites with GIS information (see Kalliola & Flores Paitán 1997, 1998 for details). The main body of descriptive data on land use was collected in 1996, when the location of each kilometre pole along the new road was determined using a GPS (Global Positioning System) to facilitate comparisons with the remotely sensed images. The passable road section was surveyed, identifying land use categories as primary forest, secondary forest or fallow (*purmas*), fields (*chacras*), pastures (*pastos*) and home yards or villages. We counted the number of houses within approximately 100 m distance from the road. We characterized rural centres by means of general descriptive notes and sketch maps, and 106 families were interviewed. We re-surveyed the same areas in 1997, 1998, 1999, 2000 and 2001. During these reassessments, we paid particular attention to any changes in the nature of activities along the road. We also occasionally interviewed the land use planners in Iquitos.

Soil descriptions as used in this work come from two sources. For general information on the soils in the region, we refer to Kauffman *et al.* (1998), including their preliminary classification according to the Food and Agricultural Organization (FAO) system (not presented here). Detailed soil descriptions in selected areas included three study transect analyses starting from the main road and ending at the Itaya River (Fig. 2). We used a clinometer to determine topography, and 50-cm deep soil cores taken every 100 m provided a visual determination of soil texture and colour (a Munsell Soil Colour Chart was used as reference). We

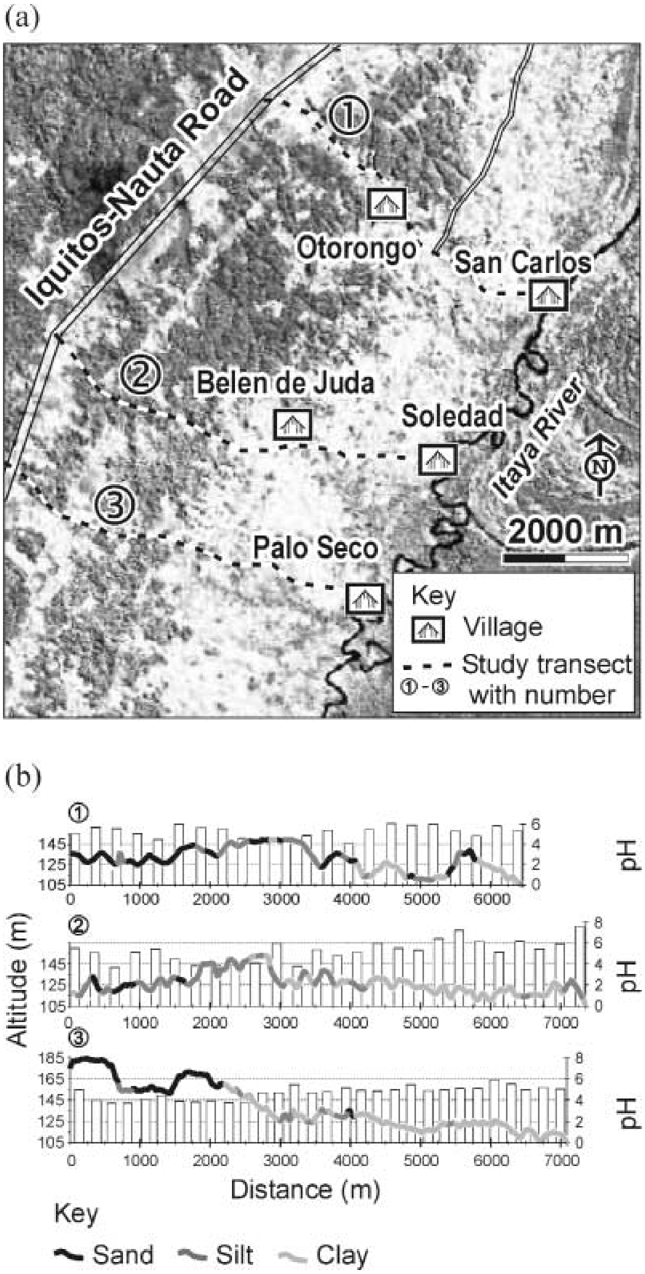

Figure 2 Landscape characteristics between the Itaya River and the Iquitos-Nauta road (for the exact location of Fig. 2, see Fig. 1): (*a*) detail of a Landsat TM image from 1993 where closed-canopy vegetation is grey and deforested areas are white or light grey, (*b*) topography (curve), top soil grain size (sand, silt or clay, indicated by shade of the curve) and acidity (histogram) in the three study transects (1–3) indicated on (*a*).

measured soil reaction with a portable pH-meter (Agrar 2000) from samples taken once every 300 m. Six to 10 samples (depth 100 cm) from each transect were preserved for laboratory analyses of grain size classes (wet sieving) and supplementary acidity measurements (in 1M KCl). We documented the land use along these transects using the same categories we used in the study of the main road, and interviewed farmers to collect information on cultivated plants, forest/fallow extraction and the productivity of the soils.

Results

Environmental conditions and land use

The landscape and soils along the road show a series of alterations from Iquitos to Nauta (Figs. 1, 3*a*, *b*). Close to Iquitos, the road borders inundated areas of the Amazon River floodplain on a slightly elevated dissected relief with a mosaic of white quartz sands and loam or clay soils. While the floodplain soils are relatively fertile, all the other soil types are nutrient-poor and unsuitable for agricultural production (Kauffman *et al.* 1998). In the middle part of the road, a slightly undulating landscape prevails, with clay soils developed in the smectite-rich Pebas formation. This geological formation has a sequence of stratigraphic phases, which occur at the surface one after another due to their southbound inclination (Räsänen *et al.* 1998). Running perpendicular to this gradient, the road cuts a variety of soil categories. In some places, the soils are less nutrient-limited than on average, yet even there the soil quality may be worsened by the soil's compressed structure, poor drainage and acidity (Kauffman *et al.* 1998). The last section of the road runs through a deeply dissected relief of tidal and fluvial (near the town of Nauta) deposits, which give rise to highly weathered nutrient-poor soils.

Each of the major terrain types shows distinctive internal variation in its edaphic properties, such as soil mineralogy and geochemistry, drainage and geomorphology. The western margin of the Itaya River exemplifies such heterogeneity at the local scale (Fig. 2). The soil conditions and topography in this area range in very short distances from relatively fertile (low lying areas near the river) to extremely poor (dissected higher-lying areas near the road). The former soils represent clay-rich deposits of the Pebas formation, which in some places contain fossilized mollusc shells that induce neutral or basic soil reaction. At a distance of approximately 3–4 km from the Itaya River, ancient fluvial deposits overlay the Pebas formation, giving rise to brown, yellow or red-coloured and nutrient-poor soils at the surface. The extreme case can be found in valleys of the higher-lying terrain, where the soils constitute coarse-grained (0.5–1 mm) quartz sands, and the soil reaction can be very low (pH 3.7–4.5).

Local farmers confirmed that these differences in soil properties are very important determinants of the agricultural potential of the terrain, and the use of land is planned accordingly. Adjacent to the Itaya River, most lands were under cultivation or recovering for the next cycle of cultivation. A typical evenly managed land unit was observed to be less than a few hectares in size, and even fallows were subjected to extractive use. Some lands had been used for several cultivation rotations, possibly for 150 years, and

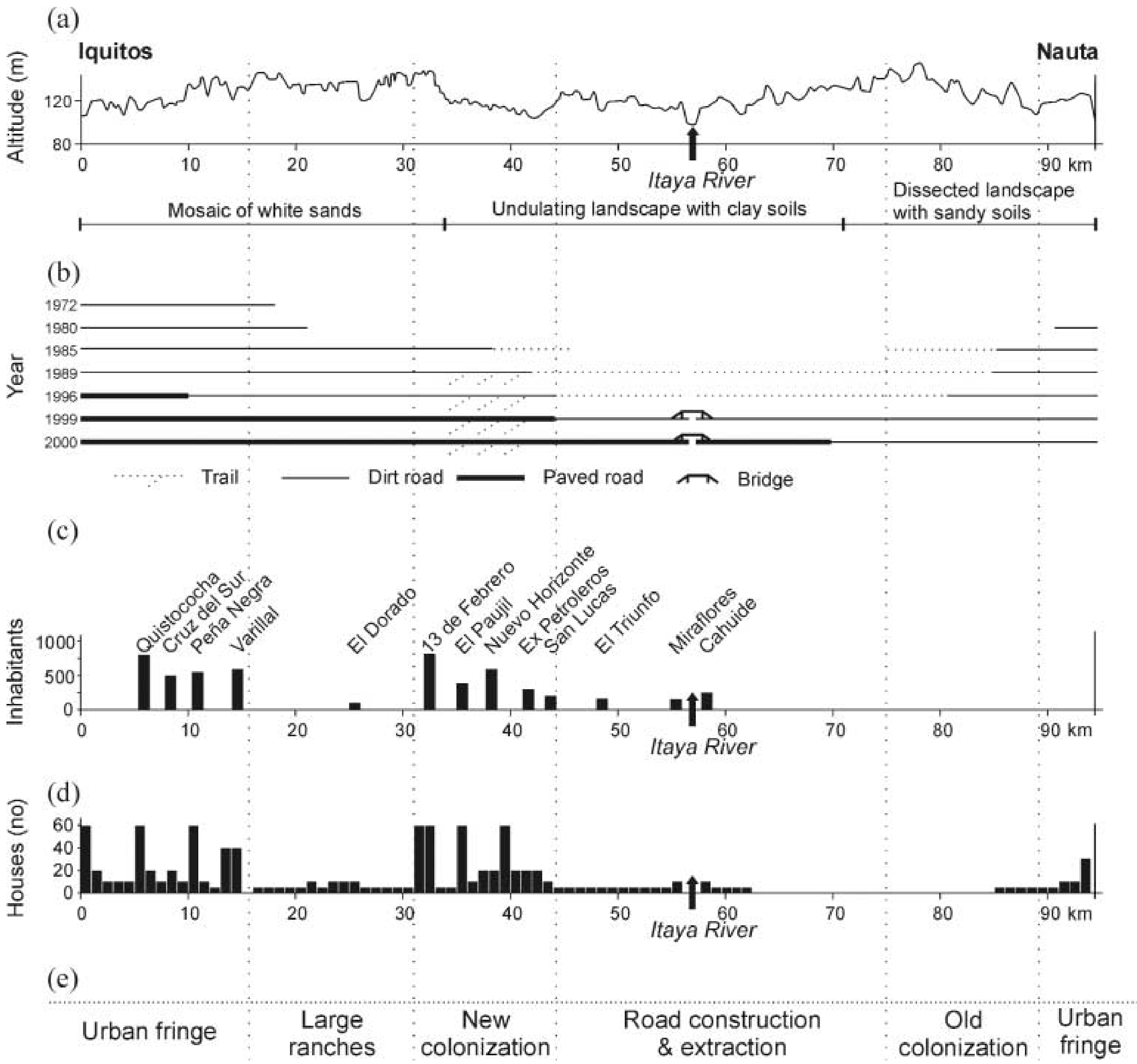

Figure 3 Road construction and settlement patterns along the Iquitos-Nauta road: (*a*) road topography and top soil conditions, (*b*) phases of road construction, (*c*) road side villages and their population (in 1996), (*d*) number of road-side houses per kilometre (0 to 50 km, counted in the field in 1996; 50 km onwards, estimations completed in 1996–1999), and (*e*) settlement and land use zones distinguished along the road.

farmers confirmed that even these soils are satisfactory, albeit bearing abundant weeds. A contrasting situation to the river margin was found in the areas of poor sandy soil near the main road, where extensive deforestation for cattle farming had resulted in short-lived production periods. In 1996, about ten years after the original forest clearance, most of these areas constituted a mixture of virtually abandoned grasslands and shrub thickets. However, some relatively large patches (tens to hundreds of hectares in area) of primary forests also remained in this approximately 3-km wide strip of sandy terrain near the main road. Here, the sizes of the managed land units were significantly larger (tens of hectares) compared to the riverside and, if not abandoned, were mainly being used as extensive and low-productivity pastures.

Road construction and deforestation

Time series analysis confirms distinctive phases of settlement expansion in the non-inundated areas during recent decades (Fig. 4). In 1948, clear-cut areas were concentrated in the immediate vicinity of the city of Iquitos, yet scattered deforestation was presumably also present beyond the area covered by the available aerial photographic data. By 1972, the entirely deforested zone near Iquitos extended about 10 km from the city, and deforestation had proceeded some 50 km further along the Itaya River. Most deforestation during the later 1970s occurred in the same region.

By 1980, the road extended only some 20 km from Iquitos and a few kilometres from Nauta (Fig. 3*b*). Five years later, a

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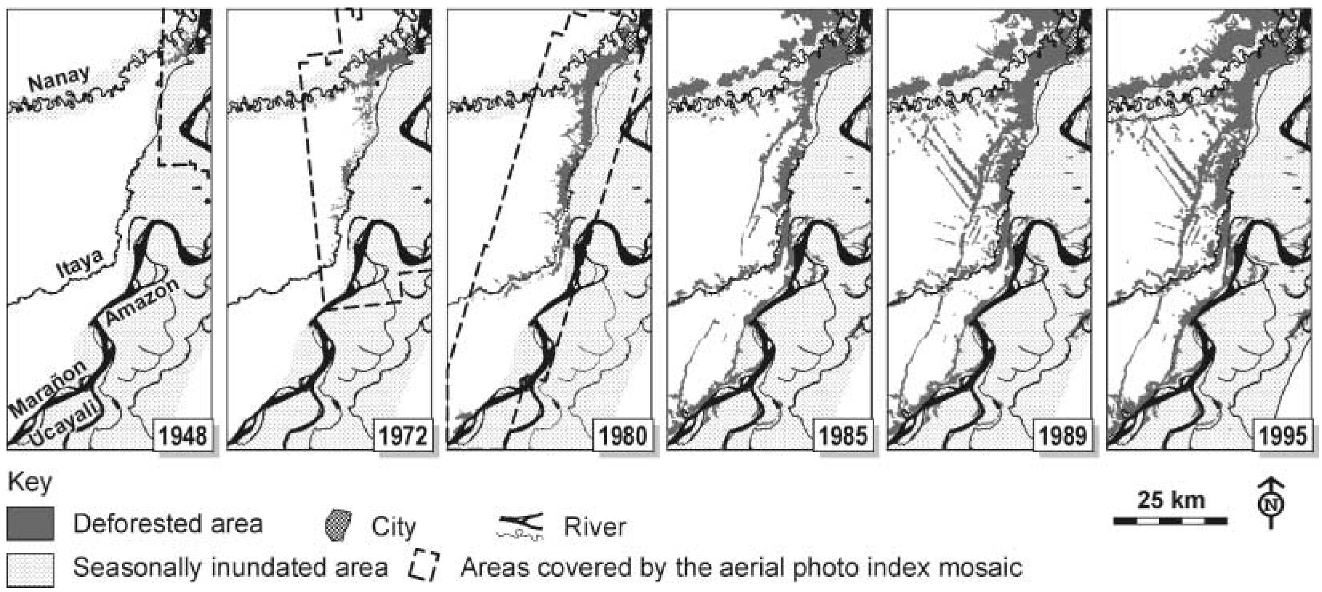

Figure 4 Expansion of deforestation in tierra firme areas between the years 1948 and 1995. The analysis between the years 1948–1980 is based on image sets with limited spatial coverage.

dirt road extended some 40 km from Iquitos and by 1989, the entire route to Nauta had been cleared of trees. Three straight parallel paths had also been opened from the main road towards the Nanay River. The paths start on undulating clay soil terrain, but soon enter areas of nutrient-poor white sand soils (Fig. 1). Deforestation followed each new road axis, and thus the late 1980s shows a peak of deforestation intensity in the region (Fig. 4).

The latest phase of road construction started in 1995, when much new road building equipment and labour were introduced. Before completion of the missing road section was even attempted, the existing sections of the road were reconstructed. Starting from Iquitos, white quartz sands (the only available source of coarse-grained material in the region) were used for a proper foundation, after which other road layers were established and finally paved with asphalt. Ditches and storm drains were built and road margins were stabilized with grass and tree plantations. The bridge over the Itaya River was constructed in 1998, and at that time, the road was already passable as far as Nauta by pick-up truck in the dry season. By March 2001, the paved road extended 70 km from Iquitos, but the sector near Nauta was still closed during the rainy season.

Settlement history

Before the road construction started in the 1970s there was already some settlement in the area of the forthcoming road as well as along the riversides. For example, the village of Varillal, 15 km from Iquitos, was already inhabited at the beginning of the 1940s, yet it had no road connection to the city (Panduro & Barletti 1996). The western margin of the Itaya River was settled by the 19th century, while the southern side of the Nanay River was not settled until in the late 20th century. This difference reflects the availability of better soils in the areas occupied first (Villarejo 1979, pp. 79–80). Spontaneous settlement appears to reflect the environmental variability in the region, unlike the new planned colonization made possible by governmental policies and road construction.

Active settlement during the late 1980s was enhanced by zero-interest loans offered by the Banco Agrario, which was an important instrument of agricultural support during the period of Alan García's presidency (1985–1990; see Coomes 1996). Claiming land and receiving the subsidies required the land to be cleared for some planned use. This mechanism induced some speculative deforestation with no intention of agricultural production, even in the most nutrient-poor white sand soils along the three parallel paths that were established in the late 1980s (see Figs. 1 and 4). One favoured group was former oil workers, who had become unemployed when the demand for labour in the petroleum industry decreased in the 1980s, and one of the new villages was given the name *Ex Petroleros*. Peru's economic crisis in the late 1980s put an end to both generous loans and road construction, causing further pressure for abandonment of the once cleared areas in the periphery.

The population centres in the road's area of influence can be grouped into five classes according to their position, age, motives for occupation, and other characteristics (Fig. 1, Table 1). This comparison shows significant differences between spontaneous and planned settlement types. In spontaneous villages (Table 1, groups I and II) land was occupied before official foundation, and administration and land titles were only established retrospectively to organize the villages. The sources of livelihood in these villages evolved over time

Table 1 Selected characteristics of major villages in the road's area of influence in the 1990s: (*a*) transportation infrastructure, (*b*) land ownership, (*c*) permanency of population, (*d*) motives for initial occupation (*agrarian association = planned agrarian production area, credits and subsidies provided by the government), and (*e*) soil productivity; – or (–) = no data. (Sources: Villarejo 1979; Panduro & Bartletti 1996; IIAP 1996*a*; Kalliola & Flores Paitán 1998.)

Description	*Villages*	*Map label (Fig. 1)*	*Popu-ation*	*Foundation and (first occupation)*
Spontaneous near-urban (I)				
(a) Good, lively interaction with the city	Quistococha	1	810	1909 (–)
(b) Insecure ownership	Cruz del Sur	2	500	1987 (1970)
(c) Mainly permanent	Peñanegra	3	550	1951 (–)
(d) Urban expansion / varying motives	Varillal	6	600	1965 (1941)
(e) Mainly poor soils				
Spontaneous riverine (II)				
(a) No road connection - paths with	Mishana	5	120	–
varying accessibility to vehicles, river traffic	Moralillo	7	750	1927 (–)
(b) Mainly secure ownership	Villa Buen Pastor	12	182	1985 (1977)
(c) Permanent	San Carlos	13	150	–
(d) Subsistence and commercial farming	Belen de Juda	15	–	–
(e) Relatively productive soils (except Mishana	Soledad	16	180	–
with poor soils)	Palo Seco	17	320	–
	24 de Junio	21	232	1990 (1980)
	San Pedro de Pintuyacu	27	130	1963 (1930)
	Miraflores	28	150	–
	Cahuide	29	250	–
Planned roadside (III)				
(a) Road connection trafficable in all	Nueva Esperanza	10	157	1990 (1986)
weather conditions	Otorongo (El Milagro)	11	–	–
(b) Mainly secure ownership	El Dorado	14	100	1996 (1983)
(c) Mainly permanent	13 de Febrero	19	820	1988 (1985)
(d) Agriculture, mainly agrarian associations*	El Paujil	20	389	1985 (1983)
(e) Poor / intermediate soils	Nuevo Horizonte	22	600	1985 (1985)
	Ex Petrolero I	23	300	1985 (1985)
	10 de Octubre	24	137	1993 (–)
	San Lucas	25	203	1990 (–)
	El Triunfo	26	160	1983 (1987)
Planned peripheral (IV)				
(a) Poor or non-existent road connection	Yarana Yuto (Nuevo Horizonte II)	4	135	1996 (1985)
(b) Mainly insecure ownership	Ex Petrolero II (1 de Mayo)	8	128	1990 (1985)
(c) High turnover	Paujil II	9	226	1985 (1985)
(d) Agriculture, mainly agrarian associations*	Ex Petrolero Centro	18	220	1985 (1985)
(e) Poor soils				

Table 2 Projections for population growth in the road's area of influence. *Calculated using constant 7.41 % annual growth, other values taken directly from IIAP (1996*a*).

Settlement zones	*Number of population centres*	*Population (1996)*	*Annual growth % (1981–1993)*	*Projected population*	
				2000	*2010*
Urban					
Iquitos	1	305 514	3.6	351 941	501 265
Nauta	1	10 471	6.8	13 659	26 549
Rural					
All rural areas (rivers Nanay, Itaya, Amazon and the Road)	106	39 394	1.72	42 181	50 040
Iquitos – Nauta Road	22	7 539	7.41	10 034*	20 509*

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and vary from subsistence farming and extractive forest uses to commercial agricultural production and handicrafts. In contrast, the planned villages (Table 1, groups III and IV), especially those along the road, were officially founded in advance as agrarian associations with financial aid and land division provided by the state. This is why these villages, in general, have stronger internal organization than those established spontaneously (Panduro & Barletti 1996). Although villages were founded to support agricultural production, the poor productivity of the soils had forced residents to seek alternative sources of income.

Population growth is fast in Iquitos, in Nauta and in the rural areas along the road (Table 2). Rural population pressure is also evidenced by emerging new villages and expansion of the existing ones each time the required level of road infrastructure has become available. Half of the rural population along the road is reported to be less than 15 years old, and 65 % of the families are classified as poor (García 2001). In addition, the lack of clean water, electricity, medical posts and schools in many places confirms that settlement expansion following road construction has not been regulated.

Land use zones in the late 1990s

Distinctive zones of land uses, economic activities and settlement were identified along the road in the late 1990s (Fig. 3*c, d, e*). Starting from Iquitos, the 'urban fringe' represented the oldest land occupation and was heavily influenced by municipal growth (Fig. 5*a*). Beyond the immediate vicinity of Iquitos, scattered houses in a rural landscape prevailed and some villages had basic services, such as health posts, schools, churches, electricity and telephones (Fig. 5*b*). The sources of livelihood in this zone were related mainly to urban economy, including shops, restaurants, a zoo, brickyards and chicken farms. In Peñanegra quartz sand mining was an important activity.

The zone of 'large ranches' comprised areas that were colonized during the early 1980s (Fig. 5*c*). The environment comprised red-coloured silty soils and white sands, the latter areas being favoured sites for the sparse settlements. Only one small village was present and there were few houses along the road (Fig. 3*c, d*). Entrance gates of deserted-looking *haciendas* (large ranch parcels), were seen intermittently by the road, but most pastures were either abandoned or were sparsely populated with cattle. Low intensity non-productive land uses prevailed, but also some publicly owned holdings were used for special purposes, including experimental plantations of pijuayo palm (*Bactris gasipaes* HBK), a forest nursery and the forest area of the Allpahuayo-Mishana Reserved Zone that received conservation status in 1999 (El Peruano 1999).

The 'new colonization' zone represented the limit of road construction in the late 1980s and early 1990s. The shift from the previous zone into this one was notable, both environmentally and culturally, because the road descended into an undulating landscape of clay soils (Fig. 3*a*). This zone was actively settled in the late 1980s when five new villages surrounded by small-scale agricultural lands were established (Fig. 3*c*). Houses were often located on hilltops and suitable brooks were dammed to create fish pools. Deteriorating road conditions induced a decline of this zone in the mid-1990s, but since the road improvement project reached these areas in the late 1990s re-colonization has taken place. From 1999 onwards, new houses have appeared by the road and slash-and-burn agriculture has been widely practised (Fig. 5*d*).

In the 'road construction and extraction' zone, dirt road conditions gave way to a simple clear-cut line that marked the planned road in the forest (Fig. 5*e*). Some settlements were established in this zone in the late 1980s but they became extremely isolated because of deteriorating road conditions and dense secondary growth in the once cleared road line. Several places were abandoned and new deforestation remained marginal until the most recent road construction reintroduced population migration into this zone in 1998. The prevailing uses of the zone were still extractive in late 1999, evidenced by the trade in timber (Fig. 5*f*), charcoal and diverse non-timber forest products, such as palm leaves and game animals.

A similar sequence of land-use zones was found near Nauta. The 'old colonization' zone had sparse settlements and no villages, and human activity declined towards the periphery (Fig. 3 *c, d*). The initial road construction phase towards Iquitos in the early 1980s had attracted families into these areas, but many had chosen to leave when road building lapsed (Fig. 3*b*). In the late 1990s, in areas 10 km or more from Nauta, primary forest had been subjected to extractive uses and few scattered fallows prevailed. Closer to the urban edge the landscape was more agricultural, mainly comprising pastures on a hilly terrain (Fig. 5*g*). The town itself was river-oriented, with urban activities extending only a few kilometres away from the river (Fig. 5*h*). Only a few trucks each day used the dead-end road towards Iquitos, while pedestrians and horse-drawn transportation were common. More recently, there has been a revival of activity in the areas further from the city.

Discussion

Road construction and land occupation

The towns of Iquitos and Nauta have been the centres of their respective economic areas since early development took place during the late 19th century. Due to sedimentation at the river port of Nauta by the Marañon River in the early 20th century, the development of Nauta was hindered, and Iquitos became the leading centre in the region (Villarejo 1979). Despite their close relationship, transportation between these communities was entirely based on slow river waterways. Under these conditions, road construction appears a very logical demand for development from the local perspective.

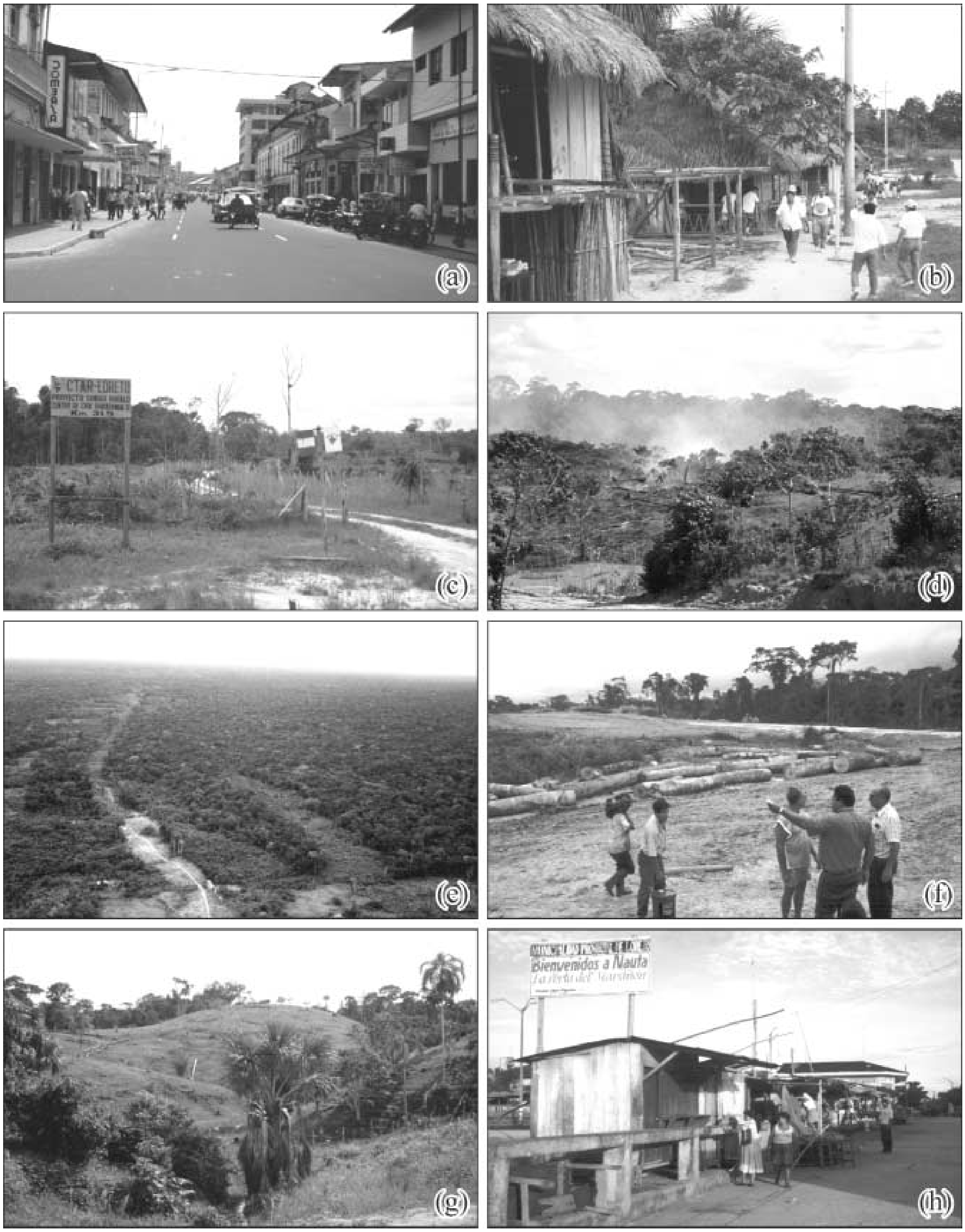

Figure 5 Photographs illustrating the different land use zones along the road in the late 1990s: (*a*) the city of Iquitos, (*b*) the village of Varillal in the white sand area, (*c*) large ranches on poor soils some 15 km from Iquitos, (*d*) slash-and-burn agriculture in the zone of new colonization, (*e*) oblique aerial view of the road construction and extraction zone, (*f*) extraction of timber from the primary forest, (*g*) deforested dissected landscape on poor soils near Nauta, and (*h*) the urban fringe of the town of Nauta. (Photographs by S. Mäki, R. Kalliola and H. Tuomisto 1996.)

When the first road building efforts were conducted in Iquitos in the early 1970s, road construction was also more generally the focus of development in the Amazon. This action was particularly strong in Brazil (see e.g. Goodland & Irwin 1975), but many new roads were also planned in the Peruvian Amazon. National topographic maps are testimony to these projected roads. However, few of these roads have actually been built. In addition, the Iquitos–Nauta road has undergone several episodes of construction and stagnation, which reflect changes in economic prosperity and governmental policies.

Changing policies are also very important in determining the size of individual land estates and their pre-defined use.

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For example, land holdings occupied during the early 1980s were large and mainly focused on cattle ranching. Many of these were abandoned after a short period of production. Later, in the mid-1980s, a preference for small-scale land holdings used for subsistence farming developed. Colonists were attracted with subsidies, which consisted of a combination of taxation, credit and interest benefits (Escobal D'Angelo 1992; Coomes 1996). In uncertain conditions of tenure, land was claimed only for short-term purposes, and the forest cover was often removed without knowledge of the soil productivity or any intention of using the land for more than a few years. Together with delayed road construction, lack of services, poor health conditions and the deficiency of new loans, many people were forced to return to Iquitos (Anon. 1987).

The last three decades of the 20th century have witnessed two dead-end roads, one starting from Iquitos and the other from Nauta, both associated with distinctive sequences of land-use zones. Each time road construction has progressed further, the zones of extraction, deforestation, agricultural production and land neglect have also moved. Many of the circumstances thus created are in accordance with the classic location or central place theories (see e.g. Dicken & Lloyd 1990). The population refer to locations along the road by distances from the road's origin rather than by their real names. The overall living and economic conditions among the colonists reflect the geographical distance factor, transportation possibilities and costs. Subsistence farming is practised in the most peripheral areas, whilst intensive commercial production, particularly that of chickens demanded by the population centres, characterizes the areas near the urban fringe.

Preconditions for deforestation and misuse of natural resources

The preconditions for negative impacts of road construction, such as accelerating deforestation, can be associated with the state of the transportation infrastructure, access and title to the land, government incentives, the colonization process, the colonists, and variation in environmental characteristics (Imbernon 1999; Verolme & Moussa 1999). According to Bromley (1999), these factors are not, however, the final causes of deforestation, but merely mechanistic explanations. That is to say, roads are constructed not to cause deforestation, but to lend access to environmental resources to provide income and wealth to the people.

Although a poorly developed road infrastructure with a small population may hinder deforestation, as was the situation in most of the Bolivian Amazon in the past (Kaimowitz 1997), peripheral conditions may also lead to insecure land ownership and poverty. In Peru, such conditions have been reported to increase short-term land uses and deforestation (Bedoya Carland 1995). However, in the states of Acre and Rondônia in Brazil where road connections are good, farmers have gained legal title to the land, land use is tightly controlled at present, and deforestation rates are especially high (Imbernon 1999). The control and land titling were only introduced, however, after the land resources became limited, and there was no longer much to be done to alleviate the deforestation problem.

The type of transportation infrastructure that would best serve different local realities has been studied and understood far too poorly (Leinbach 2000). The Trans-Amazon Highway in Brazil provides one example of an extensive road network that did not support the establishment of viable and sustainable village economies (Steward 1994; Schneider 1995). As in the case of the Trans-Amazon Highway, many other Amazonian colonization projects have suffered, and still suffer, from similar difficulties. The first settlers have poor access to the market and administrative centres, and thus also to credit and other governmental services. They often tend to be poor and are hampered in their attempts to achieve a better standard of living by low yields, struggling to make the nutrient-poor soil productive without access to expensive fertilizers. This leads to high rates of farm turnover and abandonment. When the frontier becomes better established and later waves of settlers have better access to governmental services, they have the opportunity to buy the land from the pioneers and to occupy intact areas at low cost. The cheap prices and easy accessibility of the land, together with misdirected governmental incentives supporting unsustainable uses, may lead to high rates of deforestation and mining of natural resources.

A peculiar feature of land ownership is that it may have many divergent impacts on land turnover and local and regional economic development (Bedoya Carland 1995; Rudel 1995; Kaimowitz 1997; Imbernon 1999). Insecure tenure may lead to farm abandonment, but it may also ensure that farmers maintain the cultivation of their parcels to prevent others encroaching on their land. Secure ownership, together with unstable land prices, may result in short-term use of large estates and land speculation (Rudel 1983). An attempt to secure the property rights in a newly opened area may also lead to conflicts among the colonists or between them and the indigenous people, which alters the social structure of the frontier areas (Rudel 1989). This, in turn, may lead to resource partitioning, and thus hinder economic co-operation and development. As to the Iquitos–Nauta road in late 1990s, the securing-by-use may reflect the tactics of some settlers in the zone of new colonization, while speculation occurs in the zone of large ranches.

Governmental colonization programmes are an example of controlled and planned land occupation. However, when planning is not based on adequate knowledge of environmental and social realities, its applicability remains marginal. As an example, in the Iquitos area people have been attracted to move from riparian villages to *tierra firme*, the non-inundating upland forest, and problems have arisen due to the different ways of making a living in the non-inundating areas. Riparian villagers characteristically depend heavily on the river ecosystem (see e.g. Hiraoka 1995; Padoch *et al.* 1999), but in tierra firme the environmental realities are different. While the young and fertile soils that accumulate at riversides through fluvial activity support strong vegetation growth, cultivation methods in non-inundating lands have to be adjusted in order to avoid destroying the potential of the highly weathered and nutrient-poor soil. Problems of this type multiply when people move into the area from very different environments, such as from the mountain or coastal areas or from large cities, where the means of livelihood are different. This was the case with the group of unemployed petroleum prospectors that was given land along the Iquitos–Nauta road in the early 1990s.

The role of planning and legislation

In light of the above examples, deforestation occurs under both controlled and uncontrolled conditions. The key factors to address appear to be the need for a thorough understanding of the ecological and human base for resource use and respective planning, based on site-specific knowledge and including follow-up. In the planning phase both the type and the volume of the activities proposed for the area must be carefully designed to meet the use potential for that specific area. However, providing planners with adequate knowledge on which they can base decisions can be problematic, because accurate information either does not exist or is not in an integrated and workable form. A concrete way of obtaining information for improved control of land use would be to make environmental impact assessment (EIA) and social impact assessment (SIA) prerequisites for all major projects such as road building and planning new settlement areas. However, to further sustainable development, the concept of sustainability should be explicitly integrated into EIA theory and practice (Lawrence 1997).

A private company in Lima prepared a simple study of this kind in 1997 for the road construction process documented in the present study, which was far too late, of course, considering the fact that the work began in the 1970s. Additionally, in our opinion, the scientific basis of the assessment was insufficiently rigorous for an EIA (see e.g. Donnelly *et al.* 1995; Lawrence 1997). Some years previously, the Ministry of Agriculture (Ministerio de Agricultura 1981) and the government institution ONERN (1991) conducted land suitability surveys in the region. Their recommendations were supportive of agricultural efforts in the current road's area of influence. However, these conclusions have been strongly challenged (Kauffman *et al.* 1998), and consequently we must conclude that environmental analyses, as such, do not guarantee success if their scientific base remains weak.

In December 1998, the Peruvian National Congress approved a law for the Amazon region in Peru (Ley No. 27037, Ley de promoción de la inversión en la Amazonía. El Congreso de la Republica del Perú, *El Peruano*, 30 de diciembre de 1998) to promote sustainable and integrated development, public and private investments and the conservation of biological diversity. The development of transportation and communication infrastructure, including the Iquitos-Nauta road, was among its priorities. However, in Iquitos, the law has been criticized for merely promoting economic activities without paying enough attention to sustainability or the needs for nature conservation (Y. Guzman, IIAP, personal communication 1999). The more recent Peruvian forest law (Ley No. 27308, Ley forestal and de fauna silvestre. El Congreso de la Republica del Perú, *El Peruano*, 16 de julio de 2000) approved in July 2000 creates possibilities, for example, for the promotion of versatile and sustainable uses of the primary forest areas and their resources. It gives weight to forest management planning, ecosystem services, the non-timber forest production potential, conservation, tourism and zoning of forest-use activities. Overall, the two laws provide an opportunity for the regulation of land use in the Peruvian Amazon, but their local implementation and thus real utility in sustainable development efforts remains to be seen.

Another promising process for controlling land use at the regional and local levels is the Ecological and Economic Zoning (Ministerio de Relaciones Exteriores 1998) that is being conducted by the IIAP. The zoning process in Peru is part of a large co-operation project between nine Amazonian countries and aims to promote sustainable development and recognition of the spatial variability in the potential for the use of natural resources in the Amazon region (Tratado de Cooperación Amazónica 1997). In the new Peruvian forest law (Ley No. 27308), this zoning process is cited as providing methods that should be used to determine appropriate uses for the forest areas. Thus far, a preliminary zoning exercise, favouring extensive forestry and only some degree of agriculture, has been completed concerning the area of influence of the Iquitos–Nauta road (Rodríquez Achung 2001). However, these acts as well as some other initiatives for sustainable development (Garcia 2001) have been launched late, since some of the most critical decisions concerning land division and use along the Iquitos–Nauta road have already been made.

To determine appropriate land uses for the different areas is a challenging exercise. It requires adoption of the most recent understanding from both basic and applied science and its combination with socio-economic realities. Learning from experience should also be an implicit element of a planning effort. As an example, agroforestry is an option for low-intensity, long-term production in Amazonia (Alcorn 1990; Peck 1990; Flores Paitán 1998). It could offer a possible solution for restoring the economy in some already deforested areas, although the high demand for human and physical capital, and the relatively low returns during the first years of production, may reduce the attractiveness of this alternative (e.g. Subler & Uhl 1990).

In areas where the soils are favourable and the markets are at hand, more intensive cultivation, plantation farming or cattle raising can be supported. In addition, the vast biological diversity itself creates possibilities for sustainable ways of making a living (Peters *et al.* 1989). Forest management for sustainable forestry, small-scale extractivism, carefully planned ecotourism and educational use represent potential sources of income (Vasquez & Gentry 1989; Comisión Amazónica de Desarollo y Medio Ambiente 1994, p. 179). The implicit sustainability of these activities can, however, be questioned. For example, the word 'ecotourism' frequently appears in travel advertisements, even though the enterprises in question have extremely different standards of environmental concern (Wall 1997).

Possible scenarios with varying outcomes

To illustrate alternative futures in the region examined in this paper, following road building, two hypothetical scenarios were created that portray the landscape structure twenty years from 1995 (Fig. 6). The scenarios are based on the mechanisms of tropical rain forest use and conversion discussed above, as well as all the Peruvian land use policies and decisions that we are aware of. These include the zoning process (Ministerio de Relaciones Exteriores 1998; Rodríquez Achung 2001), the law concerning the Peruvian Amazon (Ley No. 27037), the forest law (Ley No. 27308), the creation of the Allpahuayo-Mishana nature reserve (El Peruano 1999) and several reports concerning the road's area of influence (Consejo Transitorio de Administración Regional 1996, 1997; IIAP 1996*b*).

Scenario I (Fig. 6*b*) envisions the consequences of immediate development pressures, rather than direction by responsible legislation and planning. The leading goals are (1) to gain maximum economic benefit in a short time and (2) to offer new possibilities for the people through penetration into increasingly remote and intact forest areas. Under this scenario, some operations are large in scale, including investment by big enterprises that aim to produce products of high market value. Penetration roads are used for the extraction of timber from the primary forest and are surrounded by slash-and-burn fields. Environmental impact assessment is neglected because of its restraining influence on the returns to investment. While the areas with poor soils near Iquitos remain sparsely populated, and the Allpahuayo-Mishana Reserve is left unexploited, intensive land use and an influx

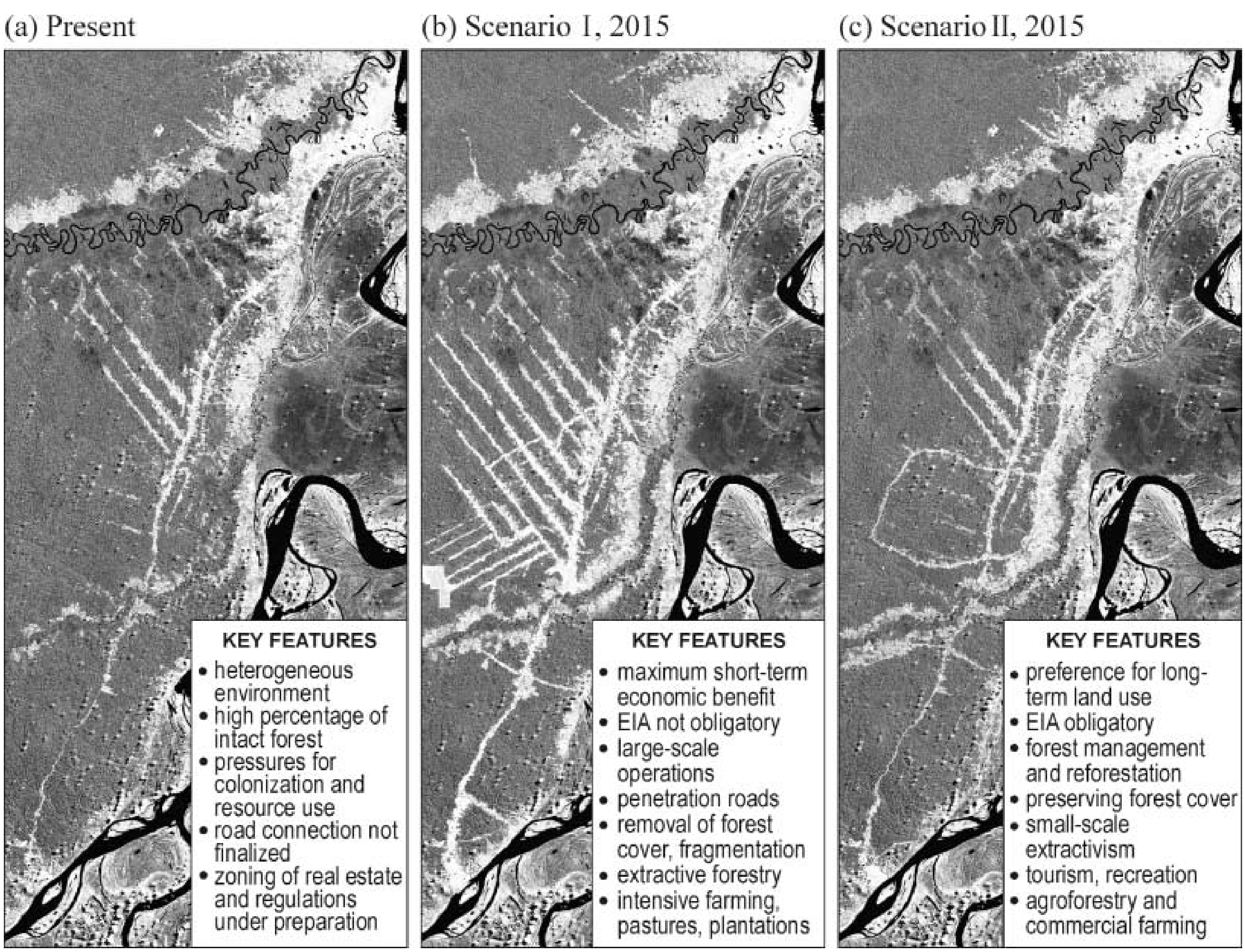

Figure 6 Landsat TM images showing the environment and deforestation in the study area: (*a*) raw image taken in 1995; (*b*) and (*c*) represent alternative scenarios for the year 2015, produced using image manipulation.

of colonists is expected close to the Itaya River. A short-term growth boom characterizes the early phase, which attracts an increasing number of people into the region. However, many areas will be abandoned after a few years and pressure for accelerating deforestation and new road construction is high. When new roads are opened and intact land is made available, without long-term planning, clearing the forest for short-term uses attracts people who hope to gain a quick income. This situation may lead to severe biodiversity loss through habitat destruction and fragmentation, thus increasing international concern for the fate of this environmentally unique region (Dale & Pearson 1997; Sierra 2000). This, in turn, would decrease the attractiveness of the Iquitos region for tourists. In short, this scenario represents the type of development that many environmentalists expect will happen in the region.

In scenario II (Fig. 6*c*), a more optimistic one, the key land-use strategy is to promote long-term sustainability and permanency of all activities. The model recognizes the variability in the use potential of different parts of the area and aims to promote long-term, economically profitable and ecologically sound production systems. Instead of penetrating into new areas, reorganization of activities is favoured in the already-deforested areas and their vicinities. Non-timber forest product extraction (Peters *et al*. 1989) and sustainable forest management (Torres Vásquez 1993) are encouraged, since they have relatively high economic potential and preserve standing forests. Forests may have their species composition altered, for example, by planting seedlings or preventing competition, to favour economically valuable species. EIA is obligatory in all projects that are anticipated to significantly affect environmental stability. Diversification of resource-use activities is favoured to prevent mining of natural resources. The preservation and maintenance of primary forest near some parts of the road serves ecotourism, recreation and education. Intensive commercial farming is zoned close to the Itaya River where the edaphic conditions best meet the requirements of such production. Seasonally inundated areas, with young fertile sediments, are widely used for commercial production (see Kalliola *et al*. 1999). An indispensable condition for the integration of economies within the region is the development and maintenance of a well-functioning transportation infrastructure, where road loops and networks are preferred to unending penetration roads. In short, the prerequisites for this scenario include science-based planning synchronized with adequate land titling and use regulations, adequate legislation and control mechanisms to favour long-term land uses, and the availability of social and economic incentives to support versatile economies.

Conclusions

Regional development associated with road construction is a reality in all Amazonian countries. The threats of destroying the rain forest environment by introducing inappropriate land use practices are as severe as the threats of economic and social problems for individuals and societies living within the region. Is it necessarily imperative, in these conditions, that there be endless cycles of failures resulting from ecologically and economically unsustainable resource use, or could there be alternatives?

This paper emphasizes that the causes of forest destruction are far more complicated than just direct correlates of road construction and settlement. The actions that take place along a newly built road reflect various societal processes and can be tightly linked with inappropriate land-use planning and lack of control, which, in turn, are results of the inadequacy of knowledge, both scientific and practical. In order to achieve a more sustainable future, the environmental restraints should be identified by adequate scientific research and each sector of society should participate in changing the preconditions for deforestation and misuse of resources into preconditions of sustainability. Finally, it should be appreciated that all the actions taken so far, no matter how unsuccessful they have been, were taken to fulfil particular economic, social or political needs. These needs still have to be met, but with alternative means to compensate for the former destructive ones.

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