Population Growth and Land Use Intensification in a Subsistence-based Indigenous Community in the Amazon

Anders Henrik Sirén

Abstract Shifting cultivation practiced by indigenous peoples living at low population densities in tropical forests has often been described as sustainable and compatible with conservation. However, shifting cultivation at increasing population densities has historically been, and still is, a main cause of deforestation worldwide. As many indigenous peoples in tropical forests currently experience rapid demographic growth, this raises the question to what extent their agricultural activities actually contribute to deforestation. This paper examines land use change in an indigenous community in the Ecuadorian Amazon which is only loosely connected to the market economy, and where agriculture is almost exclusively subsistence oriented. During the last seven decades, people have increasingly begun to clear fallows instead of old-growth forest to farm. Although the population was growing at an estimated 1.6% per year, the expansion of the area of land used for agriculture was only 0.4% per year, corresponding to an annual deforestation rate of only 0.015%. Whereas these changes may seem negligible in terms of deforestation, they do cause hardships to the local people, because of increasing walking distance to old-growth forest, and problems with weeds, pests, and decreasing soil productivity when farming after reclearing fallows.

Key words Land use change · shifting cultivation · population growth · tropical forest · Ecuador

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Introduction

A large part of the Amazon tropical rainforests is inhabited and used by indigenous peoples. Many hold collective titles of ownership to their lands, whereas others have gotten their lands declared as state-owned indigenous reserves. The total area of these indigenous lands surpasses the combined area of nature reserves and extractive reserves and holds significant conservation values (Davis and Wali, 1994; Peres, 1994; Fearnside, 2003). At least until recently, shifting cultivation for subsistence needs has been the main direct impact of the indigenous people on forest cover. Shifting cultivation in tropical forests typically involves clearing the forest in order to farm for a few years until nutrients in the soil are exhausted or weed infestation becomes too severe, and then the land is fallowed, letting the forest grow back again (Beckerman, 1987; Clay, 1988). Fallowing the land and allowing the forest to grow up restores soil fertility and reduces populations of pests, pathogens, and weeds over time. The growing forest also builds up biomass that can be burned in order to further reduce pests, pathogens and weeds, and in the short run further improve soil fertility. Therefore, the resource base for shifting cultivation consists not only of the soil, but also of the forest biomass (Nye and Greenland, 1960; McGrath, 1987). Such shifting cultivation as well as other "traditional" land use by indigenous peoples has often been described as sustainable and compatible with conservation (e.g., Dufour, 1990; Sponsel, 1992; Schwartzman et al., 2000). Where indigenous people have gotten access to markets, in contrast, they have often degraded the environment by engaging in cash cropping and cattle ranching or cashing in on timber and mineral resources (Behrens et al., 1994; Rudel and Horowitz, 1996; Henrich, 1997; Zimmerman et al., 2001; Rudel et al., 2002). Unsustainable resource use

by indigenous peoples is not, however, limited to such cases of commercialization. On the contrary, it has been shown that subsistence hunting for food by indigenous peoples often is unsustainable and significantly affects biodiversity (e.g., Robinson and Bennett, 2000; Sirén et al., 2004). This suggests that there may be reason to make a more careful assessment of the sustainability of other subsistence activities, including shifting cultivation.

At low population densities, shifting cultivation involves the clearing of only a minute proportion of the forest each year. There is little competition for land and fallows are left to grow for such a long time that they become basically indistinguishable from the primary forest (e.g., Descola, 1994). Many Amazonian peoples used to be quite mobile; changing village sites every few years, and soil exhaustion has been suggested as one reason among many for these movements (Hames, 1983; Gross, 1983; although cf. Chagnon, 1997, pp. 71–91). Whatever the prime reason for the village movements, these movements in combination with low population density meant that shifting cultivation in the Amazonian rainforest until quite recently was widely scattered in space, and of a low intensity in terms of the period of cultivation in relation to the period of fallow. Shifting cultivation, however, is practiced all over the tropics and in the past also in temperate regions, such as Europe. As populations have increased, shifting cultivators have often reduced the extent of old-growth forest and gradually decreased the length of the fallow period, which has led to decreased productivity (Boserup, 1965). Thus, the apparent sustainability observed in shifting cultivation systems of Amazonian indigenous people may depend more on low population densities than any inherent sustainability in the shifting cultivation system itself. Shifting cultivators have even been considered the main cause of tropical deforestation worldwide (e.g., Amelung and Diehl, 1992); although most of this is caused by population growth due to migratory movements, often in connection with infrastructure development or governmental resettlement schemes, rather than by the natural population increase of the native populations (Geist and Lambin, 2002).

However, many indigenous populations are growing rapidly, and if they are to continue producing their own food, they must increase their agricultural production. One way to do this is to intensify land use by increasing input of labor and technology (e.g., pest and weed control, fertilizing, irrigation) in order to increase the output per unit of land. Such land use intensification has even led to increased tree cover and decreased erosion in Tanzania (Tiffen et al., 1994) and Java (Sayer, 1995). However, farmers have little incentive for this kind of land use intensification until forest resources are used up (Boserup, 1965), so that it is more likely that the farmed area expands at the expense of old-

growth forest. Farmers may, however, also shorten fallow periods, although this may lead to problems with soil exhaustion and increasing pest and weed infestation. As most indigenous people nowadays live in permanent settlements, the travel cost to distant old-growth forest may be so high that people prefer to instead clear fallows closer to settlements. Similarly, the optimal fallow length increases with increasing distance from settlements (Angelsen, 1999). Land scarcity may also lead to competition for land among farmers. When deciding upon whether or not to clear a particular piece of land at a particular time, the farmer then has to take into account the risk that, if he does not clear it now, somebody else may do so. Such competition may lead to a further shortening of fallow periods. To avoid such competition, farmer communities may privatize land or otherwise change the local institutions governing control and access to land (Boserup, 1965; Angelsen, 1997).

Changes in land cover may be caused by a wide variety of factors other than demographic change, such as expansion of transport networks, land tenure arrangements, and macroeconomic factors. Such factors often interact with each other in intricate ways, making it difficult to separate cause and effect (see, e.g., Kaimowitz and Angelsen, 1998; Geist and Lambin, 2002). However, in cases of subsistence agriculture, where the prime purpose is to provide for the nutritional needs of the local people, one can expect population size to be a major factor affecting the extent of farmed land. The purpose of this paper is to examine how such an indigenous community, which practices agriculture almost exclusively for subsistence purposes, has adapted its agricultural system to a growing population ever since the 1930s, but with particular emphasis on the present and the recent past. Particularly I focus on the rate of expansion of farmed land (including fallows), and on changes in fallow period. After relating this to population growth I discuss the potential effects of other factors in the past, present, and future.

Study Area

Sarayaku (400 m a. s. l., 1°44′S, 77°29′W) is an indigenous Kichwa community situated on the banks of the Bobonaza River in Pastaza province, in the Ecuadorian part of the Amazon basin (Fig. 1). Sarayaku is located 65 km southeast of the town Puyo but has no road connection. Technological change has been limited during the time span of the study, the main agricultural tools still being machetes and axes, although nowadays they often are sharpened with a file rather than with a sandstone. Expansion of transport networks has been limited to the construction of an airstrip around 1960, and the construction of a road that connects to the Bobonaza River at Canelos, 35 km northwest of

Fig. 1 The study area. Hamlets and secondary homes in relation to major rivers and adjacent communities.
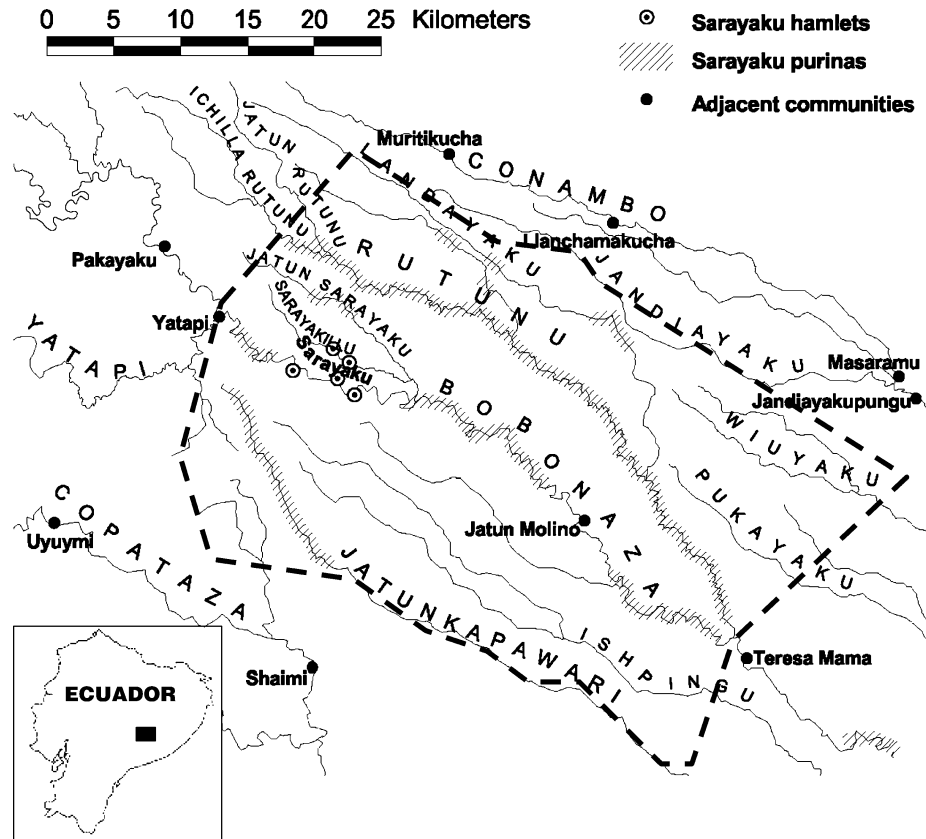
Sarayaku. Although this has facilitated transport, production for sale in external markets is still very limited, and almost all agricultural produce is consumed locally.

The community consists of five hamlets, and the population was estimated at 961 in 2001. At some distance away from the main settlement, most households have a secondary home, where they live part of the year, particularly during school vacations. Sarayaku and neighboring communities possess legal communal land titles, but the boundaries between communities are largely a construct that reflects neither current land use nor previously existing customary or mutually agreed limits (Sawyer, 1997; Sirén, 2004). Thus, delimitation of the study area was inevitably somewhat arbitrary, and was set so to correspond, although only roughly, to the area traditionally used by the Sarayaku people for farming, hunting, and gathering. Also within this area is Jatun Molino, a small community of approximately 100 inhabitants, which broke away from Sarayaku in 1983 due to conflicts related to Protestant missionary activities, and which now forms an enclave within Sarayaku territory.

The Sarayaku people practice shifting cultivation in a way that is quite typical for the indigenous people of western Amazonia (e.g., Johnson, 1983; Denevan et al., 1984; Salick, 1989). Land management practices are influenced by topography and soil. Particularly, plains are

managed differently from ridges or hills. The ridgetops have been farmed for at least one and a half millennia, whereas the farming on plains seems to have started only two centuries ago (Sirén, 2004, pp. 111–150). Steep slopes are considered less suitable for farming.

Small creeks are subject to frequent flooding following heavy rains, but the water also recedes fairly rapidly, permitting the soil to dry, such that severe crop damage rarely results. On the other hand, the Bobonaza river occasionally floods the surrounding plains. Two such large floods have occurred since 1990. On such occasions, the water may leave several decimeters of sediment in some places and it may take several days until the soil dries up, which results in severe crop damage. Households that have a low-lying field therefore usually also have a field on a hill as an insurance against flood damage.

Local people classify soils on hills into two major types; black soil and red soil, of which the black soil is considered more fertile. There are also stony soils, considered less suitable for farming. Soils on plains often have a coarser structure and are referred to simply as plain soils. Sedimentation during floods also creates small patches of clayey soils, unsuitable for cultivation, and other patches of sandy soils, highly appreciated for farming cassava, maize, papaya, and groundnuts.

Fields are small, averaging 0.20 ha, and may be just 10 m wide when planted along the riverside. Making a field involves first clearing the underbrush and felling the trees. Then the branches and twigs are cut in pieces and gathered in piles. After drying in the sun for a few days, the piles are set on fire, and to some extent the fire also spreads to the leaves and other debris left on the ground. Sometimes, however, people do not burn the debris, but instead just cut the branches and twigs into very small pieces, so as to facilitate planting and speed up decomposition. This is done on favorable sites such as sandy soils or sometimes when clearing old-growth forest or when there is a hurry to get the crops planted.

Similar to several researchers (e.g., Jordan, 1987; McGrath, 1987), the Sarayaku people recognize the role of the decomposing forest biomass in improving soil fertility. Nevertheless, they generally consider roots and fallen leaves to be enough to fulfill this role. Stems, branches, and twigs are considered as obstacles to planting, and all that is not too big, or too far from the edge, is simply thrown out of the field area.

Clearing and planting for fields takes place any time of the year. However, the "dry" season in July–August (Fig. 2) is preferred for several reasons. The debris dries up faster, which facilitates burning, and the weeds do not grow much, permitting the crops to get a head start. The risk of seeds and seedlings getting killed by heavy rain is also reduced during the dry season. The increased availability of labor in the household during the school vacations in July–August is an additional reason why many people make fields during this time of the year.
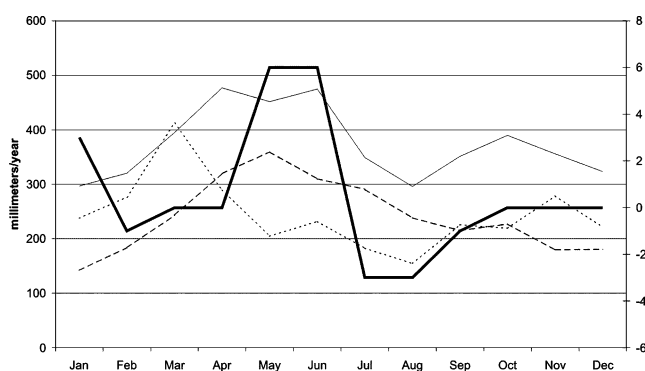
Fig. 2 Seasonality of rainfall. Given the strong climatic gradients in altitudinal as well as north–south direction, and the absence of meteorological stations in the immediate vicinity of Sarayaku (400 m a. s. l.), a subjective assessment made by local inhabitants during a workshop (*broad line, right-hand y-axis*) is provided to complement the data for the nearest meteorological stations (*left-hand y-axis* indicates the average values of rainfall according to data of the Instituto Nacional de Meteorología y Hidrología, INAMHI): Puyo (960 m a. s. l., 65 km WNW of Sarayaku, 1975–1999, *narrow line*), Taisha (508 m a. s. l., 70 km S of Sarayaku,1970–1972, *broken line*), and Nueva Rocafuerte (265 m a. s. l., 250 km ENE of Sarayaku, 1976–2000, *dotted line*).

The most important crops, in order, are sweet cassava (*Manihot esculenta*), plantain (*Musa* spp.), and maize (*Zea mays*). Sarayaku high school students Aranda and Machoa (1993) recorded no less than 54 different varieties of cassava. There are two major types of plantain, each one further divided into several varieties; the *palanda* which has larger fruits and a richer taste, and the *guinia*, which has the advantage that it is more tolerant, growing also on poor soils, and able to survive and carry fruit even when surrounded by high regrowth. There are also two major types of maize—traditional *runasara*, particularly suitable as a food crop because the ears dry slowly and asynchronously, allowing a prolonged period of harvesting of green ears, and the fairly recently introduced *morocho*, which provides higher yields and dries fast and quite synchronously, facilitating a one-time harvest in order to store the maize as poultry feed.

Cassava is planted in almost all fields, typically intercropped with a wide range of other crops (cf. Garí, 2001). On plains, plantains are almost always planted, often also maize, and on sandy soils often groundnuts (*Arachis hypogaea*) and papaya (*Carica papaya*). Plantains are also planted on hills with black soil. On hill fields on red soils, however, only the guinia type of plantain is planted, mostly along the low-lying edges. On red soils on hills pineapple (*Ananas comosus*) or barbasco (*Lonchocarpus nicou*) are frequently planted. Spots where debris piles have been burned are planted with particularly demanding crops, such as beans (*Phaseolus* spp.), tomatoes (*Lycopersicon esculentum*), native onion (*Allium* sp.), chili pepper (*Capsicum* sp.), and various starchy root crops such as cocoyam (*Xanthosoma* spp.), yam (*Dioscorea trifida*), taro (*Colocasia esculenta),* and sweet potato (*Ipomoea batatas*). A characteristic of the system is not only the habit of planting multiple crops with different lengths of time until harvest, but also that harvesting is usually continuous, only groundnuts and maize being harvested within a fairly short time span. After harvesting cassava, unless plantains are casting too much shadow, the same stem is planted again, to provide a second harvest of cassava.

Therefore, fields typically show a succession of crops where one stage gradually transforms into the next. A common succession on plains is maize–cassava–plantain, maize being harvested after 3 months, cassava harvested from about 9 months up to a year and a half, the age at which the plantains start to be harvested. At this point, weeding activities become limited to occasional above-ground slashing with machete. This stage of the crop succession is locally called *palandapurun*, literally meaning "plantain fallow." After the plantains have given a second harvest the field is usually abandoned and returned to fallow. As variations of this basic theme, maize may be omitted or, on sandy soils, groundnuts may substitute or

complement the maize. On hills, particularly red soils, common successions are cassava–pineapple or cassava–barbasco. Pineapples or barbasco are slow-growing and tolerant of competition. The first pineapples are ready for harvest together with the second harvest of cassava, and continue to give fruit after regrowth invades the field. Barbasco is ready for harvest after a minimum of 2 to 3 years. Although some weeding of the barbasco is sometimes done after the last cassava harvest, eventually regrowth takes over. The barbasco then continues to grow as an understory plant and at the time of harvest the forest canopy often has reached 15 m in height. All these different paths of succession have in common that after about two and a half years, the field becomes fallow. With a few exceptions, there is little variation in the length of the cropping period. On the other hand, there is considerable variation in the length of the fallow period.

Useful trees, wild species as well as cultivars, are often favored when clearing for a field (cf. Denevan *et al.*, 1984; Unruh, 1990). Particularly seedlings and saplings are protected, but sometimes also large trees, in spite of the shadow they cast on the crops. Important fruit tree crops are the chunda palm (*Bactris gasipaes*), a multistem palm with nutritious fruits, and the kila of the cacao family (*Theobroma bicolor*). The tropical cedar (*Cedrela odorata*), used for making canoes, is actively managed in the fields. Other tree species have more resistant wood, but the tropical cedar is the easiest one to manage, because large quantities of seedlings grow up once the ground is cleared around a large tree. Many people in Sarayaku relate that this kind of fallow management has increased in importance over the last couple of generations. Recently, some households have experimented with planting rice on the plains. However, as there is no functioning husking machine and no tradition of manual husking, the rice has so far only been used as poultry feed.

Among domestic animals, poultry is the most important. They are kept in rustic poultry houses during nighttime and let out loose during the day. They are fed on maize and kitchen waste and also eat worms, insects, and leaves. Disease outbreaks sometimes reduce poultry stocks. Predators such as small felines (*Leopardus* spp.) and opossums (*Didelphis marsupialis*) also take a significant toll. Protecting the poultry by enclosing them within poultry netting is considered impractical because of the high cost, and because the poultry do not grow well if enclosed in a limited space where they rapidly deplete the supply of worms and other wild foods.

A few families have cattle pasture with introduced grass species. The cattle are tied with a rope to a tree and typically moved to another tree once or twice a day. Useful tree species, such as locally used timber trees, have often been left to stand in the pastures, such that the degree of tree cover is fairly high. The pasture area increased drastically in the mid-1980s due to governmental incentives, and peaking at probably some 100–200 ha of pasture. However, high transportation costs made cattle ranching unprofitable, so most pastures were abandoned in the 1990s. A few households raise pigs. Cattle as well as pigs are primarily raised for export to urban markets and the meat is only occasionally sold locally.

Another type of production system that is new and growing is fishponds. A few people have had fishponds for quite some time, foremost to keep fish that have been caught alive fresh. Others have recently built fishponds in order to produce fish for consumption, some of them with the help of NGO money. Some have used tilapia (*Tilapia* sp.), an introduced species, but others experiment with native Amazonian species such as gamitana (*Piaractus brachypomus*) and uputaza (*Cichlidae* spp.) The fish is usually fed on kitchen garbage, termites, and leaves. The results have been mixed; but in spite of some frustrations, more fishponds are being constructed.

Plantations of *chili* palm (*Aphandra natalia*) are a type of land cover that has gradually been increasing since the mid-1970s, as a response to the market demand for the fibres of the leaf bases of this palm and perhaps also to a decline of the wild stands due to unsustainable exploitation. Most plantations have been established simply by removing all other vegetation, so as to enhance the growth of the chili palms (cf. Pedersen and Balslev, 1992), similar to the management of açai (*Euterpe oleracea*) palms in the Amazon estuary (cf. Brondizio *et al.*, 1994). Others have been planted near houses, using the seeds of the fleshy and good-tasting fruit. It is necessary to weed during the approximately 15 years it takes until the fiber can be harvested. By then, the canopy closes and weed growth is naturally suppressed. The total area of chili palm plantations is nevertheless small, only a few families have *chili* management as a main source of income, and the largest mature holding is just 0.6 ha. All households also possess a small home garden with fruit trees, medicinal plants, bananas, spices, etc., which tends to grow in size and height with the age of the settlement at the site.

The land tenure system in Sarayaku has gradually evolved from what a century ago was nearly open access regime (Sirén, 2004, pp. 111–150). Nowadays, each family has use rights to a certain part of the community lands, and has the right to farm, hunt, and use other forest resources within that area (Sirén, 2006). Such areas of use rights, however, overlap each other, such that the old-growth forest is nowhere the exclusive property of one family alone. On the other hand, clearing of old-growth forest within your area of use rights gives exclusive ownership not only to the field itself, but also to the fallow that grows up afterwards. Such use rights to forest and ownership of fallows is

inherited from parents to children. Given that fallow periods can be long, it is not uncommon that two generations pass between the successive clearings of a particular site, such that there may be several grandchildren claiming rights to the same fallow.

Materials and Methods

Assessing the demographic changes over time in the study area was difficult for several reasons. In particular, demographic data are scarce, particularly for earlier periods, and the data quality is overall either unknown or known to be poor. In addition, the geographical area for which population numbers are given varies between the different population estimates, is not always well defined, and often differs from the area of this study. Finally, it is currently very difficult to even define whom to count as a resident of the community and whom not, because many young people very frequently move into and out from the study area.

Given these limitations, I made five separate estimates of the rate of demographic change, based on four different methods and sets of data. The procedures, which have been further described in Sirén (2004, pp. 70, 139–147), were in short the following. Two of the estimates were based on fitting exponential functions to official census data from 1974, 1982, 1990, and 2001. As the published censuses were not aggregated at the level of the Sarayaku community, this was instead done for the Sarayaku *parish* (a unit which contains, but is not limited to, the study area) and for the central hamlet of Sarayaku (a subunit of the study area), respectively. Another estimate was similarly calculated based on a figure provided by the Dominican Mission in 1942 for the Sarayaku community, compared with unpublished data from a pre-census carried out by the government in 2001 a few months before the actual census. A fourth estimate was made based on counting households indicated by local inhabitants doing retrospective mapping for the years 1960, 1978, and "present," i.e., 2001. Finally, an estimate was also made based on the birth and death rates recorded by Edeli *et al.* (1998), but also corrected for the effects of emigration. Although each one of these estimates is based on data of questionable accuracy, the different datasets are independent of each other, and are therefore unlikely to all carry the same biases.

To quantify land use change, two complementary methods were used. Both methods were based on field data collected between 1999 and 2001, consisting of a botanical description of georeferenced plots, together with their corresponding history of land use, recorded by means of interviews with the respective owners. For one part, these field data were used as ground-truth input for remote sensing analysis, based on the analysis of Landsat TM and Landsat ETM+ images from 1987 and 2001, respectively. The image classification was very challenging because the differences in spectral signatures between fallow and old-growth forest were in the same magnitude as differences caused by topographic shade effects, haze, and an east–west DN gradient (see Toivonen *et al.*, 2006). The procedure applied in order to deal with these challenges is exhaustively described in Sirén (2004, pp. 79–100).

The remote sensing analysis allowed the identification of fallows of an age up to about 20 years, which in the following text will be referred to as "young fallow." An evaluation of the image classification indicated that about 50% of young fallows actually were classified as such, whereas the rest was classified as "old-growth forest." Other than this, classification errors were negligible. Thus, to calculate the total area of young fallow, the area resulting from the image classification was multiplied with a factor two in order to correct for classification errors.

For another part, the field data were analyzed directly. Based on a random sample of households, I estimated the total area of agricultural fields in the community. Given that almost all fields had a life span of about two and a half years before they were abandoned and got invaded by regrowth, I estimated the annual rate of clearing of forest and fallows by dividing the area of cultivated land by 2.5. Using the full data set, I analyzed how variables related to land use intensity, such as time for first clearing, and fallow age at last clearing, were related to site characteristics such as soil type and distance. Distances were measured from schools, as these tend to be centrally located in each hamlet. When measuring distances on the alluvial plain of the Bobonaza River, however, distances were measured only from the *plaza* which forms the center of the whole community. Only plots that were accessed directly from the permanent hamlets were included in such analysis, excluding gardens accessed from the secondary homes ("purinas"). Plots on plains were excluded from analyses regarding distances, because all plains are located near hamlet centers or secondary homes.

When relevant, a weighted distance was calculated to account for the improved facility of transport provided by river access. Based on the author's experience, it was estimated that river transport is approximately three times easier than land transport. Therefore, the weighted distance was whatever was the shortest; either the distance in a straight line from each plot to a school, or the distance from the plot to the Bobonaza River plus 0.3 times the distance in a straight line from that point to a school. Similarly, I plotted against time the proportion of clearings made in old-growth and secondary forest, respectively.

Based on the age of the fallow at the last clearing of each land use plot, I also calculated the age distribution of fallows in the landscape. Although the remote sensing

analysis only allowed estimation of the area of fallows younger than 20 years of age, during fieldwork I found fallows up to 65 years old. As the field data analysis provided an estimate of the age distribution of fallows in the landscape, this allowed me to calculate also the area of fallows between 20 and 65 years old.
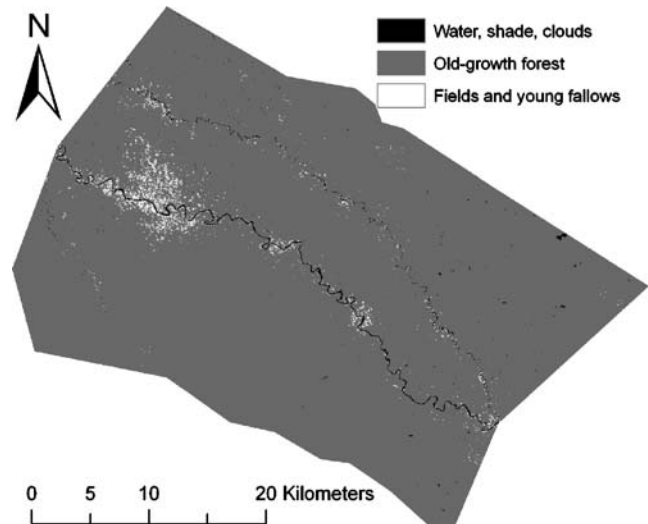
Results

The five different estimates of population growth rate were surprisingly similar to each other, four of them being within the range of 1.63 to 1.68%, whereas the fifth was 1.42% (Table I). Thus, in spite of the concerns about the quality of the data, it seems reasonable to state that mean annual population growth during the last few decades has been fairly close to 1.6%.

The area under crops was about 0.1–0.2% of the study area. Young falllow (i.e., those younger than 20 years) covered 2.2% of the study area (Fig. 3), whereas old fallows (i.e., those between 20 and 65 years of age) covered 1.3%. In sum, fallows occupy 3.4% of the area, not including those very old fallows spread out on ridge tops all over the study area which are remnants of the previously prevailing agricultural practices and dispersed settlement pattern that were gradually abandoned during the nineteenth and early twentieth centuries (Sirén, 2004, pp. 111–150). Some of these old "fallows" are still recognized as such, but others have become indistinguishable from old-growth forest. The changes in land use between 1987 and 2001 were very small, and could not be detected by means of remote sensing analysis (Fig. 4). However, by means of analysis of land use history data of field plots, it was possible to identify and quantify some changes.

The proportion of fields cleared in old-growth forest has, since the 1930s, decreased from about 100 to 33% (Fig. 5), while the population has roughly tripled over the same time. If we assume that the total area cleared per year per capita has been constant, this would imply that the absolute rate (in hectares per year) of secondary forest expansion has

Fig. 3 Land use classification of a 2001 Landsat TM image. Note that only 50% of the young fallows actually show up on the image. The class "old-growth forest" includes also old fallows (>20 years).

been fairly constant since the 1930s. Also, the distance to fields cleared in old-growth forest has increased over time (Fig. 6). This reflects the expansion of the fallows and the resulting shortage of old-growth forest. During fieldwork, people sometimes showed me fields that had recently been made by clearing old-growth forest quite close to settlements. However, these were usually on steep slopes or had stony soil considered unsuitable for cultivation, and had therefore previously been left intact.

The annual rate of clearing of forest and fallow for establishing fields was 53 ha. Out of this, an estimated 18 ha was cleared in old-growth forest. In relation to the total area of fields and fallows, this corresponds to a rate of expansion of the intervened area of about 0.4% per year. This may be a slight underestimate, because clearing for a field in old-growth forest also involves a heavy impact on the forest at the margins of the fields due to the impact of falling trees. Nevertheless, it is markedly lower than the annual rate of population growth, estimated to 1.6%. In relation to the total area of old-growth forest in the study area, on the other hand, this corresponds to a deforestation rate of 0.015% per year.

If we divide the present total area of fallow by the age of the Sarayaku community, i. e., about 180 years, we get an average annual expansion of 25 ha, just slightly above the estimated current 18 ha per year. This suggests that, except for a brief increase in the mid 1980s when many people established cattle pastures, the absolute rate of old-growth forest clearing has changed little since the establishment of the community in spite of population growth.
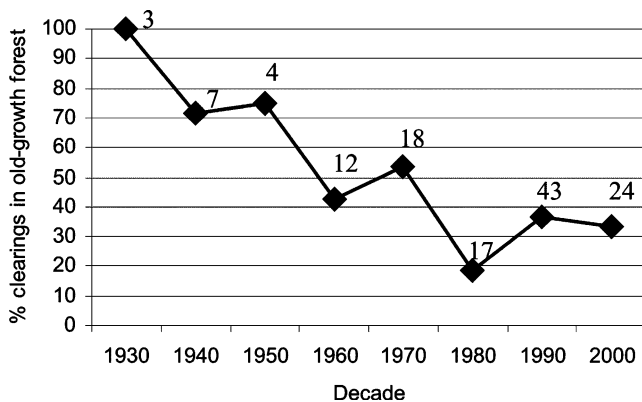
Farming is concentrated in the areas proximal to the hamlets. Of the area classified as "young fallow," 59% were within a 5 km radius from the central plaza of the

Table I Estimates of Annual Rate of Population Growth, Based on (a) Fit of Exponential Function to Official Census Data for the Sarayaku Parish, (b) Fit of Exponential Function to Official Census Data for the Centro Sarayaku Hamlet, (c) Fit of Exponential Function to Population Figures Provided by Dominican Mission in 1942 and Official Pre-Census in 2001, (d) Fit of Exponential Function to Estimates of Numbers of Households, Made by Retrospective Mapping, and (e) Estimates of Rates of Birth, Death, and Migration

Time period	1974–2001[a]	1974–2001[b]	1942–2001[c]	1960–2000[d]	1998[e]
% Annual growth	1.63	1.68	1.42	1.67	1.65

Fig. 4 Land use classification of Landsat imagery from 1987 and 2001 of the surroundings of the village. Note that only 50% of the young fallows actually show up on the image. The class called "old-growth forest" includes also old fallows (>20 years).

Water, shade, clouds
Old-growth forest
Young fallow
Fields
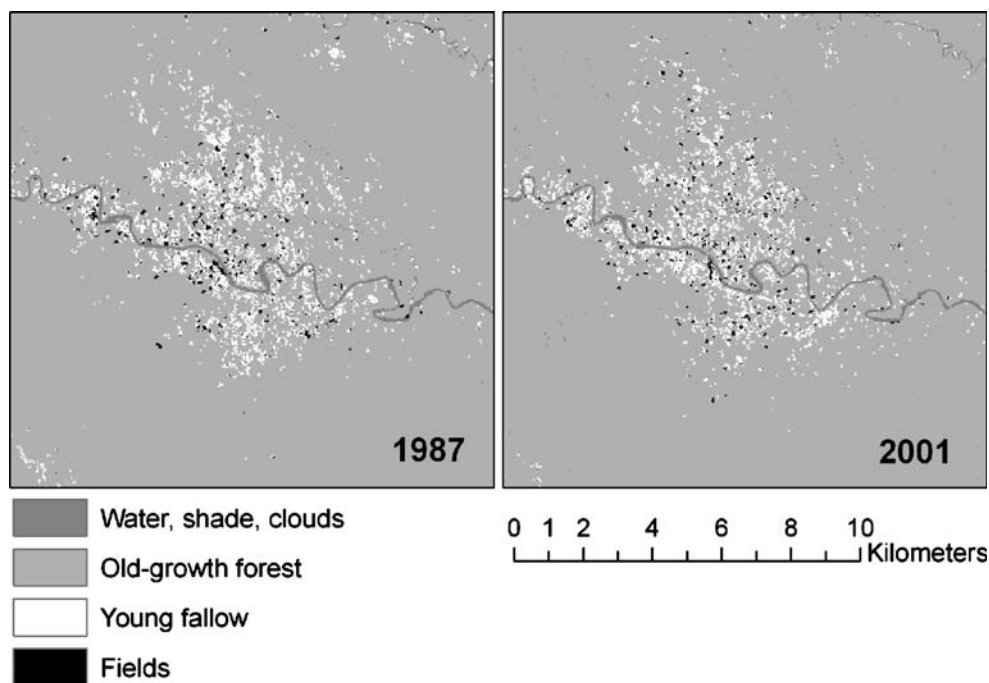
community. The alluvial plain of the Bobonaza River has a particularly high percentage of young fallows (Fig. 7). Near the hamlets, 70–90% of the land on this plain is either young fallow or field. The proportion of fields and young fallows decreases with distance from the hamlets. Beyond the Bobonaza plain, the decrease in the proportion fields and young fallows with distance is even steeper (Fig. 8).

For areas outside the major alluvial plains, i.e., mostly hill areas, the ratio of field area to total intervened area (fields plus young fallows) decreases with distance from settlement (Fig. 9). On the alluvial plain of the Bobonaza River, on the other hand, this ratio changes little with distance from settlement (Fig. 10). On hill soils, fallow length increases markedly with distance to settlements

(Fig. 11). Also the soil type and topography affected fallow length, fallow periods on red hill soils being longer than on black hill soils and plains (Figs. 11 and 12).

Discussion

Fields and fallows occupy just a small percentage of the study area, but their area is increasing. However, the expansion rate of the intervened area, 0.4% per year, is considerably lower than the rate of population increase, approximately 1.6% per year.

Distance to settlement is important in determining land use. Basically all land near the hamlets is used for farming.

Fig. 5 Change over time in the proportion of the fields that are made by clearing old-growth forest. The proportion of fields made by clearing old-growth forest has decreased strongly since the 1930s (r= −0.88. p=0.02, Spearman rank correlation). The numbers above the markers indicate the number of field plots used for calculating each percentage.
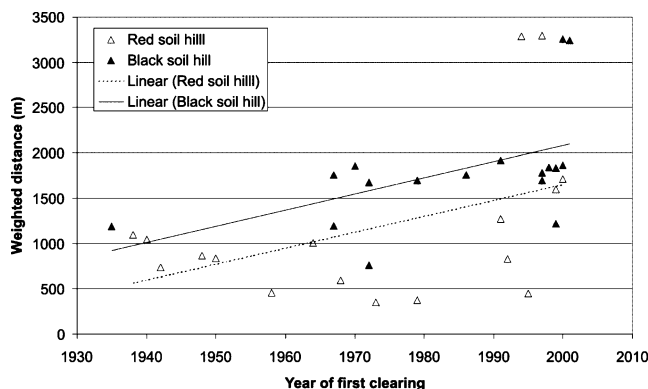
Fig. 6 The change over time in the distance from hamlet centres (schools) to clearings of old-growth forest. Each data point represents one field plot. Filled triangles and the unbroken regression line represent black soils on hill (Spearman rank correlation coefficient r_s= 0.64). Open triangles and the dotted regression line represent red soils on hill (r_s=0.32). Confidence intervals were not calculated because the plots are not fully independent of each other.
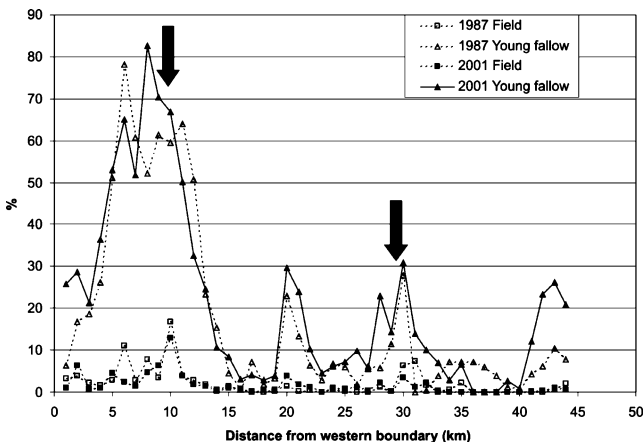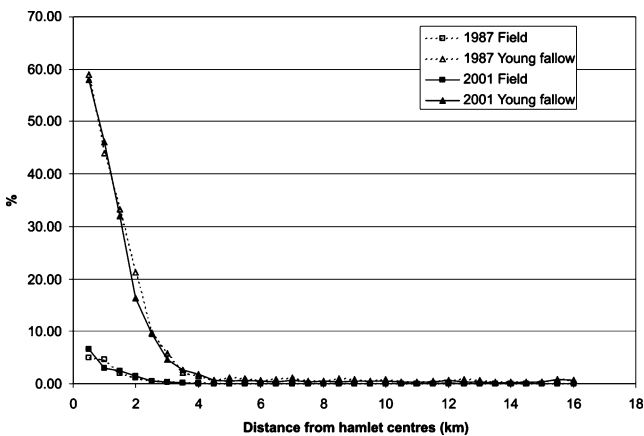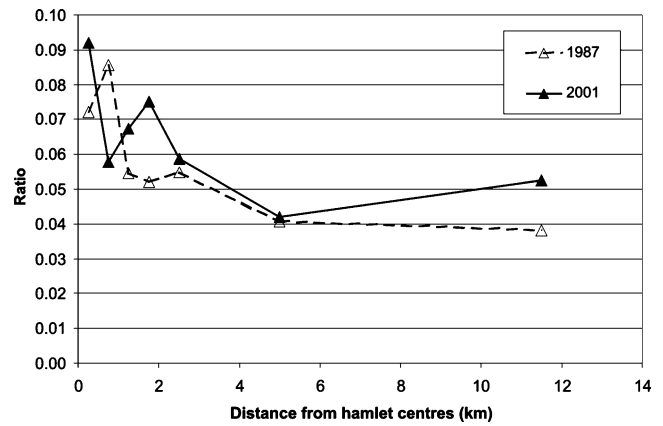
Fig. 7 Percentage of fields and young fallows on the alluvial plain of the Bobonaza river. The *black arrows* indicate the locations of the village centres of Sarayaku and Jatun Molino, respectively. Based on remote sensing analysis.

Fig. 9 Ratio of field/(field + young fallow) outside major alluvial plains, in relation to the distance from hamlet centres (schools) in 1987 and 2001, based on remote sensing analysis. Land use classes of the classified images were tabulated according to 500 m buffers around schools. The buffers were then aggregated into larger areas, each one including a minimum of 100 ha of fields and young fallow.

On the other hand, beyond four or five km from the hamlets hardly any land is farmed, except for a narrow rim along the major rivers. Soil characteristics and topography also influence land use, and the preference for farming on black soils is notable. Forests on stony soils or steep land may be temporally protected by the unsuitability of such sites for farming, but when the distance to better sites becomes too long, even stony and steep sites are farmed. Although the current deforestation rate is not alarming, it should be noted that almost all land seems to be farmable and in the long run few spots of forest are protected by their physical characteristics alone.

Currently, the problem of land use change is not so much a problem of forest loss as such, as the rate of decrease in old-growth forest cover is very slow. More importantly, it is a problem of resource scarcity for the Sarayaku people. This scarcity obliges them to farm at increasingly larger distances from their homes, to increasingly rely on clearing
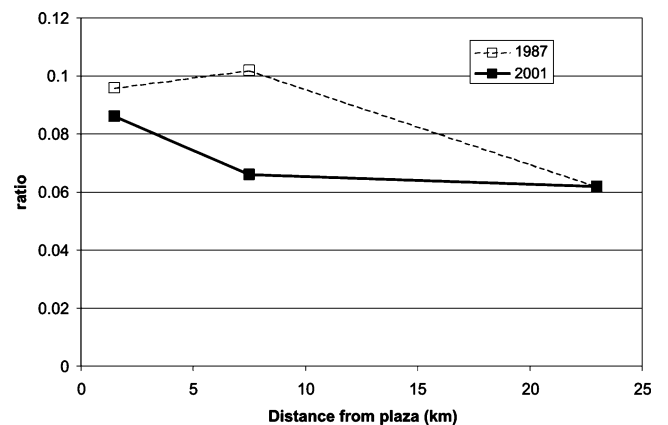
fallows instead of old-growth forest, and to shorten fallow periods. Longer distances to fields, decreased soil fertility, and increased weed infestation, cause increased workload and decreased yields.

People adapt to such increased hardships in different ways. There has been some technological innovation and intensification in the production systems in Sarayaku during recent years. This has been oriented towards animal production such as poultry and fish in order to substitute for wild game and fish, to fallow management for locally used timber and fruits (cf. Raintree and Warner, 1986; Unruh, 1990), and limited cash cropping, such as the chili palm plantations. None of these innovations, however, provide any substantial amount of food energy, and therefore probably have little effect on the area needed for cultivation.

Fig. 8 Percentage of fields and young fallows outside the major alluvial plains (those of the Bobonaza, Rutunu, and Jatunkapawari rivers), according to the distance to hamlet centres (schools). Based on remote sensing analysis.


Fig. 10 Ratio of field/(field + young fallow) on the alluvial plain of the Bobonaza river, in relation to the distance from the central plaza of Sarayaku, in 1987 and 2001, based on remote sensing analysis. Land use classes of the classified images were tabulated according to 500 m buffers around schools. The buffers were then aggregated into larger areas, each one including a minimum of 100 ha of fields and young fallow.
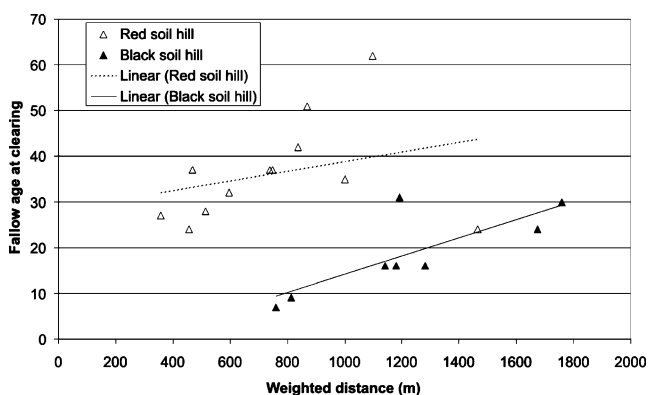
Fig. 11 Age of fallows at the time of the last clearing, in relation to weighted distance from hamlet centers (schools), for red hill soils (*open triangles*, *broken regression line*, r_s=0.30) and black hill soils (*filled triangles*, *unbroken regression line*, r_s=0.77). Each data point represents one field plot.

Resource scarcity may also cause changes in local institutions regarding control and access to resources. Absence or insufficiency of institutions that regulate the use of communally owned land may speed up agricultural expansion or shorten fallow periods beyond the social optimum (Rudel, 1995; Angelsen, 1997; Baland and Platteau, 1996, p. 285). The Sarayaku community has adapted to increasing competition for land by adopting firmer rules regulating the rights to land for farming (Sirén, 2006). However, there is still some competition for land that may lead to a race to clear an area of forest or fallow before somebody else does. It may be possible to strengthen rules further, encouraging permanent agriculture on alluvial plains and/or discouraging the type of competition for land that leads to shortened fallow periods or expansion into old-growth forest.

Fig. 12 Recorded age of fallows at the time of the last clearing (*left column*), and the calculated age distribution of fallows in the landscape (*right column*).
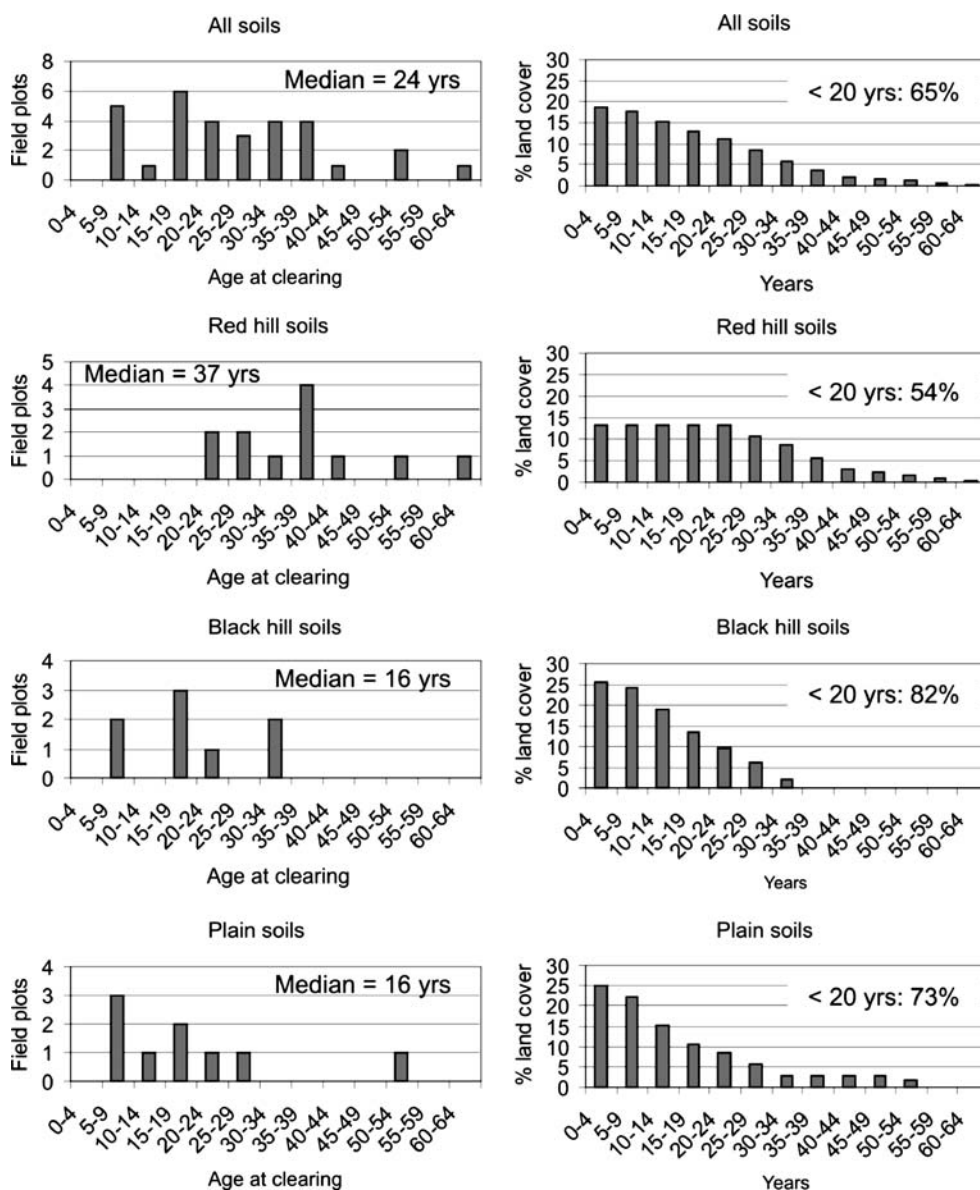
Another way to adapt to land scarcity is community fission or relocation. During the last half century, two community fissions have occurred, as small segments of the community have established new communities downstream of Sarayaku. The direct cause of the last fission was social conflict resulting from the activities of Protestant missionaries. But whatever the direct cause, such fissions reduce competition for land for cultivation, and such competition for resources may be an underlying cause of social conflict. The current land scarcity is ultimately an effect of sedentarization and nuclearization of settlement, and with a dispersed settlement pattern, land scarcity would be relieved. Given the current demand for services such as schools, shops and airstrip, a return to the dispersed settlement pattern of the past is not an option. Continued fissions of the community may, however, occur in the future. This would facilitate access to old-growth forest, and thus alleviate land scarcity while also causing loss of old-growth forest. While some people in Sarayaku have nurtured plans to bud off new communities in order to alleviate resource scarcity, others have opposed such plans because of the negative impact that would have on wildlife populations in areas hitherto protected by their remoteness.

Increasing scarcity of land to farm is a serious socioeconomic problem for the Sarayaku people. In the long run, it would be necessary to improve agricultural productivity without compromising sustainability. There are no easy solutions. Permanent cultivation of the alluvial plains may be technically possible, as shown by a few examples of continuous plantain cultivation, over several decades, on the fertile alluvial plain of the Bobonaza River. Perhaps improved technology for weed control or improved river transport could make this type of agriculture more attractive, reducing pressure on less fertile soils. Technological improvement may, however, also increase deforestation, depending on the particular circumstances and the type of technology (Angelsen and Kaimowitz, 2001). Increased access to salaried off-farm employment could also lead to increased consumption of imported foods, reducing the need for land to farm (cf. Kaimowitz and Angelsen, 1998, pp. 15–35). This is happening in Sarayaku, although on a limited scale; store-bought foods make up only 0.5% of the total food consumption, but contribute perhaps as much as 8% of fat intake (Sirén, 2004, pp. 161–165).

All over the tropics, communities similar to Sarayaku have often temporarily relieved their economic hardships by cashing in natural resources, particularly timber or minerals (e.g., Turner, 1999). Similar processes are found 35 km upriver from Sarayaku in the community of Canelos, where timber and oil companies have been operating. The road network is slowly expanding and may in the not too distant future cause drastic socioeconomic and environmental changes in Sarayaku as well. Up to now, however, the Sarayaku people have been very active in defending their land against environmentally destructive activities, such as agricultural colonization and oil development (Sawyer, 1997; Chávez et al., 2005). In calculating the balance of the impact of the Sarayaku people on the environment, this role as political actors may be more important than the direct physical impact they cause using axes and machetes.

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