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Changing Drivers of Deforestation and New Opportunities for Conservation

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Abstract: *Over the past 50 years, human agents of deforestation have changed in ways that have potentially important implications for conservation efforts. We characterized these changes through a meta-analysis of case studies of land-cover change in the tropics. From the 1960s to the 1980s, small-scale farmers, with state assistance, deforested large areas of tropical forest in Southeast Asia and Latin America. As globalization and urbanization increased during the 1980s, the agents of deforestation changed in two important parts of the tropical biome, the lowland rainforests in Brazil and Indonesia. Well-capitalized ranchers, farmers, and loggers producing for consumers in distant markets became more prominent in these places and this globalization weakened the historically strong relationship between local population growth and forest cover. At the same time, forests have begun to regrow in some tropical uplands. These changing circumstances, we believe, suggest two new and differing strategies for biodiversity conservation in the tropics, one focused on conserving uplands and the other on promoting environmental stewardship in lowlands and other areas conducive to industrial agriculture.*

Keywords: conservation, population trends, tropical deforestation, tropical rainforests

Cambio en los Factores de Deforestación y Nuevas Oportunidades de Conservación

Resumen: *Los agentes humanos de la deforestación han cambiado en los últimos 50 años de manera que tienen implicaciones potencialmente importantes para los esfuerzos de conservación. Caracterizamos estos cambios mediante un meta-análisis de estudios de caso de cobertura de suelo en los trópicos. De la década de 1960 a la de 1980, campesinos de pequeña escala, con asistencia del estado, deforestaron grandes extensiones de bosque tropical en el sureste de Asia y en América Latina. A medida que la globalización y la urbanización incrementaron en la década de 1980, los agentes de la deforestación cambiaron en dos partes importantes del bioma tropical, los bosques lluviosos en tierras bajas de Brasil e Indonesia. En estos lugares se volvieron más prominentes los granjeros, agricultores y madereros bien capitalizados y esta globalización debilitó la relación históricamente estrecha entre el crecimiento de la población local y la cobertura forestal. Al mismo tiempo, los bosques han comenzado a recuperarse en algunas montañas tropicales. Creemos que estas circunstancias cambiantes sugieren dos estrategias nuevas y diferentes para la conservación de la biodiversidad en los trópicos, una enfocada a la conservación de terrenos montañosos y la otra enfocada a promover la gestión ambiental en tierras bajas y otras tierras favorables para la agricultura industrial.*

Palabras Clave: bosques lluviosos tropicales, conservación, deforestación tropical, tendencias poblacionales

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Introduction

Since the 1960s agricultural expansion has destroyed large areas of tropical forest habitat, the most biologically diverse biome on the planet. The losses in tropical forests from the 1980s to the 1990s increased in Southeast Asia and remained roughly constant in the Amazon basin (Hansen & DeFries 2004; Asner et al. 2009 [this issue]), so the biodiversity threat posed by habitat loss remains acute. At the same time, the human agents driving tropical deforestation appear to have shifted in ways that provide new challenges and opportunities for biodiversity conservation.

We examined historical changes in the forces driving tropical deforestation through a meta-analysis of studies of change in tropical forest cover. By focusing on the changing historical trajectory of forest loss, we highlight the potential value of new strategies for conserving tropical forests and place the current debate over the tropical biodiversity crisis (e.g., Wright & Muller-Landau 2006; Laurance 2007*a*) in a broader context. Our analysis outlines two constellations of social forces, one that drove tropical deforestation from the 1960s to the 1980s and another that emerged after 1990 in the Amazon basin and insular Southeast Asia. We also considered several emerging and countervailing trends that provide opportunities for new initiatives to conserve tropical biodiversity.

Observers of tropical deforestation have, for decades, disagreed about the relative strength of the social forces that drive deforestation. The early theorists (Myers 1980) saw growing populations of shifting cultivators and smallholder colonists as the main driver of tropical forest loss. Increases in rural population densities along pioneer fronts did drive deforestation across a wide range of settings during this period (Carr 2009). More recently, analysts (Geist & Lambin 2002) have found population-based arguments wanting and have argued that economic incentives best explain the expansion of agriculture into old-growth forests in the tropics. Other observers argue about the size of these agricultural enterprises, asserting that it is primarily the well-capitalized operators of large ranches or plantations rather than smallholders who are responsible for most tropical deforestation (Plumwood & Routley 1982; Hecht & Cockburn 1989).

Given the broad geographic scale at which these arguments have been made, all of them, to varying degrees, tend to discount the local and regional mix of factors that drive deforestation. Because these more localized factors can often be important determinants of conservation policies in particular places (Rudel 2006), it is important to regionalize and contextualize historically analyses of the forces that have driven forest-cover change in the tropics. To this end we carried out a meta-analysis of place- and time-specific case studies of tropical deforestation.

Meta-Analysis

We collected data from case studies of tropical forest-cover change between 1975 and 2002. As concern about the losses of biodiversity mounted during the 1970s, people began to study the driving forces behind deforestation. By the turn of the century, more than 1000 articles had been written about changes in tropical-forest cover, but only a subset of these studies used primary data (satellite imagery, field observations, and interviews with farmers). In a 2002 literature search, we found 268 studies for which primary data were collected, usually in either a village or a region of a country. We used these studies in our meta-analysis. Of the 268 studies, 41 reported either no change in forest cover or net regrowth. The remaining 227 reported net deforestation, and we analyzed these (see Rudel 2005 for a list of the studies).

In all of these studies, the authors identify factors that contributed to forest-cover change in their study sites, so meta-analyses can be used to identify the forces that drove forest-cover change across the studied locales. Because the researchers collected their data during different periods, the meta-analysis can also distinguish between the drivers of forest-cover trends at different points of time. We used the year 1990 as an approximate cut off between two differing periods of deforestation.

There are several caveats to the data we examined. First, the studies in the meta-analysis do not represent a random sample of places experiencing change in tropical-forest cover. Instead, the sample of studied locales reflects a number of factors, some having to do with the severity of forest-cover change occurring in a place and others having to do with the personal security of field researchers in a place. Researchers gravitated to places with higher rates of deforestation, such as southern Mexico in the 1980s. This process of selection increased the studies of places that experienced extensive deforestation, which, in a meta-analysis, should make the places studied and drivers identified more representative of the universe of deforested places. Researchers also stayed away from places, such as Colombia, Angola, and Mozambique, that experienced recurring rural violence during the last three decades of the 20th century.

A second caveat concerns the possibility that different readers of a study might identify different drivers in the same study. To gauge the extent of these biases, we conducted intercoder reliability studies in which two readers coded the same article. Each reader coded the presence or absence of each driver based only on the original author's assessment; the readers did not impute drivers not explicitly mentioned by the original author. For the specific causes examined in this study (road building, small farmers, etc.), the rates of intercoder reliability were high, around 90% (see Rudel 2005, 2008 for further discussion).

We included a large number of studies of forest-cover change in each of the major tropical regions. Because the human ecologies of the major regional blocks of tropical forest differ so much, we chose, like Geist and Lambin (2002), to conduct separate analyses for each region. To this end we report analyses for seven different regions: Central America (densely populated, small rainforests), the Orinoco–Amazon (sparsely populated, large rainforests), West Africa (densely populated, small coastal rainforests), Central Africa (sparsely populated, large interior rainforests), East Africa (sparsely populated, middle-elevation dry forests and small, densely populated, high-elevation rainforests), South Asia (densely populated, dry forests), and Southeast Asia (densely populated rainforests). Following Geist and Lambin's (2002) meta-analytic method, we inferred a driver's contribution from the frequency with which it appeared in the case studies.

Results and Discussion

Small farmers were ubiquitous as drivers of deforestation, especially during the pre-1990 period when government colonization programs built roads that opened previously isolated, forested regions for agricultural expansion by small farmers (Table 1). This pattern changed after 1990, at least in the two main loci for post-1990 deforestation, Southeast Asia and the Amazon basin. More studies identified agribusinesses (cattle ranching, soybean farming, and plantation agriculture) as drivers and fewer studies identified government-funded colonization programs (new land-settlement schemes) as a driver after 1990. In both regions a more enterprise-driven deforestation emerged to both supplement and to some extent replace the state-assisted, smallholder-driven deforestation of the earlier era. In other regions, small farmers continued to clear land, and, increasingly, they did so to grow foodstuffs for urban markets (Mertens et al. 2000).

State-Enabled, Smallholder Deforestation (1965–1985)

Political turmoil and technological advances during the two decades after World War II laid the foundations for the first modern wave of tropical deforestation during the 1960s and 1970s. With postwar decolonization and the extension of the Cold War to the Americas through

Table 1. The drivers of tropical deforestation from 1980 to 2000 in seven tropical forest areas.*

Regions (number of studies for 1980s/1990s)	*Drivers, 1980s (% of studies)*	*Drivers, 1990s (% of studies)*	*Change from 1980s (χ^2, p) to1990s*
Central America (41/16)	small farmers (73)	small farmers (94)	2.9, 0.09
	insecure tenure (22)	insecure tenure (50)	4.3, 0.04
	ranching (71)	ranching (44)	3.6, 0.06
	colonization (56)	colonization (13)	8.8, 0.00
Amazon (31/29)	ranching (52)	ranching (76)	3.7, 0.05
	soybean farms (0)	soybean farms (10)	3.4, 0.07
	international markets (13)	international markets (31)	2.9, 0.09
	colonization (74)	colonization (38)	8.0, 0.01
	small farmers (87)	small farmers (69)	2.9, 0.09
	road building (71)	road building (83)	not significant
West Africa (11/8)	urban markets (18)	urban markets (62)	3.9, 0.05
	political unrest (0)	political unrest (25)	3.1, 0.08
	small farmers (100)	small farmers (88)	not significant
	population growth (82)	population growth (88)	not significant
Central Africa (7/4)	small farmers (85)	small farmers (100)	not significant
	road building (71)	road building (100)	not significant
	urban markets (71)	urban markets (100)	not significant
East Africa (10/9)	small farmers (70)	small farmers (100)	3.2, 0.07
	population growth (90)	Population growth (78)	not significant
	fuelwood (60)	fuelwood (33)	not significant
	urban markets (40)	urban markets (56)	not significant
South Asia (12/5)	small farmers (75)	small farmers (100)	not significant
	fuelwood (75)	fuelwood (100)	not significant
	population growth (67)	population growth (60)	not significant
Southeast Asia (29/15)	plantation agriculture (21)	plantation agriculture (60)	6.8, 0.01
	insecure tenure (3)	insecure tenure (53)	15.1, 0.00
	small farmers (90)	small farmers (67)	3.5, 0.06
	colonization (45)	colonization (20)	2.6, 0.105
	logging (52)	logging (67)	not significant
	population growth (52)	population growth (53)	not significant

**The drivers listed for each region are only those that were frequently mentioned for those regions (>39% of the cases). Drivers mentioned with less frequency have been included in the table if the frequency with which they were mentioned changed significantly from the 1980s to the 1990s.*

Table 2. An inventory of colonization programs (new land-settlement schemes) in rainforest regions.*

Region	*Country*	*Period of greatest activity*	Source*
Asia	Indonesia	1970s	Bahrin 1988
	Malaysia	1960s–1970s	Bahrin 1988
	Nepal	1950s–1960s	Shresta 1989
	Philippines	1950s–1960s	Bahrin 1988
	Thailand	1970s	Bahrin 1988
	Vietnam	1975s–1980s	Lang 1995–1996
Latin America	Bolivia	1960s–1970s	Stearman 1978
	Brazil	1970s–1980s	Rattner 1988
	Colombia	1960s–1970s	Duran 1988
	Dominican Republic	1970s	Stansfield 1989
	Ecuador	1970s	Salazar 1986
	Guatemala	1960s–1970s	Jones 1988
	Honduras	1970s–1980s	Jones 1988
	Mexico	1960s–1970s	O'Brien 1998
	Nicaragua	1970s–1980s	Jones 1988
	Paraguay	1960s–1970s	Hanratty & Meditz 1988
	Peru	1960s, 1980s	Carpio 1988
	Venezuela	1960s–1970s	Eidt 1975

**Complete source information is provided in Supporting Information.*

the Cuban revolution, rural insurrections proliferated in forest-rich rural regions in both Southeast Asia and Latin America. During the 1960s every newly independent state in Southeast Asia faced a rural insurgency. In most instances the insurgents operated from bases in remote rural regions with forests (Uhlig 1988). A similar pattern took hold in the Americas during the 1960s when groups of young people, inspired by the success of Cuban revolutionaries, formed resistance movements based in remote, forested regions (Wickham Crowley 1992).

In this context U.S. officials in Latin America pushed for agrarian reform and colonization programs, through a program called Alliance for Progress, which promised to reduce the attractiveness of revolutionary appeals by providing smallholders with land (Grindle 1985). In practice, colonization programs proved politically much easier to implement than land reforms because colonization programs did not require that governments take land away from large landholders (Domike 1971). In response to these political pressures, state officials built penetration roads into remote rainforest regions, established new settlements along the roads, and populated the new settlements with poor rural people who supported the central government (Jones 1988). Indonesian officials resettled Javanese smallholders in the predominantly forested outer islands of Indonesia (Hardjono 1989). Brazilian leaders promised to bring the "people without land" from Northeastern Brazil to the "land without people" by establishing settlements along the newly constructed Trans-Amazon highway (Hecht & Cockburn 1989:108). Governments throughout Southeast Asia and Latin America adopted these programs during the 1960s and 1970s (Table 2; Supporting Information).

For every migrant who moved to a planned community, the frontiers attracted three to four spontaneous migrants (Scholz 1986; Jones 1988). The large numbers of young people intent on carving small farms out of the forests during the 1960s reflected advances in public health 15 years earlier, in particular declines in infant mortality after World War II (Caldwell 2002). These streams of rural to rural migrants underscored the still small size of urban labor markets. Cities in the 66 countries with tropical forests contained slightly <22% of their national populations in 1960 (UN 1961). Under these circumstances young people growing up in rural areas looked to the forest frontiers, not to the cities, for economic opportunities.

The spatial patterns of forest loss reflected the social forces driving deforestation during this period. To facilitate colonists' access to markets and urban amenities, construction crews in Amazon colonization zones built feeder roads running at right angles off of the main penetration roads. Viewed from the air, the cleared lands in these zones resembled a fishbone as colonists and cattle ranchers cleared strips of land along the newly constructed roads. Additional clearings ran parallel to these roads, 1 km to each side, as rows of colonists with lands 1 km into the forest from the road cleared the lands on their properties closest to the road. This pattern of clearings created edge effects along forest–pasture boundaries (Laurance et al. 2002) and fragmented forest habitats over extensive areas (Skole & Tucker 1993). The smallholder clearing during this period extended even into places with accentuated topography like interior Southeast Asia (Geddes 1976) or the Amazon foothills of the Andes (Rudel & Horowitz 1993). Rural population

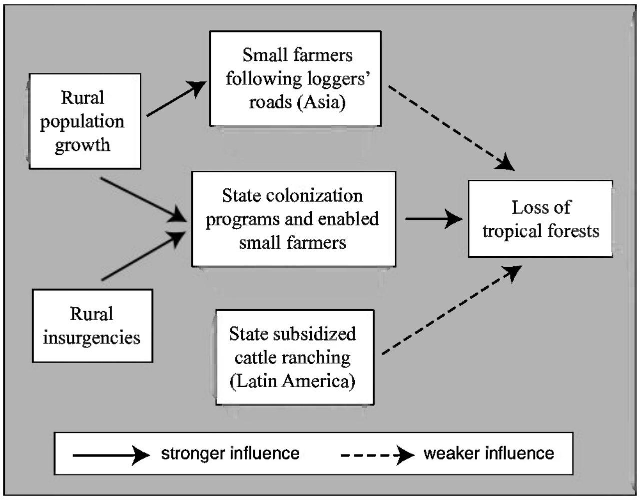

Figure 1. The first wave (1960–1985) of deforestation driven by state-enabled smallholders.

growth, coupled with rural insurgencies, spurred governments to support smallholder colonization of rainforest regions and the associated destruction of rain forests (Fig. 1).

Africa did not follow the prevalent pattern. Although some African states resettled rural people along roads or in villages (Hyden 1980), they did not create new land-settlement schemes in rainforest regions (Table 1). Throughout Africa, smallholders, driven by increases in numbers and by poor soil fertility, expanded croplands at the expense of forests, sometimes for export crops such as cocoa (Hill 1963) or for foodstuffs to be consumed or marketed in urban areas (Mertens et al. 2000). The role of highly capitalized enterprises also varied from region to region. Timber companies, attracted by the high value of wood from *Dipterocarpaceae* forests in international markets, logged more old-growth forests in Southeast Asia than in Africa or Latin America (Collins et al. 1991). "Follow-on farmers" in Southeast Asia then fanned out along the logging firms' roads and cleared small plots of land to cultivate cash crops such as pepper (Vayda & Sahur 1985). In Latin America settlers created cattle ranches, acting in part out of a cultural legacy from the colonial period. The creation of these pastures spurred deforestation in a way not seen in the other tropical regions (Shane 1986).

Enterprise-Driven Deforestation (1985–Present)

Changes in the dynamics of deforestation in the Amazon basin and the outer islands of Indonesia have been (Table 1) particularly significant because Brazil and Indonesia, together, have accounted for an increasing proportion of all tropical deforestation since 1980. In calculations of net changes in forest cover (which included losses of primary forest and gains from plantations and spontaneous regrowth), Brazil and Indonesia accounted for 20.3% of the global tropical forest loss during the 1980s, 25.7% of the loss during the 1990s, and 40.7% of the loss between 2000 and 2005 (FAO 1993, 2000, 2005). More reliable MODIS- and Landsat-derived measurements of forest-cover change underscore the geographical concentration of land clearing. By these measures, Brazil and Indonesia accounted for 60.6% of the worldwide losses of humid tropical forest between 2000 and 2005 (Hansen et al. 2008).

During the 1990s publically assisted, smallholder colonization projects declined as drivers of deforestation in America and in Southeast Asia (Table 1). Threats to central governments from rural insurgencies also declined in both regions. At the same time, fiscal austerity following the debt crises of the 1980s induced cost-cutting measures in central governments (Sturzenegger & Laban 1994). In this context politicians found it easy to abandon new land settlement schemes and build fewer penetration roads into forest-rich regions, given their high cost and diminished strategic importance (Thiesenhusen 1995).

Private groups now build most roads in the Brazilian Amazon, typically to access unexploited timber, soils, or mineral deposits (Perz et al. 2007). Governments have assisted the owners of agricultural enterprises with tax breaks and producer-inspired infrastructure projects such as *Avança Brasil* in the Amazon basin, but the impetus for these projects has come from the private sector (Laurance et al. 2001). In Indonesia oil-palm plantations became a more important source of forest losses (Table 1). Although the crops driving agricultural expansion vary from the Amazon to Southeast Asia, road building and land clearing in both regions have become more enterprise driven. The enterprises include small farmers organized into associations and highly capitalized, well-organized soybean farmers, cattle ranchers, and oil-palm planters. The growing salience of these private enterprises in studies of deforestation in the Amazon and Southeast Asia reflects this shift in deforestation's drivers (Table 1).

Private agricultural enterprises in the tropics increasingly produce for international markets. Farmers in southern Amazonia have begun exporting large quantities of soybeans to Asia. Following successful campaigns against hoof and mouth disease in the 1990s, ranchers in the Brazilian Amazon began exporting beef to European markets (Nepstad et al. 2006). Since 2005 the increased use of corn-, sugarcane-, and palm-oil-based biofuels has spurred the growth in global demand for feed grains and oils, generating new international trade flows and further pressures to convert old-growth tropical forests into croplands or plantations in the Amazon (Laurance 2007*b*) and in Southeast Asia (Koh & Wilcove 2008). These trends explain the increasing salience of international markets as a driver of deforestation in the Amazon basin (see Table 1).

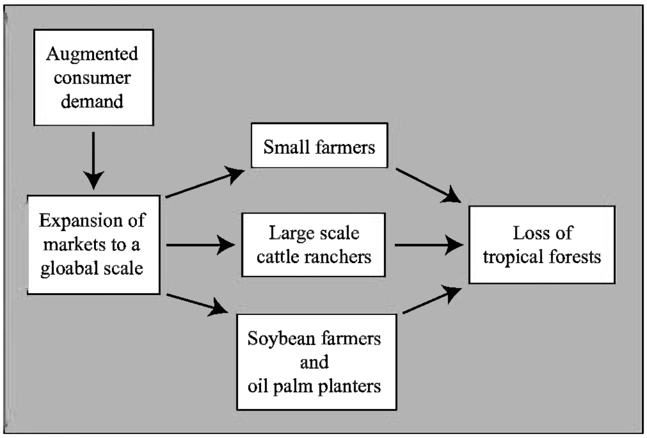

Figure 2. The second wave (1985–present) of deforestation driven by enterprises in the Amazon basin and insular Southeast Asia.

In the Amazon and Southeast Asia, a pattern of enterprise-driven deforestation emerged after 1990 (Fig. 2).

Under these circumstances, the relationship between rural population densities and forest loss shifted in the Amazon basin and insular Southeast Asia (Laurance 2007*a*). During the earlier period, small increments in rural population densities produced small declines in forest cover. During the later period, small increments in rural population densities were associated with larger declines in forest cover in the Brazilian Amazon (Wright & Muller-Landau 2006). This shift in the population density–forest-cover relationship probably reflects the emergence of well capitalized enterprises that clear large areas of old-growth forest with small work forces (Laurance 2007*a*). Overall, the Brazilian Amazon experienced modest declines in rural populations during the early 1990s and lost appreciable amounts of old-growth forest (Browder & Godfrey 1997). Marginal declines between the 1980s and 1990s in the frequency with which studies cited small farmers as a cause of deforestation in the Amazon basin and Southeast Asia (Table 1) probably reflects these altered demographic circumstances.

Urbanization also spurred change in processes of deforestation. Between 1960 and 1990, populations of tropical nations became more urbanized, with the proportion of people living in cities and towns nearly doubling to 39.4% from 1960 to 1990 (UN 1991). In forest-rich Brazil the proportion of urban residents in the population grew dramatically, from 45% to 77% from 1960 to 1990 (UN 1991). Under these circumstances urban labor markets became the main destination for young migrants leaving rural communities (Bilsborrow 1998). The growing number of urban residents, some newly affluent, have increased their consumption of agricultural products and, in so doing, spurred agricultural expansion at the expense of the forests. This trend is most pronounced in African countries (see West Africa in Table 1), where rapid population growth in cities has increased incentives for farmers to convert forests into fields for crops to sell in urban markets. The debt crisis also induced, at least in Cameroon, an increased emphasis on producing foodstuffs for urban markets because the new emphasis on fiscal austerity led the government to cut subsidies for export crops like cacao (Mertens et al. 2000).

The spatial form of deforestation shifted with changing agents of destruction. Large blocks of land cleared by agribusinesses replaced fishbone clearings by smallholders as the prevailing spatial pattern for recent deforestation (Ewers & Laurance 2006; Morton et al. 2006). As farms have grown in size, farmers' preferences for flat land have increased, in part perhaps because, to clear and work their lands, large-scale farmers rely on heavy machinery (bulldozers, tractors, harvesters, etc.) that perform better on flat land.

The shift toward enterprise-driven processes of deforestation seems most evident (e.g., up until 2002) in the Amazon basin and Southeast Asia. Smallholders did not disappear as a force driving deforestation in the Amazon (Vosti et al. 2001), but in relative terms their contributions to the losses of old-growth forest lessened in these places. Trends differed in Central America, South Asia, East Africa, and West Africa, where impoverished small farmers, including recent migrants to an area (Carr 2009), continued to clear most of the now-diminished forests in these settings (Table 1). Central Africa, with its large block of relatively intact forest, appears to be a special case. The inaccessibility of Congo Basin forests and the weakness of states wracked by political turmoil have prevented widespread exploitation (Rudel 2005). For this reason African deforestation rates have remained low. From 2000 to 2005, for example, Africa accounted for <7% of the worldwide loss of humid tropical forests (Hansen et al. 2008). Recent events suggest this pattern may be changing. In particular, the rapid spread of logging in Central Africa by Asian logging firms (Laporte et al. 2007) suggests that pressure on forests induced by international trade are becoming more prevalent in Central Africa, just as they have in the Amazon basin.

Countervailing Trends and Policy Opportunities

As our meta-analysis suggests (Table 1), the patterns of state-enabled, smallholder deforestation and enterprise-driven deforestation vary in their applicability both regionally and historically. For example, even during the past decade in the Amazon basin, where large-scale enterprises have become much more prominent as agents of deforestation, circumstances like policy changes or business cycles have changed the agents of deforestation from year to year, increasing in some instances the impacts of smallholders and decreasing the effects of large-scale enterprises (Ewers et al. 2008; Killeen et al. 2008). Still, viewed through the long-term lens of four decades of deforestation, agricultural enterprises linked to global markets appear to have replaced state-enabled small farmers as the primary drivers of deforestation in the two regions where most of the recent forest losses have occurred.

This shift in the drivers of deforestation has created new opportunities for conserving tropical forests in a context in which conservation organizations have become much stronger. The historical circumstances surrounding creation of parks illustrate the changing form and growing strength of conservation efforts. Beginning in the 1970s, usually in the aftermath of an alarming report about deforestation in a country, advocacy networks composed of concerned scientists, international environmental NGOs, local and national environmental NGOs, and indigenous peoples pressured politicians to create new protected areas. Events leading up to the recent creation of the "Heart of Borneo" reserve network in Kalimantan exemplify this pattern. In 2005 the Indonesian State Plantation Agency decided to create the world's largest oil-palm plantation with financing from Chinese investors. A coalition of international and national NGOs mobilized, with the participation of local people, to protest the plans for the mega plantation. Following an intense campaign, the coalition succeeded in having a series of 22 reserves spanning a large upland area designated as a park network, the "Heart of Borneo" (FOE 2006; WWF 2006). Other conservation victories have come only after many years of political pressure by conservationists. As a consequence of such concerted efforts, the overall extent of protected areas in the tropics has increased rapidly during the past 50 years. By 2004, protected areas (IUCN categories I–VI) encompassed nearly 18.9% of the world's tropical humid forest biome (Chape et al. 2005:450) and covered a larger percentage of all land in the low latitude tropics, within 10° of the equator, than at any other latitude (Brooks et al. 2009 [this issue]). In this political context, two conservation strategies seem most plausible: upland conservation reserves and lowland stewardship agreements.

Upland Conservation Reserves

Secondary forests have become more common in a diverse set of tropical locales. As cutover, cultivated, and formerly forested lands have accumulated in the tropics during the past 40 years, a significant number of studies, spread across Africa, Asia, and Latin America, have begun to report an expansion in secondary forests (Asner et al. 2009). These new forests take a variety of forms. In some instances, secondary forests have regenerated spontaneously on abandoned farmlands, a pattern particularly prevalent in Latin America. In other locales, such as South and Southeast Asia, landowners have established plantations of exotic, fast growing tree species, such as *Pinus roxburghii*, in upland areas. In still other cases, such as in densely settled upland zones in East Africa, smallholders have created species-diverse agroforests on small plots around their homes.

In about 70% of reported cases, the committed regrowth occurs in hilly or mountainous topography (Asner et al. 2009). Several dynamics may account for the association of rugged topography with regrowth. For obvious engineering reasons road building usually occurs on flatter, lower elevation lands. Road building or improvement, in turn, seems to generate predictable changes in lands close to and far from the new roads. In Laos (Thongmanlvong & Fujita 2006), the Philippines (Shively & Martinez 2001), and Amazonia (Andersen et al. 2002), landowners intensified agriculture close to newly constructed or improved roads at the same time that regrowth began in upland regions farther from the roads, presumably because cultivators abandoned these lands or decided to work on them less intensively.

If a global pattern of lowland deforestation, upland depopulation, and upland regrowth emerges in the tropics, it could have significant implications for the conservation of tropical biodiversity. The general decline in upland population densities might make the conservation of biodiversity in the vacated areas more politically palatable. Provided that continuing agricultural intensification in lowlands satisfies augmented urban demand for foodstuffs, declining populations in uplands could spur forest regrowth in these places (Wright & Muller-Landau 2006). The high density of locally endemic species in these sites should make the conservation of these lands a high priority among environmentalists (Ohlemuller et al. 2008).

Is there any evidence that recently created nature reserves and parks tend to cluster in tropical areas with rugged topography? The pattern of reserve creation where the Andes meets the Amazon in southeastern Ecuador would support this contention. Figure 3 illustrates the overall pattern in a single image. Rural to urban migrants have moved to the small provincial city of Macas in the Ecuadorian Amazon while deforestation has concentrated on the flatter lands across the river. The Andean foothills in the background, the Kutuku range, became a National Forest in 1990. The generality of this pattern remains open to question.

Lowland Stewardship Agreements

Increasing industrialization of deforestation is a cause for concern. A single bulldozer can destroy as much forest as dozens of small-scale farmers, leading to higher per-capita rates of forest loss, as has occurred in the Brazilian Amazon in recent decades (Wright & Muller-Landau 2006; Laurance 2007*a*). Well-capitalized agricultural enterprises (large-scale ranchers, soybean farmers, some small-scale ranchers) clear forests rapidly, and large extractive enterprises, such as logging firms, build extensive networks of roads that in turn facilitate

Figure 3. Municipality of Macas, the Upano-Palora Plain (foreground), and the Kutuku Range in Ecuador (background) (photo: Macas City Administration). Recent deforestation has all occurred on the Upano-Palora plain.

additional clearing. At the same time, the conservation movement has become better organized, with well-funded international environmental groups, local NGOs, and a public newly concerned about the negative impact of deforestation on global warming. Under these circumstances direct bargaining between the two sides becomes increasingly possible (Butler & Laurance 2008): the corporations reduce the damage they inflict on tropical forests, becoming stewards of the forests on their lands, in exchange for gaining access to markets with environmentally concerned consumers. This type of dynamic may explain the recent decision by the Brazilian Association of Vegetable Oil Producers to place a 2-year embargo on the purchase of soybeans grown on recently deforested lands in the Amazon. The association took this action only after Greenpeace-Brazil embarked on a campaign to publicize the environmental damage caused by new soybean producers (Nepstad et al. 2008). More generally, this emerging dynamic underlines a growing potential for environmental certification to reduce corporate impacts on tropical forests. Governments can play a pivotal role in bringing about these negotiations by mobilizing disparate groups and facilitating interactions between them.

Implications for the Debate on Tropical Extinction

Our analyses have two key implications for the current debate over the fate of tropical biodiversity. First, the growing role of well-capitalized agricultural enterprises in driving deforestation in several regions could weaken the historically strong negative correlations between total and rural population densities and net forest cover in tropical nations (Wright & Muller-Landau 2006). Second, if the locus of rural depopulation and forest regeneration occurs in uplands, not lowlands, then the benefits of increasing urbanization for biodiversity would be more geographically restricted than suggested by Wright and Muller-Landau (2006).

Significant questions remain about these arguments. How extensive are the uplands in the tropics that are becoming depopulated, and will such areas eventually recover their biological values? Can environmental groups negotiate effectively with corporations? Typically, momentum characterizes innovations as they sweep across new fields (DiMaggio & Powell 1983). Will organizations representing Chinese and Brazilian consumers buy into the idea of environmentally certified products after organizations representing European consumers have done so? Will soybean growers in Bolivia and cattle ranchers in Ecuador follow the lead of Brazilian cultivators in seeking ecocertification? How will new international agreements to control greenhouse emissions through REDD (reducing emissions from deforestation and degradation) affect these agreements?

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Supporting Information

Sources for information on colonization programs listed in Table 2 are available as part of the on-line article (Appendix S1). The authors are responsible for the content and functionality of these materials. Queries (other than absence of the material) should be directed to the corresponding author.

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