Population Dynamics and Tropical Deforestation: State of the Debate and Conceptual Challenges

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What is the role of population in driving deforestation? This question was put forth as a discussion topic in the cyberseminar hosted by Population Environment Research Network (PERN) in Spring, 2003. Contributors from diverse backgrounds weighed in on the discussion, citing key factors in the population-deforestation nexus and suggesting further courses of action and research. Participants explored themes of their own choosing, with many coming to the forefront. Scale, time, and place-based effects were cited as areas in need of particular attention. Consumption patterns as the mechanism for spurring deforestation were discussed, drawing attention to the differential patterns associated with urban vs. rural demands on forest resources and land. The applicability of the IPAT formula and the influence of its component parts, affluence and technology, when operating in tandem with population, was debated. The relation of demographic factors to these pathways was critically examined. Institutional and governmental influence, such as infrastructure and policies affecting access and incentives, the valuation of resources, and institutional failures such as mismanagement and corruption emerged as a crucial set of factors. This article synthesizes the critical debates in the population-deforestation literature, makes suggestions for future paths of research, and discussed possible policy and direct action initiatives.

KEY WORDS: demography; deforestation; land use/cover change (LUCC); population.

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DOI: 10.1007/s11111-005-0014-x

INTRODUCTION

The role of population in influencing environmental outcomes has a long history, with the first comprehensive population–environment relations formulated by British parson Thomas Malthus (1873) in which he predicted that as population growth out-paced food production (geometrically:arithmetically), humanity's future was doomed to famine, followed by population crash, assuming constant technology, farming techniques, and land resources. More recently, neo-Malthusian arguments (those based on the belief that improving people's standard of living is impossible without limiting population growth) remain predicated on the assumption of a fixed resource base and, therefore, of an ultimate ''carrying capacity,'' the maximum number of people that an area can support given resource endowments, resource use, and consumption levels (Pimentel, 1998). From this heritage has sprung current theories concerning the recursive circumstances of high population growth, environmental degradation, human immiseration, and resulting ecological desolation, including deforestation (Dasgupta, 1995).

A century after Malthus, Ester Boserup offered an alternative to this population–environment discourse, arguing that as available arable land becomes scarce relative to labor, farmers adopt more labor-intensive techniques that take advantage of increased labor–land factor ratios (Boserup, 1965). Thus, population could actually stimulate agricultural intensification. The implication for tropical deforestation was that population growth, assuming the reasonable availability of technologies, could ultimately have a benign or possibly even a positive effect on forest cover.

Scores of studies support these seemingly conflicting hypotheses put forth by both Malthus (e.g. Ehrhardt-Martinez 1998; Inman 1992; Rudel 1989; Southgate 1994,) and Boserup (e.g., Darity, 1980; Pender, 1998; Robinson & Schutjer, 1984; Turner et al. 1977, 1993), with no unifying conclusion yet drawn as to the environmental outcome of growing density and numbers of humans. To further address these issues, the Population Environment Research Network (see PERN,2005 for Web-address), was launched in 2001 as an Internet-based network whose mission is to facilitate scientific analysis and dialogue about population environment relationships, co-sponsored by the International Union for the Scientific Study of Population (IUSSP) and the International Human Dimensions Programme

(IHDP) on Global Environmental Change, and additionally supported by the Center for International Earth Science Information Network (CIESIN) at Columbia University.

As one means of pursuing its stated mission, PERN hosts cyberseminars inviting researchers and experts to weigh in on chosen topics relating to population–environment relations. One such seminar, entitled ''Population and Deforestation'' and held April 7–23, 2003, had the goal of promoting a discussion and dissemination of insights and ideas towards understanding demographic impacts on forests, in particular threatened forests. The seminar commenced with Helmut Geist and Eric Lambin's 2002 meta-analysis ''Proximate Causes and Underlying Driving Forces of Tropical Deforestation,'' a distillation of their 2001 book (Geist & Lambin 2001). Their 2002 paper served as a seed for discussion, and was complimented by an additional opening statement by the two authors commenting specifically on the role of demographic factors in their survey. This paper captures and expands upon the PERN discussion, situating it within the literature and enhancing the debate through critiques of the discourse.

Population dynamics are widely accepted in the land use/cover change (LUCC) scientific community as one of the significant drivers of global deforestation (Houghton, 1991; Myers, 1991; Vanclay, 1993; Wibowo & Byron, 1999). Some studies suggest that population explains half or more of the variation in deforestation worldwide (Allen & Barnes, 1985; Mather et al., 1998). Geist and Lambin's meta-analysis of 152 case studies throughout the tropics (2001) indicated that three-quarters of surveyed literature included population as a proximate or underlying cause of deforestation. However, the authors stress that demographic drivers of deforestation nearly always operate in tandem with political, economic and ecological processes at various scales (Geist & Lambin, 2001; Turner et al., 2001). Population dynamics will tend to have an indirect effect on LUCC, for example through changes in fertility or migration modifying consumption and production patterns. Conversely, economic outcomes (for example, farmland expansion) can have a direct impact on forest conversion. At the household level, responses occur simultaneously and ''multiphasically'' (Davis, 1963; Carr & Bilsborrow, 2001). Participants in the PERN cyberseminar hailed Geist and Lambin's conclusions as a step forward in researching humanity's role in deforestation, citing its strongest contribution as the ''rejection of single factor explanations that put most of the blame of deforestation upon shifting cultivators and population growth (Jefferson Fox, PERN, 2003, 4/8)'' and acknowledging the process is more complex than a simple positive linear relation between numbers of people and deforestation.

The conclusions of Geist and Lambin's work, however, have been met with some criticism, many of which has been readily acknowledged by the authors. For example, some seminar participants considered it subjective to attempt to categorize the drivers of deforestation, which in many cases are hypothesized and unproven (Jefferson Fox, PERN, 2003, 4/8). Indeed, the authors acknowledge that neither step for studying land change, namely the detection of change in the landscape and the subsequent assignment of causal factors to the attested change, is by any means simple. Remotely sensed imagery has facilitated estimates of land change over the past decade, but this task is minor in comparison to that of the explication of the observed change by assignment of causal power to candidate factors. Additionally, when linkages are assigned, at times they merely reflect an author's interests or disciplinary proclivities. As Frederick Meyerson (PERN, 2003, 4/19) remarked:

> The relative frequency does not, as Geist and Lambin infer, demonstrate that economic factors (81%) are more prominent underlying forces of tropical deforestation than demographic factors (61%) or cultural or sociopolitical factors (66%). What it appears to prove is that more economists have studied this issue than demographers or sociologists... Therefore, the article can only be considered as a useful jumping-off point.

In their book (2001), Geist and Lambin explicitly address this question: ''Does the disciplinary background of case study authors influence findings?''(Chapter 4.6). Though they take pains to address the topic and assert that author bias in is negligible and has little effect on the results of the analysis, the question remains if they have done so sufficiently. Lastly, perhaps within the individual case studies more linkages were assigned than their authors would have ascribed as primary underlying causes of deforestation in order to encourage an appreciation for the holistic quality of the system.

The PERN cyberseminar provided a platform for a lively discussion concerning the role of population in deforestation. That the cyberseminar successfully attracted participants from a wide-range of backgrounds demonstrates that human-induced environmental change in general and deforestation in particular is a topic which cannot be adequately covered by one discipline, attesting to the complexity and compelling nature of the issue. The following discussion summarizes and expands upon topics relevant to population and deforestation linkages broached by the cyberseminar's participants.

SPACE, TIME, AND PLACE

Because spatial and temporal discontinuities obfuscate links between population and environment interactions, identifying drivers of deforestation is facilitated by cleaving processes into proximate and underlying factors. The role of spatial and temporal scale, and the uniqueness of place-based effects, were highlighted as key heuristics in examining population–deforestation relations. We will first examine scale contingencies here.

Space

Much of the work attempting to quantify causal linkages with deforestation estimates has been limited by an early focus on global-level regression analyses; these tend to suffer from data limitations, particularly in terms of which variables exist in extant data bases, and how well they measure what they purport to measure (Alex Pfaff, PERN, 2003, 4/17; Geist & Lambin 2002). Cross-national statistical analyses popular in the 1980s and early 1990s managed to correlate national level rates of deforestation with economic and population growth rates (e.g., Amelung & Diehl, 1992; Rudel & Roper, 1997). Though these studies demonstrated that population does indeed reveal an association with deforestation at aggregate scales, further studies have shown that at local to regional scales there may be no such association (Carr, 2002a; Rindfuss, Turner, Entwisle, & Walsh, 2004). Further, the achievement of an overarching theory has been hampered by disaggregated case studies at the smallest scales, and by gross aggregations at the largest scales. Thus, LUCC conclusions sometimes commit the ecological fallacy by confusing patterns with processes operating at incommensurate temporal and spatial scales. The seeming paradox of rural population decline in many Latin American nations coinciding with continued high rates of forest clearing illustrates the importance of scale-dependency in analysis (Carr & Bilsborrow, 2001).

At the local scale, the site of forest conversion, deforestation is positively related to population growth, while the overall decline in rural population is a result of a more general trend towards urbanization and international migration. While analysis at the fine-scale where land use decisions take place merits attention, these decisions may also be in response to circumstances at a more aggregated level (Alex Pfaff, PERN, 2003, 4/17). With the previous example of declining rural populations accompanied by high rates of forest clearing, increasing population density in migration origin areas (from land concentration or population growth through immigration and fertility) can lead to frontier settlement (Barbier, 1997; Moran, 1993; Wood & Perz, 1996). Of course, out-migration from origin areas is a prerequisite to frontier settlement and subsequent forest conversion (Carr, 2004a), illustrating that processes acting in one place may lead to deforestation elsewhere.

LUCC drivers are typically intertwined across various levels of human-environment systems. Such factors can interact directly or through feedbacks and thresholds (Lambin, Geist, & Lepers, 2003; Steffen et al., 2004). Globalization processes can also intervene in local LUCC trajectories, both increasing and decreasing the effects of LUCC drivers and highlighting the interconnectedness of people across political boundaries (Lambin et al., 2001, 2002). When choosing a scale of analysis, national borders do not prevent (though they may constrain) people from responding to changing conditions, and including a regional approach to case study analysis may prove informative.

Time

Similar to the spatial scale of analysis, temporal lags are also inherent in population–deforestation linkages. Attempts to determine the effects of policies on deforestation, for example, must consider the fact that policies require a gestation period, and their effects may not be easily captured in cross-sectional studies (Alisson Barbieri, PERN, 2003, 4/16). Further, policies affecting migration, or reproductive health, rural employment, or land tenure and consolidation, can have indirect affects on forest conversion both where the policies are implemented or elsewhere following migration. Attempts to link concurrent deforestation and population growth rates similarly neglects that children may require several years before becoming potential agents of further forest clearance (Mather & Needle, 2000). An example of a lag effect is presented by Deacon (1994), whose study suggested a stronger relation between deforestation and population growth with a 5-year lag than with coterminous growth. Similarly, population growth elsewhere was at least partially responsible for pushing migrants to the Guatemalan frontier and subsequent forest conversion in the Maya Biosphere Reserve (Carr, 2004a; Schwartz, 1995)

Place

Are attempts to focus on causal principles and unified explanatory models fruitless? (John Sydenstricker-Neto, PERN, 2003, 4/15). There has been some agreement on general regional trends, such as those concluded by Geist and Lambin (2001, 2002) and Rudel and Roper (1996), suggesting some possibility of generalizable findings. Nevertheless, the great heterogeneity of space and time scales as well as the wide variety of drivers of LUCC, which typically interact with population in complicated pathways, would appear to hamper such a goal. A seemingly similar change, such as a decrease in rural population numbers, could mean a strikingly different outcome for forest cover, depending on the particular intersection of variables operating across different spatial and temporal scales. Individual case studies have certainly emphasized the unique set of circumstances operating on a specific site driving deforestation (Carr, 2002a). Local case studies frequently find that population dynamics yield quite different results in different places. For example, in Ecuador, population growth in the Amazon region has led to a widespread process of land clearing and deforestation by agricultural colonists in recent decades (Pichón, 1997; Pichón & Bilsborrow, 1999). Ongoing research by Bilsborrow and others suggests continuing rapid population growth, due as much to high fertility in the region as new in-migration, and further deforestation due to continuing agricultural extensification (Murphy, 2001; Pan & Bilsborrow, 2005). Conversely, during recent years forest conversion in the Brazilian Amazon has been associated with declining rural populations. Indeed, the region is now mostly urbanized and forest conversion is occurring increasingly due to soybean expansion among large landholders (Browder 1997; Brown et al., 2005; Hecht, 2005).

POPULATION DISTRIBUTION: REMOTE VS. LOCAL DEMANDS

The difference in the relative proportions of urban and rural populations are a distinguishing feature of the developed and developing worlds, and even in circumstances where distinct population distributions experience the same environmental outcome (deforestation, for example) the mechanisms operating upon the landscape can be strikingly different. As stated by Alex Pfaff, '"Spatial Distribution Matters": While this may be just an application of attention to setting and data aggregation, when analyzing data involving both rural and urban settings it is worth noting the spatial distribution of population (PERN, 2003, 4/17).' In particular, we distinguish between the remote demands on forest resources through urban consumption from the local impacts of rural population change.

Remote Demands: Urbanizing Populations

Although the concentration of populations within urban centers in the developed world is associated with forest regrowth (Mather, 1990; Mather & Needle, 1998; Walker & Smith, 1993), remote demand for products can lead to deforestation even when the population within the forested region has remained static if even decreased (Steve Kurtz, PERN, 2003, 4/11). According to UN Population Division estimates, the world's population was 37% urban in 1970, but will become majority urban by 2010. Urban expansion claims only a modicum of the world's total share of tropical deforestation, however its environmental impact is significant. The urban ecological footprint (Turner, 2001) impacts upon areas many times larger than the actual physical footprint to supply urban dwellers with raw products for food, construction, industry, and a large number of other goods and services (Schiller, de Sherbinin, Hsieh, & Pulsipher, 2001). Folke, Jansson, Larsson, and Costanza (1997), for example, concluded that Baltic European cities meet their consumption and waste assimilation needs by appropriating forest, agricultural, marine and wetland ecosystems totaling 565–1130 times greater than the area of the cities themselves. In addition to the indirect impacts on forests though consumption demands of urban populations, urbanization is linked to deforestation as a distal cause by way of food demand which has the direct LUCC effect of increasing cropped area in high-production areas, and the secondary effect of promoting out-migration of poor farm families to forest-rich agricultural frontiers through land consolidation. Urban and export oriented plantations in Guatemala, for example, have created some of the most skewed land distributions on the planet, setting the stage to squeeze the most impoverished farmers out of their origin areas in search of unclaimed frontier land in the Petén (Carr, 2002b). Urbanization further impacts forests through changes in social norms and increases in consumption aspirations (Lambin et al., 2001).

Despite the far-reaching demands of urban areas, however, many developed and developing countries experience favourable forest trends associated with urbanization, related to several characteristics of the developing world. One may be the lower degree of dependence on fuelwood; another is the lower likelihood of forest clearance for purposes of subsistence agriculture. Urban populations' food and fuel needs (and in the case of fuel, more likely in the form of fossil fuels than wood or charcoal) are more likely to be supplied via market mechanisms than through unfettered forest conversion for purposes of subsistence (Mather & Needle, 1999). Forest regrowth may take place as marginal agriculture land is abandoned because of a dearth of rural labor as the urbanizing populations find non-agricultural alternatives, or in the case of forest product scarcities, though implementation of planting programs, usually mediated by a government office (Mather & Needle, 1999; Rudel et al., 2005). Whether these trends are the direct result of urbanization or whether urbanization serves as a proxy for development in general in these models remains unclear (Mather & Needle, 1999).

However, forest regrowth frequently yields only an impoverished replacement of the original forest. As David Kummer explains, ''reforestation is now as great a threat to bio-diversity as deforestation. This is so because everyone is reforesting with the same 5 or 6 fast growing, exotic tree species (PERN, 2003, 4/10).'' Though perhaps lower in biodiversity than old-growth forests, which once stood in their place, expanding forests do provide many environmental services such as reducing soil erosion (Ammer, Breitsameter, & Zander, 1995) and reducing atmospheric greenhouse gases through carbon sequestration as they mature (Houghton et al., 2000).

Are these favorable forest trends characteristic of developed countries because, as Alex de Sherbinin asserts, ''rich industrial countries externalize materially-intensive processes and environmental burdens (PERN, 2003, 4/17)''? The extraction of resources in the ''periphery'' to enrich the ''core'' has long been evident in coffee, fruit, and sugar plantations throughout Central America (Frank, 1967), where surplus labor depresses wages, exploiting peasants in order to enhance capital accumulation for those who control large-scale production (de Janvry, 1991). Such relationships help explain deforestation Kuznetz curves observed throughout the world: forest impacts in early stages of development are low, become accelerated during development, and are again attenuated at later stages of development when primary resource extraction is moved to a new developing region (Mather et al., 1999). Mather and Needle's 1999 work on forest trends contests this assertion, at least in regards to forest products. The authors cite FAO 1990 Agrostats (1993), which lists half of the twelve richest nations as net-exporters of forest products. Nevertheless, much of the developing world's deforestation is caused by small frontier farmers, whose frontier settlement and subsistence production are at least partially a result of unequal terms of trade in agricultural commodities with the developing world. Thus, whether or not the developed world enjoys improved environmental conditions by plundering the developing world for other extractive goods, core–periphery relations do appear to play an important (though difficult to quantify) role in tropical deforestation.

Further, the international timber market is implicated in numerous cases of tropical deforestation: "In the case of Southeast Asia and the western Pacific (Philippines, Indonesia, Malaysia, Cambodia, Thailand, Burma, PNG and the Solomons) in the past 40 years, it is obvious that the major cause of deforestation has been commercial logging (David Kummer, PERN, 2006, 4/10)." In the Philippines, for example, commercial logging of tropical woods for the export market as arranged via corrupt political structures has been the first wave in deforesting the land (Kummer & Turner, 1994). Thus the literature indicates a disproportionate influence of logging on the deforestation processes in Southeast Asia (Rudel, Flesher, Bates, Baptista, & Holmgren, 2000). Some authors assert that more landscape impacts come from the remote demands of urban and international markets than from the demands of local users (Geist, Lambin, Palm, & Tomich, 2006; McConnell & Keys, 2005). In the words of Albert Barlett, "Modern agriculture is the use of land to convert petroleum into food," and in Peter Salonius' words, "The world is *not* running out of oil, however the imminent oil production peak is important for the world's forests as we begin the slow slide from abundant, cheap, convenient liquid hydrocarbon energy *and* expanding economies with global markets, toward less abundant, more expensive, much less flexible renewable energy *and* a contraction of world markets with more local trading patterns (PERN, 2003, 4/11)." If this is indeed the case, local demands on forests may reassert their primacy.

Local Demands: Rural Populations

Though the impact of local land users wanes in its relative impact upon the land, instances of deforestation resulting from local uses persist. Expansion of subsistence farming is associated with growing populations in Africa (Geist & Lambin, 2002). Additionally, the demand for fuelwood for household consumption, in the arid and populous regions of East Africa as well as South Asia is perhaps the primary proximate driver of deforestation in these regions (Rudel et al., 2000). Deforestation in Central America is characterized by in-migration to the frontier for subsistence agriculture, followed by land consolidation for pasture, pushing the frontier further and displacing the peasant farmers (Carr, 2004a). Where local demands drive deforestation, in-migration, as opposed to natural population growth, figures more heavily in the expansion of populations and their increasing demands on the land (Geist & Lambin, 2002). Therefore, although at national and regional scales rural populations may be declining, deforestation may continue unabated (Carr & Bilsborrow, 2001). In the instance of frontier colonization, the early migrants to a region have a far greater impact than later arrivals, demonstrating the importance of population distribution, and to maintaining a critical eye to temporal and spatial scales (Pfaff, 1999).

With the vast majority of the most suitable land for agriculturae already in production, forest conversion will continue to meet food demand. And as more agricultural land leaves production through soil degradation, forest areas shall increasingly become exploited. Most of the prime agricultural land in tropical Latin America, for example, was stripped of forest centuries ago; more recent conversions have taken place on marginal lands, leading to a cycle of pasture creation, land degradation, and the pushing of the agricultural frontier further into erstwhile forest cores (Hecht, 1985; Moran et al., 1994). During the 20th century, global cropland decreased from approximately 0.75 ha capita to approximately 0.35 ha (Ramankutty, Foley, & Olejniczak, 2002). The developing world lost the greatest proportion, nearly two-thirds of their per capita cropland. Further, cropland distribution has become increasingly unequal. Overall, agricultural yields, while increasing, have scarely kept pace with population growth in developing countries, and in some cases, such as regions of Sub-Saharan Africa, population growth has handily outpaced population growth (Ramankutty et al., 2002). Further, although the FAO optimistically classifies large tracts of land as ''arable'' in Sub-Saharan Africa and Latin America, this assessment neither considers the marginal farming quality of the land, nor acknowledges the importance of maintaining its current covering of tropical moist forests (Ehrlich & Ehrlich, 1990).

RECONCEPTUALIZING IPAT

The equation I = PAT has been perhaps ''[t]he single comprehensive approach to the question of driving forces'' (Meyer & Turner, 1992, p. 51). First made popular by Ehrlich and Ehrlich (1990) and Commoner (1972, 1990), the equation is formulated as follows: I = environmental impact, P = population, A = affluence, and T = technology. Geist and Lambin concluded that only 3% of all cases in their meta analysis comprised these three factors. (From Geist & Lambin, 2001). Nevertheless, they found that in nearly half of all cases P, A and T, operate in synergetic tandem. Importantly, in virtually all cases, policy and institutional factors (absent in the I = PAT formulation) were implicated as driving factors. Therefore, although IPAT in its strictest sense may have minimal power in predicting deforestation, each component of the equation raises considerable debate regarding deforestation drivers and merits closer scrutiny.

Population and Affluence

Economic factors appear to exert a stronger influence on deforestation than does population. Consistent with this observation, global economic growth increased at nearly sevenfold during the latter half of the 20th century while population doubled (Millenium Ecosystem Assessment, 2005). Some authors argue that the most powerful factor among economic variables is consumption (Myers, 1997; Kates, 2000). Demands for forest products and for agricultural produce, including livestock, represent basic needs (i.e., food for human and animal consumption, fibre for clothing, timber for construction). Other demands surpass immediate livelihood needs (e.g., precious tropical timber and fruits, and counterseasonal agricultural products). Increasing consumer demand affects cropland and pastures conversion from forests (e.g., cattle, soya) in addition to the intensification of existing farmland, including the planting of trees (e.g., coffee, fruit trees) (Geist, 2005; McConnell & Keys, 2005). Lastly, profit aspirations by local producers are a key determinant of deforestation at the household level (Geist & Lambin, 2002;). Just as higher levels of consumption demand (i.e., meat vs. grains) in local or distant markets has greater impacts on land cover change, successful frontier farmers tend to deforest more than their poorer neighbors, usually through the adoption of more extensive land uses such as cattle pasture (Carr, 2005; Pichón, 1997).

Population and Technology

Increased technological efficiency has enabled more destructive and more conservationist resource extraction practices. According to Geist and Lambin (2002), technological factors relating to timber and agriculture production, in combination with other drivers, represents the third most important driver of deforestation. The use of such technology as chain saws and heavy equipment are associated with deforestation in nearly half of all cases, particularly in Asia. However, technological changes in agricultural production (especially plows) also contributed to the forest expansion experienced in Europe during the 19th and 20th centuries (Mather, 2001).

Thus, technology *in se* is agnostic whereas its use is not; it may lead to increasing or decreasing forest cover.

An increasingly popular method of agricultural intensification is through technology substitution to raise yields on a given area of land as opposed to raising yields by investing in more labor or by expanding cultivation to encompass a larger area (Shriar, 2000). Relative to the effects of population density on deforestation, most literature on the topic suggests that increases in population density leads to some type of intensification (Boserup, 1965; Clarke, 1966; Stone & Downum, 1999; Turner et al., 1977). However, intensification will likely also occur in tandem with continued forest conversion for agricultural expansion. As mentioned previously, this helps explain the apparent anomaly of continued deforestation in nations with declining rural populations as is pervasive in the Latin American tropics (Carr, 2002a, b). The debate, therefore, is not whether changes in population density relative to farmland will lead to intensification—we know it often will-but rather, what kind of intensification will follow, when will increasing population density, instead or simultaneously, lead to extensification, and what are the trade-offs to land, labor, and capital inputs as well as the economic and environmental outcomes.

ENDOGENOUS/EXOGENOUS EFFECTS

Demographic Factors

Some authors have defined rural-rural migration as a key condition for frontier deforestation and LUCC (Barbier, 1997; Carr, 2005; Moran, 1993; Wood & Perz, 1996). In this regard, deforestation impact per rural person will continue to be greater among settlers of new farms (extensification) rather than on already colonized lands (intensification). In the study by Geist and Lambin (2001) demographic characteristics (such as natural growth and migration to forest areas) are associated with 61% of such cases, but their effects are usually interlinked with the five major drivers of deforestation.

Although migration is increasingly given primacy, fertility in frontier environments may be more important than Geist and Lambin allow. As documented by Bilsborrow and Stupp (1997), there is a close association between population growth due to high fertility and environmental destruction (deforestation), soil degradation, land fragmentationa and rural out-migration. Other studies have also associated the exceptional population growth in frontier areas as driven largely by high fertility (e.g., Murphy et al., 1999; Rundquist & Brown, 1989; Weil, 1981).

A few surveys have allowed statistical analysis of household and land use dynamics, including studies from the Ecuadorian Amazon (Pan et al., 2004), the Brazilian Amazon (McCracken et al., 1999), Costa Rica (Rosero-Bixby & Palloni, 1998), and Guatemala's Petén (Carr, 2002a). A common finding in these studies is the positive association between household size and deforestation, particularly due to a higher demand for land in subsistence crops (for family consumption). Nonetheless, as individuals in these households reach adulthood, there is a great potential for demanding new agricultural lands outside the farm, and thus rural–rural migration leading to further deforestation. Rather than only population size, these studies suggest an important role of household life cycles (household age and sex structure) on labor availability and consequently demand for land and deforestation (Murphy et al., 1999; Walker et al., 2002).

Government/Institutional

As mentioned above, I=PAT when combined with policy and institutional factors explains roughly 93% of the deforestation cases surveyed by Geist and Lambin (2001). However, one important drawback in the IPAT model is the lack of consideration of contextual factors, especially policy and institutional drivers. The effect of contextual factors, particularly those associated with road opening and policies to occupy the frontier (e.g., tax incentives, cheap credit, land subsidies) have had a particularly important role in deforestation, as illustrated by remote sensing analysis of high deforestation along roads in the Brazilian Amazon (Alves, 2002; Frohn et al., 1996; Fujisaka et al., 1996; Mc Cracken et al., 1999; Pfaff, 1999; Skole, 1993) or in other countries, such as Ecuador (Sierra, 2000), Guatemala (Sader, 1997), Costa Rica (Sader & Joyce, 1988), and Mexico (Geoghegan et al., 2001; Nelson & Hellerstein, 1997; Velázquez et al., 2004). The relationship between roads and deforestation is validated by the dearth of roads and small population density associated with low deforestation in lowland Bolivia (Kaimowitz, 1997). Urban-biased policies which favor urban consumers (e.g., policies on taxes and subsidies which artificially depress agricultural prices and increase rates of resource consumption and negative externalities) may also be a motivation for further extensification on the frontier (Deininger & Minten, 1999; Myers & Kent, 2001). (Geist, ch. 3, p. 15). The undervalued price of natural resources (including non-commercial products and ecosystem services) acts as an incentive to replace these natural products with profitable and commercial products (e.g., cash crops) (Noble & Dirzo, 1997). The literature also suggests a host of other policies which may affect frontier deforestation, including official schemes of land colonization and induced migration to the Amazon, as is the case of Brazil (Hecht & Cockburn, 1989; Stewart, 1994), subsidies and tax incentives for investment in cattle ranching, which demand large extensions of land in the Amazon and triggered land speculation (Mahar, 1989; Moran, 1993), incentives, through technical assistance, to commercial crops instead of a higher variety of crops, especially native crops which are more productive and more resistant to pests and plagues failure (Bunker, 1984), and subsidies for transportation and use of equipments used in deforestation such as chainsaws (Southgate & Whitaker, 1992).

Institutional failure, especially due to inefficiency, mismanagement and corruption in the government sector, has also hindered the effective use of natural resources (e.g., logging in Indonesia) and induced deforestation (42% of all cases) (Jepson, Jarvie, MacKinnon, & Monk, 2001). Indeed, Mather and Needle (1999) note that poor and dictatorial countries face rapid deforestation (e.g., Indonesia in the President Suharto regime), while countries characterized by democratic regimes and higher welfare levels are associated with stable, or even expanding, forests (see also Palo, 2002).

Of course, government and institutional policies do not only serve to exacerbate deforestation; they may also attenuate it. Sundberg (2003), for example, suggests that interactions between local communities with "exogenous" groups (national or international institutions, NGOs, transnational corporations, etc.) have fostered resource conservation at the local level. These conservation initiatives, as a product of local forces mediated by exogenous organizations, have provided some examples of success, which contradicts neighbor experiences of high deforestation in the Maya forest of northern Guatemala and southern Yucatán (Bray, Ellis, Armijio-Canto, & Beck, 2004; Klepeis & Chowdhury, 2004).

Ultimately, local users will conserve forest if in their best interest to do so. Singh, Shi, Zhu, and Foresman (2001) also suggest that it is economic (ir)rationality to associate deforestation with lower costs and higher benefits, arguing that "forests will be protected when the people conclude that forest conservation is more beneficial (e.g., generates higher incomes or has ecological or social values) than forest conversion." On the other hand, changing this rationale would involve pricing and valuing ecosystem or environmental services (David Kummer, PERN, 2003, 4/19).

POLICY IMPLICATIONS AND FUTURE RESEARCH

Cyber-seminar participants overwhelmingly called for further context-directed research, even when the phenomenon occurs in similar environments. This suggestion was illustrated with the example of the current research at the Carolina Population Center (University of North Carolina at Chapel Hill) on the process of deforestation in the Ecuadorian Amazon, which does not occur for the same reason seen elsewhere in most of the Amazon such as in Brazil, despite the similarity in environments. To this end, future research should emphasize acknowledging the influences of different factors across many scale by pursuing multilevel analysis, which permits aggregated data analysis nesting household land-use strategies. Likewise, longitudinal studies capture temporal dimensions of demographic factors affecting deforestation (Alisson Barbieri, PERN, 2003, 4/16) as, for example, to examine the role of migration in LUCC in Nang Rong, Thailand, (Entwisle, Walsh, Rindfuss, & Chamratrithirong, 1998; Rindfuss et al., 2003; Walsh, Bilsborrow, & McGregor, 2003). In sum, it is important that scientists undertake longitudinal and multilevel studies in order to unveil the proximate and underlying causes of deforestation (as suggested by Geist and Lambin and pursued in e.g. Mertens et al., 2000; Moran et al., 1996; Pan et al., 2004) with higher accuracy and validity (Jefferson Fox, PERN, 2003, 4/8).

Gains in remote sensing to quantify LUCC and efforts to link LUCC to household data (e.g. Liverman, Moran, Rindfuss, & Stern, 1998; McCracken et al., 1999; Moran et al., 1994; Walsh et al., 1999; Walsh, Messina, & Zonn, 2004) were also hailed as a step forward, as was the application of remote sensing to detecting illegal deforestation (M.C. de Castro, PERN, 2003, 4/14). However, in classifying land cover, participants argued that advances should be made to distinguish between primary forest and regrowth, as focusing solely on total forest cover treats them as equal and ignores the most likely irreversible loss of biodiversity inherent in deforestation (David Kummer, PERN, 2003, 4/13).

Despite gains in understanding the causality of deforestation, some participants expressed frustration with the speed and efficacy of proving associations. As Frederick Meyerson remarked, ''chasing proof of causality of tropical forest loss may be akin to rearranging deck chairs on the Titanic (PERN, 2003, 4/19).'' Such comments were often accompanied by suggestions for more explicitly policy-oriented courses of research or action. Such policies may include, for example, efforts to create or extend the supply of family planning initiatives as a way to achieve a long-run balance and stabilization between consumption and supply of natural resources, particularly forests.

Scholars have also called for the creation of new forest preserves designed with particular strategies in mind with a focus not merely on forest cover but rather on the preservation of areas of high biodiversity (David Kummer, PERN, 2003, 4/11). A related strategy suggests setting aside forests where the best (or lowest cost) conservation opportunities remain, as illustrated in the *Last of the Wild* map (see http://wcs.org/humanfootprint/) recently produced by the Wildlife Conservation Society and CIESIN. Further economic research, such as paying populations who maintain forests for the environmental services the intact forests provide (David Kummer, PERN, 2003, 4/20), could combat the undervaluation of forests and provide an economic incentive for their preservation.

In order to combat further forest loss, some participants suggested voluntary measures to scale back harmful consumption and production practices (Steven Kurtz, PERN, 2003, 4/11). M.C. de Castro urges a consideration of all policies and decisions, which could potentially result in deforestation in light of carrying capacity analyses (PERN, 2003, 4/14), following e.g., Pimentel et al. (1994). Some researchers commented on the delicate position of researchers in examining population dynamics related to deforestation. As Ram B. Bhagat states, ''Population is the soft targets for the elites and easy to be subjected to policy met with greater legitimacy. Deforestation is also a non-controversial issue because of its direct link with the populous and poor compared with green house gases (PERN, 2003, 4/22).''

Despite methodological developments over the last year there still remains a lack of consensus about the causes and consequences of tropical deforestation and how it is related to population dynamics. While the development of new theories or integrative theories is an important step, a *sine qua non* to promote conservation and sustainable use of resources is to achieve a fully public participation (especially with the empowerment of those at the local level) (see, e.g., Sydenstricker-Neto, 2003).

One challenge faced by the LUCC community is the standardization of case-studies. Although there have been many efforts to perform meta-analyses on small-scale case studies of deforestation (e.g. Geist & Lambin, 2001, 2002; Rudel et al., 2000), one source of error and confusion faced by all such comparative works is incomplete data and confusion about whether or not similarly named variables are actually comparable between studies. This issue suggests the necessity to develop ways to make data publicly available in order to achieve a better comparison of case studies, as well as to share experiences regarding questionnaire and sampling designs and protocols (Ronald Rindfuss, PERN, 2003, 4/18). Steps are being taken in this direction, as is illustrated by a number of questionnaire survey instruments which have been used in LUCC research, and are available at the East-West Center's web site: http://www2.eastwestcenter.org/environment/lucclink/papers.htm. Researchers are urged to follow suit and make their survey instruments available. In addition, researchers can pursue systems of standardization of land cover classification, for example using the system developed by FAO. A more standardized approach to collecting data could allow for more facile comparison, while still respecting the unique circumstances leading to deforestation in a particular place.

Future avenues of research could fruitfully explore the role of land tenure in promoting or preventing deforestation, the role biophysical factors such as climate and topography deforestation, and the use of agent-based modeling to simulate land cover change. Simulation of human–environment relations through the use of cellular automata is increasingly being applied to examine land-use decision making, such as in the work modeling deforestation in the Ecuadorian and Brazilian Amazon (e.g. Deadman et al. 2004; Lim, Deadman, Moran, Brondizio, & McCracken, 2002; Messina & Walsh, 2003, 2001).

In conclusion, the role of population in driving deforestation is complex, and characterized by a host of spatial and temporal contingencies. Population effects are nearly always mediated through political, economic, and ecological factors. Demands for forest resources are produced both locally and distally. The former will play an increasingly greater role as the developing world becomes urbanized. Continued collaboration across disciplines, sharing pioneering methodologies and standardizing instruments of measurement will be key to furthering understanding of the population–deforestation nexus. Reducing population pressures on scarce remaining forests is a priority that should be shared by rural developers, proponents of free trade, family planning advocates, and conservationists.

REFERENCES

Allen, J., & Barnes, D. (1985). The causes of deforestation in developing countries. *Annals of the Association of American Geographers, 75*(2), 163–184.

Alves, D. S. (2002) Space-time dynamics of deforestation in Brazilian Amazonia. *International Journal of Remote Sensing, 23*(14), 2903–2908.

Amelung, T., & Diehl, M. (1992). *Deforestation of Tropical Rain Forests: Economic Causes and Impact on Development.* Tübingen Germany: Mohr J. C. B.

Ammer, U., Breitsameter, J., & Zander, J. (1995). Contribution of mountain forests towards the prevention of surface runoff and soil erosion. *Forstwissenschaftliches Centralblatt, 114*, 232–249.

Barbier, E. (1997) The economic determinants of land degradation in developing countries. *Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences, 352*(1356), 891–899.

Bilsborrow, R. E., & Stupp, P. (1997). Demographic processes, land, and environment in Guatemala. In L. R. Bixby, A. Pebley & A. B. Mendez (Eds.), *Demographic Diversity and Change in the Central American Isthmus*, (pp. 581–624). Rand: Santa Monica.

Boserup, E. (1965). *The Conditions of Agricultural Growth: The Economics of Agrarian Change Under Population Pressure*. New York: Aldine Publishing Company.

Bray, D. B., Ellis, E. A., Armijo-Canto, N., & Beck, C. T. (2004). The institutional drivers of sustainable landscapes: A case study of the 'Mayan Zone' in Quintana Roo, Mexico. *Land Use Policy, 21*, 333–346.

Browder, J. (1997). *Rainforest Cities*. New York: Columbia University Press.

Brown, J. C., Koeppe, M., Coles, B., & Price, K. P. (2005). Soybean production and conversion of tropical forest in the Brazilian Amazon: The case of Vilhena, Rondonia. *AMBIO, 34*(6), 462–469.

Brown, L. R., Durning, A. B., Flavin, C., Heise, L., Jacobson, J. L., Postel, S., Renner, M., Shea, C. P., & Starke, L. (1989). *State of the World 1989*. New York: Norton.

Bunker, S. G. (1984). *Underdeveloping the Amazon: Extraction, Unequal Exchange, and the Failure of the Modern State*. Champaign: University of Illinois Press.

Carr, D. L. (2002a) The role of population change in land use and land cover change in rural Latin America: Uncovering local processes concealed by macro-level data. In M. H. Y. Himiyama & T. Ichinose (Eds.), *Land Use Changes in Comparative Perspective*, , Enfield, NH and Plymouth, UK: Science Publishers.

Carr, D. L. (2002b). Rural-frontier migration and deforestation in the Sierra de Lacandón National Park, Guatemala. Ph.D. dissertation, Department of Geography, Chapel Hill, NC: University of North Carolina.

Carr, D. L. (2004a) Proximate population factors and deforestation in tropical agricultural frontiers. *Population and Environment, 25*(6), 585–612.

Carr, D. L. (2004b) Tropical deforestation. In D. Janelle & K. Hansen (Eds.), *Geographical Perspectives on 100 Problems*, , London: Kluwer Academic Publishers.

Carr, D. L. (2005) Population, land use, and deforestation in the Sierra de Lacandón National Park, Petén, Guatemala. *The Professional Geographer, 57*(2), 157–168.

Carr, D. L., & Bilsborrow, R. E. (2001). Population and land use/cover change: A regional comparison between Central America and South America. *Journal of Geography Education, 43*, 7–16.

Clarke, W. C. (1966) From extensive to intensive shifting cultivation—A succession from New Guinea. *Ethnology, 5*(4), 347 .

Commoner, B. (1972). *The Closing Circle*. New York: Knopf.

Commoner, B. (1990). *Making Peace with the Planet*. New York: Pantheon Books.

Darity Jr., W. A. Jr. (1980) The Boserup theory of agricultural growth. *Journal of Development Economics, 7*, 137–157.

Dasgupta, P. S. (1995). Population, Poverty, and the Local Environment. Scientific American February: 40–45.

Davis, K. (1963) The theory of change and response in modern demographic history. *Population Index, 29*(4), 345–366.

Deacon, R. (1994) Deforestation and the Rule of Law in a Cross-Section of Countries. *Land Economics, 70*(4), 414–430.

Deadman, P., Robinson, D., Moran, E., & Brondizio, E. (2004). Colonist household decision-making and land-use change in the Amazon Rainforest: an agent-based simulation. *Environment and Planning B-Planning & Design, 31*(5), 693–709.

de Janvry, A. (1991). *The Agrarian Question and Reformism in Latin America*. Baltimore: Johns Hopkins University Press.
Deininger, K., & Minten, B. (1999). Poverty policies and deforestation: The case of Mexico. *Economic Development and Cultural Change*, *47*(2), 313–344.
Ehrhardt-Martinez, K. (1998) Social determinants of deforestation in developing countries: A Cross-National Study. *Social Forces*, *77*(2), 567–586.
Ehrlich, P., & Ehrlich, A. (1990). *The Population Explosion*. New York: Simon and Schuster.
Entwisle, B., & Walsh, S. et al. (1998). Land-use/land-cover and population dynamics, Nang Rong, Thailand. In D. Liverman, E. Moran, R. Rindfuss & P. Stern (Eds.), *People and Pixels: Linking Remote Sensing and Social Science*, (pp. 121–144). Washington D.C: National Academy Press.
FAO, (1993) AGROSTAT.PC. FAO, Rome.
Folke, C., Jansson, A., Larsson, J., & Costanza, R. (1997). Ecosystem appropriation by cities. *Ambio*, *26*(3), 167–172.
Frank, A. (1967). *Capitalism and Underdevelopment in Latin America*. London: Pelican.
Frohn, R. C., & McGwire, K. C. et al. (1996). Using satellite remote sensing analysis to evaluate a socio-economic and ecological model of deforestation in Rondonia, Brazil. *International Journal of Remote Sensing*, *17*(16), 3233–3255.
Fujisaka, S., & Crawford, E. et al. (1996). Slash-and-burn agriculture, conversion to pasture, and deforestation in two Brazilian Amazon colonies. *Agriculture, Ecosystems and Environment*, *59*(1–2), 115–130.
Geist, H. (2005). *The Causes and Progression of Desertification*. Aldershot, UK, Burlington, VT: Ashgate 258.
Geist, H. J., & Lambin, E. F. (2001). *What Drives Tropical Deforestation? A Meta-analysis of Proximate and Underlying Causes of Deforestation Based on Sub-national Case Study Evidence*. Louvain-la-Neuve Belgium: LUCC International Project Office 116.
Geist, H. J., & Lambin, E. F. (2002). Proximate causes and underlying driving forces of tropical deforestation. *BioScience*, *52*(2), 143–150.
Geist, H. J., Lambin, E. F., Palm, C., & Tomich, T. P. (2006). Land use and land cover change: Local processes, global impacts (The IGBP Book Series, E. F. Lambin & H. Geist, Eds.). Berlin, GE: Springer-Verlag.
Geoghegan, J., Villar, S. C., Klepeis, P., Mendoza, P. M., Ogneva-Himmelberger, Y., Chowdhury, R. R., Turner, B. L., & Vance, C. (2001). Modeling tropical deforestation in the southern Yucatán peninsular region: comparing survey and satellite data. *Agriculture, Ecosystems & Environment*, *85*(1–3), 25–46.
Hecht, S. (1985) Deforestation in the Amazon Basin: Magnitude, dynamics, and soil resource effects. *Studies in Third World Societies*, *13*, 61–100.
Hecht, S. B. (2005) Soybeans, development and conservation on the Amazon Frontier. *Development and Change*, *36*(2), 375–404.
Hecht S., Cockburn A., (1989). *The Fate of the Forest*. New York: Harper Collins.
Houghton, R. A. (1991) Tropical deforestation and atmospheric carbon dioxide. *Climate Change*, *19*, 99–118.
Houghton, R., Skole, D., Nobre, C., Hackler, J., Lawrence, K., & Chementowski, W. (2000). Annual fluxes of carbon from deforestation and regrowth in the Brazilian Amazon. *Nature*, *403*, 301–304.
Inman, K. (1992) Fueling expansion in the Third World: Population, development, debt and the global decline of forests. *Society and Natural Resources*, *6*, 17–39.
Jepson, P., Jarvie, J. K., MacKinnon, K., & Monk, K. A. (2001). The end of Indonesia's lowland forests?. *Science*, *292*, 859–861.
Kaimowitz, D. (1997) Factors determining low deforestation: The Bolivian Amazon. *Ambio*, *26*(8), 537–540.
Kates, R. W. (2000) Population and consumption: What we know, what we need to know. *Environment*, *42*(3), 10–19.

Klepeis, P., & Chowdhury, R. R. (2004). Institutions, organizations, and policy affecting land change: Complexity within and beyond the ejido. In B. L. Turner II, J. Geoghegan & D. Foster (Eds.), *Integrated Land-Change Science and Tropical Deforestation in the Southern Yucatán: Final Frontiers*, (pp. 145–169). Oxford: Oxford University Press.

Kummer, D. M., & Turner II, B. L. (1994). The human causes of deforestation in Southeast Asia: The recurrent pattern is that of large-scale logging for exports followed by agricultural expansion. *BioSience*, *44*(5), 323–328.

Lambin, E. F., Chasek, P. S., Downingv, T. E., Kerven, C., Kleidon, A., Leemans, R., Lüdeke, M., Prionce, S. D., & Xue, Y. (2002). The interplay between international and local processes affecting desertification. In J. F. Reynolds & D. M. Stafford smith (Eds.), *Global Desertificaton: Do Humans Cause Deserts? (Dahlem Workshop Report No. 88)*, (pp. 387–401). Berlin GE: Dahlem University Press.

Lambin, E. F., Geist, H. J., & Lepers, E. (2003). Dynamics of land-use and land-cover change in tropical regions. *Annual Review of Environment and Resources*, *28*, 205–241.

Lambin, E. F., Turner, B. L., Geist, H. J., Agbolac, S. B., Angelsend, A., Brucee, J. W., Coomes, O. T., Dirzog, R., Fischerh, G., Folkei, C., Georgej, P. S., Homewoodk, K., Imbernonl, J., Leemansm, R., Lin, X., Moran, E. F., Mortimorep, M., Ramakrishnan, P. S., Richardsr, J. F., Skåness, H., Steffent, W., Stoneu, G. D., Svedinv, U., Veldkampw, T. A., Vogelx, C., & Xu, J. (2001). The causes of land-use and land-cover change: moving beyond the myths. *Global Environmental Change*, *11*(4), 261–269.

Lim, K., Deadman, P. J., Moran, E., Brondízio, E., & McCracken, S. (2002). Agent-based simulations of household decision making and land use change near Altamira, Brazil. In R. Gimblett (Ed.), *Integrating Geographic Information Systems and Agent-Based Modeling: Techniques for Simulating Social and Ecological Processes, Santa Fe Institute Studies in the Sciences of Complexity series*, (pp. 277–310). New York: Oxford University Press.

Liverman, D. , Moran, E. F. , Rindfuss, R. R. & Stern, P. C. (Eds.) (1998). *People and Pixels: Linking Remote Sensing and Social Science*. Washington D.C: National Academy Press 244.

Mahar, D. J. (1989). *Government Policies and Deforestation in Brazil's Amazon Region*. Washington D.C: World Bank.

Malthus, T. (1873). *An Essay on the Principles of Population*. New York: Random House.

Mather, A. (1990). *Global Forest Resources*. London: Bellhaven Press.

Mather A., (2001). The transition from deforestation to reforestation in Europe In: A. A. Kaimowitz (Ed.), *Agricultural Technologies and Tropical Deforestation*. Wallingford UK, New York NY: CABI pp. 35–52.

Mather, A., & Needle, C. L. (1998). The forest transition: A theoretical basis. *Area*, *30*, 117–124.

Mather, A. S., & Needle, C. L. (1999). Development, democracy and forest trends. *Global Environmental Change*, *9*(2), 105–118.

Mather, A. S., & Needle, C. L. (2000). The relationships of population and forest trends. *Geographical Journal*, *166*(1), 2–13.

Mather, A. S., Needle, C. L., & Fairbairn, J. (1998). The human drivers of global land cover change: the case of forests. *Hydrological Processes*, *12*(13–14), 1983–1994.

Mather, A. S., Needle, C. L., & Fairbairn, J. (1999). Environmental Kuznets curves and forest trends. *Geography*, *84*(1), 55–65.

McConnell, W. J., & Keys, E. (2005). Meta-analysis of agricultural change. In E. F. Moran & E. Ostrom (Eds.), *Seeing the Forest and the Trees: Human–Environment Interactions in Forest Ecosystems*, (pp. 325–353). Cambridge, Mass., London, UK: MIT Press.

McCracken, S., Brondizio, E., Nelson, D., Moran, E., Siqueira, A., & Rodriguez-Pedraza, C. (1999). Remote Sensing and GIS at farm property level: Demography and deforestation in the Brazilian Amazon. *Photogrammetric Engineering and Remote Sensing*, *65*(11), 1311–1320.

Mertens, B., Sunderlin, W. D., Ndoye, O., & Lambin, E. F. (2000). Impact of macroeconomic change on deforestation in South Cameroon: Integration of household survey and remotely-sensed data. *World Development*, *28*(6), 983–999.

Messina, J.P., & Walsh, S.J. (2001). Simulating Land Use and Land Cover Dynamics in the Ecuadorian Amazon through Cellular Automata Approaches and an Integrated GIS. In Proceedings of the 2001 Open Meeting of the Human Dimensions of Global Environmental Change Research Community.

Messina, J. P., & Walsh S. J. (2003). The Application of a Cellular Automaton Model for Predicting Deforestation: Patterns and Processes of LULCC in the Ecuadorian Amazon. In Proceedings of the 4th International Conference on Integrating GIS and Environmental Modeling. Banff, Canada.

Meyer, W. B., & Turner II, B. L. (1992). Human population growth and global land-use/cover change. *Annual review of ecology and systematics*, *23*, 39–61.

Millenium Ecosystem Assessment. (2005). *Millenium Ecosystem Assessment and Synthesis Report*. Washington, D.C: Island Press.

Moran, E. M. (1993) Deforestation and land use in the Brazilian Amazon. *Human Ecology*, *21*(1), 1–21.

Moran, E., Brondizio, E., Mausel, P., & Wu, Y. (1994). Integrating Amazonian vegetation, land-use, and satellite data. *BioScience*, *44*(5), 329–338.

Moran, E. F., Packer, A., Brondizio, E., & Tucker, J. (1996). Restoration of vegetation cover in the eastern Amazon. *Ecological Economics*, *18*(1), 41–54.

Murphy, L. L. (2001) Colonist farm income, off-farm work, cattle, and differentiation in Ecuador's Northern Amazon. *Human Organization*, *60*(1), .

Murphy, L. L., Marquette, C., Pichón, F. J., & Bilsborrow, R. (1999). Land use, household composition, and economic status of settlers in Ecuador's Amazon: A review and synthesis of research findings, 1990–1999. University of Florida, Center for Latin American Studies 48th Annual Conference: ''Patterns and Processes of Land Use and Forest Change in the Amazon,'' March 23–26, 1999, Gainesville, FL.

Myers, N. (1991) Tropical forests: Present status and future outlook. *Climatic Change*, *19*(1–2), 3–32.

Myers, N. (1997) Environmental refugees. *Population and Environment*, *19*(2), 167–182.

Myers, N., & Kent, J. (2001). *Perverse Subsidies: How Tax Dollars can Undercut the Environment and the Economy*. Washington, D.C: Island Press.

Nelson, G. C., & Hellerstein, D. (1997). Do roads cause deforestation? Using satellite images in econometric analyses of land use. *American Journal of Agricultural Economics*, *79*(February), 80–88.

Noble, I. R., & Dirzo, R. (1997). Forests as human dominated ecosystems. *Science*, *277*(25), 522–525.

Pan, W., & Bilsborrow, R. E. (2005). The use of a multilevel statistical model to analyze factors influencing land use: A study of the Ecuadorian Amazon. *Global and Planetary Change*, *47*(2–4), 232–252.

Pan, W. K., Walsh, S. J., Bilsborrow, R. E., Frizzelle, B., Erlien, C., & Baquero, F. (2004). Farm-level models of spatial patterns of land use and land cover dynamics in the Ecuadorian Amazon. *Agriculture, Ecosystems & Environment*, *101*, 117–134.

Palo, M. (2002). Causes and patterns of tropical forest area changes. Paper presented at the Land Use and Cover Change Workshop, Louvain-La-Neuve.

Pender, J. L (1998) Population growth, agricultural intensification, induced innovation and natural resource sustainability: An application of neoclassical growth theory. *Agricultural Economics*, *19*(1–2), 99–112.

Pfaff, A. S. (1999) What drives deforestation in the Brazilian Amazon? Evidence from satellite and socioeconomic data. *Journal of Environmental Economics and Management*, *37*(1), 26–43.

Pichón, F. J. (1997) Colonist land-allocation decisions, land use, and deforestation in the Ecuadorian Amazon frontier. *Economic Development and Cultural Change*, *45*(4), 707–744.

Pichón, F. J., & Bilsborrow, R. E. (1999). Land-use systems, deforestation, and demographic factors in the humid tropics: Farm-level evidence from Ecuador. In R. E. Bilsborrow

& D. Hogan (Eds.), *Population and Deforestation in the Humid Tropics*, , Liège, Belgium: International Union for the Scientific Study of Population.

Pimentel, D. (1998) An optimum population for North and Latin America. Population and Environment. *A Journal of Interdisciplinary Studies*, *20*(2), 125–148.

Pimentel, D., Pacenza, M., Pecarsky, J., & Pimentel, M. (1994). Natural resources and an optimum population . *Population and Environment*, *15*(5), 347–369.

Population Environment Research Network (PERN) (2005). http://www.populationenvironmentresearch.org/index.jsp.

Population Environment Research Network (PERN) (2003). Population and Deforestation Cyberseminar. http://listhost.ciesin.org/lists/public/pernseminars/.

Ramankutty, N., Foley, J. A., & Olejniczak, N. J. (2002). People on the land: Changes in global population and croplands during the 20th century. *Ambio*, *31*(3), 251–257.

Rindfuss, R. R., Turner II, B. L., Entwisle, B., & Walsh, S. J. (2004). Land cover/use and population. In G. Gutman, A. C. Janetos, C. O. Justice, E. F. Moran, J. F. Mustard, R. R. Rindfuss, D Skole, B. L. Turner II & M. A. Cochrane (Eds.), *Land Change Science: Observing, Monitoring and Understanding Trajectories of Change on the Earth's Surface. (Remote Sensing and Digital Image Processing Series 6)*, (pp. 351–366). Dordrecht, NL, Boston, Mass., London, UK: Kluwer.

Rindfuss, R. R., & Prasartkul Walsh, P. S. J. (2003). Household-parcel linkages in Nang Rong, Thailand: Challenges of large samples. In R. Rindfuss, J. Fox, S. J. Walsh & V. Mishra (Eds.), *People and the Environment: Approaches for Linking Household and Community Surveys to Remote Sensing and GIS*, (pp. 131–172). Boston, MA: Kluwer Academic Publishers.

Robinson, W., & Schutjer, W. (1984). Agricultural development and demographic change: A generalization of the Boserup model. *Economic Development and Cultural Change*, *32*, 355–366.

Rosero-Bixby, L., & Palloni, A. (1998). Population and deforestation in Costa Rica. *Population and Environment*, *20*(2), 149–178.

Rudel, T (1989) Population development and tropical deforestation: A cross-national study. *Rural Sociology*, *54*, 327–338.

Rudel, T., Coomes, O., Moran, E., Achard, F., Angelsen, A., Xu, J., & Lambin, E. (2005). Forest transitions: towards a global understanding of land use change. *Global Environmental Change*, *15*, 23–31.

Rudel, T., & Roper, J. (1996). Regional patterns and historical trends in tropical deforestation, 1976–1990. *Ambio*, *25*(3), 160–166.

Rudel, T., & Roper, J. (1997). The paths to rain forest destruction: cross-national patterns of tropical deforestation, 1975–90. *World Development*, *25*(1), 53–65.

Rudel, T. K., Flesher, K., Bates, D., Baptista, S., & Holmgren, P. (2000). Tropical deforestation literature: Geographical and historical patterns. *Unasylva*, *203*, 11–18.

Rundquist, F. M., & Brown, L. A. (1989). Migrant fertility differentials in Ecuador. *Geografiska Annaler, Series B*, *71*(2), 109–123.

Sader, S. (1997). Forest Monitoring and Satellite Change Detection Analysis of the Maya Biosphere Reserve, Petén District, Guatemala. Final Report submitted to CI and AID.

Sader, S., & Joyce, A. T. (1988). Deforestation rates and trends in Costa Rica, 1940–1983. *Biotropica*, *20*(1), 11–19.

Schiller, A., de Sherbinin, A., Hsieh, W., & Pulsipher, A. (2001). The Vulnerability of Global Cities to Climate Hazards. Paper presented at the Open Meeting of the Human Dimensions of Global Environmental Change Research Community, 4–5 October 2001, Rio de Janeiro.

Schwartz, N. (1995) Colonization, development and deforestation in Petén, Northern Guatemala. In M. Painter & W. H. Durham (Eds.), *The Social Causes of Deforestation in Latin America*, (pp. 101–130). Ann Arbor, MI: University of Michigan Press.

Shriar, A. J (2000) Agricultural intensity and its measurement in frontier regions. *Agroforestry Systems*, *49*(3), 301–318.

Sierra, R. (2000) Dynamics and patterns of deforestation in the western Amazon. The Napo deforestation front, 1986–1996. *Applied Geography*, *20*(1), 1–16.

Singh, A., Shi, H., Zhu, Z., & Foresman, T. (2001). *An Assessment of the Status of the World's Remaining Closed Forests*. Nairobi, Kenya: United Nations Environment Program (UNEP).

Skole, D. (1993) Tropical deforestation and habitat fragmentation in the Amazon: satellite data from 1978 to 1988. *Science*, *260*(5116), 1905–1910.

Southgate, D. (1994) Tropical deforestation and agricultural development in Latin America. In K. D. W. Brown Pearce (Ed.), *The Causes of Tropical Deforestation*, (pp. 134–145). London: UCL Press.

Southgate, D., & Whitaker, M. (1992). Promoting resource degradation in Latin America: tropical deforestation, soil erosion, and coastal ecosystem disturbance in Ecuador. *Economic Development and Cultural Change*, *35*(4), 786–807.

Steffen, W., Sanderson, A., Tyson, P. D., Jäger, J., Matson, P. A., Moore III, B., Oldfield, F., Richardson, K., Schellnhuber, H. J., Turner, B. L. II, & Wasson, R. J. (2004). *Global Change and the Earth System: A Planet Under Pressure*. Berlin, GE: Springer 336.

Stewart, D. (1994). *After the Trees: Living on the Transamazonian Highway*. Austin: University of Texas Press.

Stone, G. D., & Downum, C. E. (1999). Non-Boserupian ecology and agricultural risk: Ethnic politics and land control in the arid southwest. *American Anthropologist*, *101*(1), 113–128.

Sundberg, J. (2003) Strategies for authenticity and space in the Maya Biosphere Reserve, Petén, Guatemala. In K. S. Zimmerer & T. J. Bassett (Eds.), *Political Ecology: An Integrative Approach to Geography and Environment-Development Studies*, (pp. 50–69). New York, NY, London, UK: The Guilford Press.

Sydenstricker-Neto, J. (2003) Transnational peasants: Migrations, networks, and ethnicity in Andean Ecuador. *Contemporary Sociology-A Journal of Reviews*, *32*(2), 210–212.

Turner, B. L. II. (2001) Toward integrated land-change science: Advances in 1.5 decades of sustained international research on land-use and land-cover change. In W. Steffen (Ed.), *Advances in Global Environmental Change Research*, , Berlin, New York: Springer.

Turner II, B., Hanham, R., & Portoraro, A. (1977). Population pressure and agricultural intensity. *Annals of the Association of American Geographers*, *37*(3), 384–396.

Turner II, B., Moss, R., & Skole, D. (1993). *Relating Land Use and Global Land-Cover Change: A Proposal for the IGBP-HDP Core Project, International Geosphere-Biosphere Programme, Report No. 24*. Sweden: IGBP Secretariat.

Turner II, B. L., Geoghegan, J., Keys, E., Klepeis, P., Lawrence, D., Mendoza, P. M., Manson, S., Ogneva-Himmelberger, Y., Plotkin, A. B., Salicrup, D. P., Chowdhury, R. R, Savitsky, B., Schneider, L., Schmook, B., Vance, C., Villar, S. C., & Foster, D. (2001). Deforestation in the southern Yucatán peninsular region: An integrative approach. *Forest Ecology and Management*, *154*(3), 353–370.

United Nations Population Division (UNPD). (2003). *World Population 200*. New York: United Nations Population Division.

Vanclay, J. (1993) Saving the tropical forest: Needs and prognosis. *Ambio*, *22*(4), 225–31.

Velázquez, A., Durán, E., Ramírez, I., Mas, J., Bocco, G., Ramírez, G., & Palacio, J. (2002). Land use-cover change processes in highly biodiverse areas: the case of Oaxaca, Mexico. *Global Environmental Change Part A*, *13*(3), 175–184.

Walker, R., Perz, S., Caldas, M., & Teixeira Silva, L. G. (2002). Land use and land cover change in forest frontiers: The role of household life cycles. *International Regional Science Review*, *25*(2), 169–199.

Walker, R., & Smith, T. E. (1993). Tropical deforestation and forest management under the system of concession logging: a decision-theoretic analysis. *Journal of Regional Science*, *33*(3), 387–419.

Walsh, S. J., Bilsborrow, R. E., McGregor, S. J., Frizelle, B. G., Messina, J. P., Pan, W. K. T., Crews-Meyer, K. A., Taff, G. M., & Baquero, F. (2003). Integration of longitudinal surveys, remote sensing time series, and spatial analyses: Approaches for linking people and place. In J. Fox, R. R Rindfuss, S. J. Walsh & V. Mishra (Eds.), *People and the environment: Approaches for linking household and community surveys to remote sensing and GIS*, (pp. 91–130). Boston, Mass., Dordrecht, NL, London, UK: Kluwer.

Walsh, S. J., Messina, J. P., & Zonn, L. (2004). Human–environment interactions in the Ecuadorian Amazon: Characterizing landscape dynamics and modeling the drivers of deforestation in the tropics. In B. Warf, D. Janelle, & K. Hansen (Eds.), *WorldMinds: Geographical Perspectives on 100 Problems* Boston: Kluwer Academic .

Walsh, S. J., Rindfuss, R. R., Evans, T. P., Welsh, W. F., & Entwisle, B. (1999). Scale-dependent relationships between population and environment in northeastern Thailand. *Photogrammetric Engineering and Remote Sensing, 65*(1), 97–105.

Weil, C. (1981) Health problems associated with agricultural colonization in Latin America. *Social Science and Medicine, 15D*, 449–461.

Wibowo, D., & Byron, R. N. (1999). Deforestation mechanisms: A survey. *International Journal of Social Economics*, *26*(1/2/3), 455–474.

Wood, C., & Perz, S. (1996). Population and land-use changes in the Brazilian Amazon. In S. Ramphal & S. W. Sinding (Eds.), *Population Growth and Environmental Issues*, (pp. 95–108). Westport, Connecticut: Praeger.