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Forest transition pathways in Asia – studies from Nepal, India, Thailand, and Cambodia

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Tropical forest habitat continues to decline globally, with serious consequences for environmental sustainability. The South/Southeast Asian landscapes represent one of the most challenging parts of the world to study issues of landscape change. High population densities in the region pose major threats to forest cover. Despite presentations of supposedly catastrophic declines in forest cover, substantial areas have been observed to maintain or increase forest cover in recent years. This research draws on data from Nepal, India, Thailand, and Cambodia to examine trajectories of forest-cover change along gradients of deforestation and reforestation. The gradients we observe extend from Cambodia, a still predominantly forested landscape, with development and change at initial stages, to Nepal which, despite having experienced large-scale forest clearing in the past, has considerable reforestation in recent years. Understanding these processes is critical for policymakers working on climate change and adaptation. This research allows us to link national-scale and local-scale analyses, in terms of both their similarities and differences, and also to see changes still in progress via the inclusion of regrowth and degradation classes, not just reforestation and deforestation.

Keywords: reforestation; regrowth; land-cover change; South Asia; Southeast Asia; Forest Transition Theory

Introduction

Tropical forest habitat continues to decline globally, with serious negative consequences for environmental sustainability. Most studies on land-cover change have been focused on deforestation occurring in different countries, monitored by national-level databases such as FAO, national-level studies, and even smaller case study type approaches (Cropper, Puri, and Griffiths 2001; Seidl, Vila de Silva, and Steffens Moraes 2001; Kao and Iida 2006; Messina, Walsh, Mena, and Delamater 2006). A number of recent studies have increasingly focused on regrowth, reforestation, and afforestation, often hand in hand with deforestation and degradation processes (Southworth and Tucker 2001; Moon and Park 2004; Munroe, Southworth, and Tucker 2004; Nagendra, Pareeth, Sharma, Schweik, and Adhikari 2008). The dual and simultaneous focus on regrowth/regeneration and

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reforestation/afforestation is a welcome change and has serious implications for global biodiversity, carbon sequestration, soil maintenance, and reduction of greenhouse gases that contribute to global climate change (Grainger 2008). Understanding the contexts within which reforestation and regrowth occurs is particularly critical for policymakers interested in addressing issues of climate change, both at the national level and globally. We therefore seek to describe the processes behind different forest transitions in four Asian countries, while assessing the applicability of an emerging framework – forest transition theory (FTT).

FTT could prove useful to land-change science, as it aims to understand the drivers that determine the point at which a country switches from a trend of net deforestation to one of net reforestation (Kauppi *et al*. 2006). Mather (1990) proposed the term 'forest transition' to describe a trajectory of change, where initial forest loss is followed by recovery as a country undergoes social and economic changes (Rudel *et al*. 2005). This 'economic development pathway' to forest transition has been documented in many developed regions across the globe and is posited to be linked to an increased level of development, a lower emphasis on agriculture, land abandonment, movement to cities, and higher gross domestic products (GDPs) (Rudel *et al*. 2005). The second major forest transition path, the 'forest scarcity pathway,' relates loss of forest cover to scarcity of forest products, which in turn make forest products viable and increase forest rehabilitation and plantation efforts (Rudel *et al*. 2005; Kauppi *et al*. 2006). The relevance of the forest transition concept is evident in other examples of such reforestation, but incorporating other influences, such as government policy and globalization, which have been explored both in Asia (Mather 2007) and elsewhere (Rudel, Bates, and Machinguiashi 2002; Mather 2004; Angelsen, Station, and Cameroon 2007). FAO data have highlighted that about 38% of the world's countries have had some forest-cover increases since the 1990s, many of which also had substantial levels of deforestation in earlier time periods. Such numbers seem to substantiate FTT. However, not all countries display forest transitions nor will all locations currently experiencing high rates of deforestation necessarily follow this route (Rudel *et al*. 2005). The question is to what degree does forest transitions happen and what factors can predict its magnitude? Studying a diverse group of countries within the same geographical region, each with different underlying processes, can help highlight some of the trends and potential pathways of forest-cover change, both historical and current.

Research has found that tropical forest transitions may actually follow a different pathway than temperate forest transitions from earlier periods. Whereas for temperate forests, reforestation often follows land abandonment, in tropical regions, land abandonment is often not the precursor because land continues to be managed, with reforestation occurring as a management practice (Rudel *et al*. 2002). In addition, such changes may not be permanent, as indicated by FTT, but rather may be more malleable in nature, with smallholders reforesting or deforesting land depending on the economic conditions (Rudel *et al*. 2002; Perz 2007).

The South/Southeast Asian region represents a challenge in terms of the study of land-cover change. These landscapes harbor globally important biological and cultural heritages, which coexist with high population densities, posing major threats to forest cover. Geographically, politically, and ecologically, the landscapes of this region present an incredible diversity of patterns. Yet there is a broader similarity in biogeography, flora and fauna, culture, institutions, and shared histories that defines the region. Despite alarmist presentations of supposedly catastrophic declines in forest cover in some countries in the region such as Burma, Malaysia, and Thailand, substantial areas have been observed to maintain or increase forest cover in recent years. This research draws on datasets and ongoing research to evaluate gradients of deforestation and reforestation at sites in Nepal, India, Thailand, and Cambodia.

The 2005 Forest Resources Assessment (FAO 2006) highlights these deforestation and reforestation trends across the region (Tables 1a and b) The overarching goal of this study is to examine the processes that drive forest transition pathways in South and Southeast Asia. Specifically, we address this through four case studies located in India, Nepal, Thailand, and Cambodia, assessing the nature and extent of reforestation and regrowth and evaluating the applicability of FTT in interpreting the drivers of frequently observed forest transitions, specifically related to the degradation, afforestation, and regeneration forest classes. We utilize a multidisciplinary, multi-scalar approach that combines information from localized, remotely sensed data with field surveys and with aggregate country-level information from FAO data, as a way of actualizing FTT and understanding its broader regional ramifications.

Study areas

Due to the use of four distinct study countries and regions, a brief description of each location, key differences, and potential drivers of change are discussed here.

Thailand

Sisaket is a predominantly rural province situated in northeast Thailand, at the southern edge of the Khorat Plateau (Figure 1a). The province, measuring approximately

Table 1. FAO data tables for the four countries of interest.

Country	Cambodia	Nepal	India	Thailand
(a) Extent of and change in forest and other wooded land				
Total area (1000 ha)	18,104	14,718	328,726	51,312
Forest area, 1990 (% of landscape)	71.51	32.73	19.45	31.11
Forest area, 2000 (% of landscape)	63.75	26.50	20.55	28.87
Forest area, 2005 (% of landscape)	57.71	24.70	20.59	28.30
Average annual change rate, 1990–2000 (%)	−1.1	−2.1	0.6	−0.7
Average annual change rate, 2000–2005 (%)	−2	−1.4	not sig.	−0.4
(b) Change in extent of forest plantations				
Plantation as percent of total forest area, 1990	0.5	1	3.1	16.5
Plantation as percent of total forest area, 2000	0.6	1.3	4.2	20.8
Plantation as percent of total forest area, 2005	0.6	1.5	4.8	21.3
Average annual change in plantation area, 1990–2000 (ha/year)	500	300	85,100	43,700
Average annual change in plantation area, 2000–2005 (ha/year)	−2,600	200	84,200	4,400

Sources: FAO (2006)

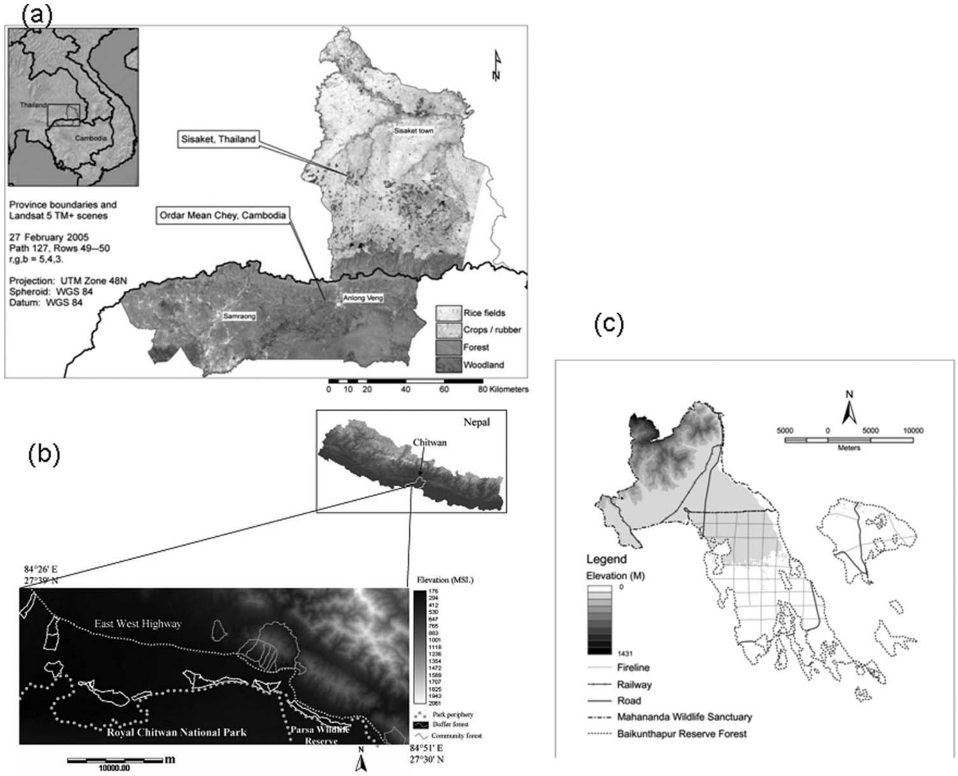

Figure 1. Study maps of the areas of study for (a) Thailand and Cambodia sites, (b) Nepal sites, and (c) India sites.

8860 km^2, is home to just over 1.4 million people, giving a mean population density of 158 people/km^2. The northeast is drier and poorer than the rest of Thailand. Until recently, it lagged behind in economic and infrastructural development, as well as in agricultural expansion (Parnwell 1988). When the province was visited in 2005 and 2006, however, nearly all rural villages were found to be linked by paved roads and to have electricity and clean water supply, as well as schools and health facilities. Much of the province's forested area is found on the escarpment of the southern border with Cambodia. The escarpment hills have access limited and controlled by the military and are further protected by the wildlife sanctuaries of Huiy Sala and Phanom Dong Rak to the west and center and by Khao Phra Whihan Park to the east.

Cambodia

Ordar Mean Chey shares the eastern third of its northern border with the western half of Sisaket's southern border (Figure 1a). It comprises an area of about 5210 km^2, with a population of about 70,000. Its population density, at 13 people/km^2, is an order of magnitude smaller than Sisaket's. It is one of Cambodia's poorest districts. Although little documentation on Ordar Mean Chey is available, field visits to the area in 2005 and 2006 confirmed that the area is sparsely populated and all roads are dirt and are seasonally impassable. Most settlements do not have electricity or water supplies, and forests still dominate the landscape. Although the southern part of Ordar Mean Chey, where much of the forest remains, falls within the Kulen-Promtep Wildlife Sanctuary, limited management and corruption (cf. Global Witness 2004) have left the area largely unprotected.

Nepal

The study area, covering an area of about 400 km^2, is located in the inner Terai valley region of Chitwan district, Nepal (Figure 1b). In recent decades, the emphasis on agricultural productivity within this region has resulted in substantial decreases in forest cover. This has occurred even while the country has become recognized internationally as a huge proponent of community forestry, resulting in recovery of forest cover in much of the middle hills region of Nepal (Agrawal and Ostrom 2001). The inner Terai valley region is one of the higher population densities and mixed communities made up of the traditional inhabitants (and the economically and socially more powerful hill migrants). The landscape represents an interesting contrast in management types, including the Chitwan National Park and Parsa Wildlife Reserve; the region adjacent to these protected areas (park periphery) where management regimes of buffer zone forestry occur; and community-managed regions of surrounding forest.

India

Figure 1c depicts the study area of 390 km^2, with the Mahananda Wildlife Sanctuary (MWS) to the north and the Baikunthapur Reserve Forest (BRF) to the south. The MWS is located in the southern part of the Darjeeling district of West Bengal. This area was declared a wildlife sanctuary in 1976, with the boundaries subsequently increased after 1988 (Wildlife Circle 1997). The MWS is located along the foothills of the Himalayas.

Methods

The data provided by the FAO reports (FAO 2006) provide an interesting regional overview of forest transition. The FAO national-level data provide context, which allows comparison between countries, particularly with regard to GDP and the relative contribution to the national economy from agriculture, the largest source of forest loss. However, at this broad scale of data, local-level dynamics are obscured, such as changes in accessibility through the introduction of roads, settlements, or markets (Liu 1999; Southworth and Tucker 2001; Verburg *et al*. 2002; Walker 2004; Walker and Soleki 2004). Further, the FAO data are largely based on coarse-scale classifications without extensive field verification, and there have been questions about the accuracy of these global- and national-level data. Further, FAO's definition of forest as 10% canopy closure does not always correspond to accepted forest definitions. Such a standardized definition obscures underlying variations in forest types (Perz 2007). Thus, such national and global assessments require supplementation through more detailed approaches to forest change detection.

Accordingly, we supplement this information by using remote sensing and field techniques, to position four case studies in sites in India, Nepal, Cambodia, and Thailand, within the FAO forest database on forest-cover change from 1990 to 2005. These local studies are based on extensive field verification and both household- and community-level interview data in order to better determine cause–effect relationships and likely drivers of transition. This allows us to both determine patterns of change and identify human drivers of change across all four study regions, and is an important component of this research, allowing us an extra level of verification and support for the remote sensing-based local analyses, as well as the FAO national-level data. By taking such a hierarchical analytical approach that pulls together the local and national levels, we can both capture the specifics of each case study and contrast their condition as a reflection of their nation's stage of development.

Detailed classifications also enable us to move beyond the confines of only forest or woodland definitions of forest type, to include classes of regeneration and degradation, as well as reforestation, deforestation, and the much needed class of afforestation (where feasible). This approach allows us to expand our understanding of land-use change by differentiating drivers of land-cover change such as land abandonment or tree plantation (which may be associated with reforestation) from drivers of modification such as change in fire regime, protection of partially degraded lands, or succession. It also facilitates an appreciation of future trends, such as gradual regeneration of degraded forest classes, something a more traditional classification may not detect as change. Finally, this approach enables a closer comparison with the data provided by FAO, which examine changes in forest density (which we term here as regrowth/degradation) as well as in forest cover (which we consider reforestation/deforestation).

Remote sensing analyses

For the Thailand and Cambodia region, cloud-free, seasonally comparable, paired Landsat scenes were selected for four points in time across the study period (January 1989, January 1994, March 2000, and February 2005). For Nepal, two Landsat images were used from the winter, dry season (TM January 1989, ETM March 2000). For India, Landsat TM satellite imagery from November 1990 and Landsat ETM+ imagery from December 2000 were used, with both images from the season following the rains, which enable us to ensure that the images are completely cloud free and also allow us to differentiate forest from fallow agriculture with a greater degree of accuracy. For all four study areas the images were atmospherically calibrated (Markham and Barker 1986; Teillet and Fedosejeus 1995; Green, Schweik, and Hanson 2000), georectified using the most current image date as the base, and, in the case of Thailand and Cambodia, the image pairs were mosaicked together. Care was taken to ensure that the root mean square error of image-to-image registration was less than 0.5 pixels (15 m). In addition, an overlay function and careful visual comparisons were used to verify that the images overlapped exactly across image dates and that there were no sliver areas of misregistration (Jensen 2000), to ensure that changes observed from year to year are a result of actual land-cover change and not compounded by errors in registration.

Classification was undertaken for all sites, based on extensive field visits[1] and training sample data, using hybrid supervised/unsupervised techniques (Jensen 2000), and while initial classes were site specific these initial land-cover classes were then grouped into a common set of classes based on their change trajectories, to allow us to compare these processes and changes across all sites – stable forest, stable nonforest, deforestation, reforestation, regeneration, and degradation. Based on training sample data retained for accuracy assessments, all classifications for all sites had classification κ values over 0.85, and no individual class accuracy levels below 0.8, well within the levels considered appropriate for accuracy in image classifications (Jensen 2000; Foody 2002). These final land-cover change trajectories grouped the potential classes. Given the level of classification (based on forest and nonforest classifications) and the relative ease of determining these classes in the images, such an approach was deemed appropriate for these analyses.

FAO datasets

Before 1990, there was much debate on the quality of the FAO database. However, for the 1990–2000 and 2005 datasets, recalculations were undertaken, in which a single forest definition was used (10% canopy closure), and along with the advent of the use of coarse-scale remote sensing as a means of collecting supplementary data, these data are now more useable and standardized (Rudel *et al*. 2005; FAO 2006). By using FAO databases, some basic national-level information on the four countries can also be discerned for the same time period. These data are presented in Table 2.

Results

At the national scale, FAO data show that Cambodia has the highest levels in forest cover with 59%, followed by Thailand at 28%, Nepal at 25%, and India at 23% (Table 1a, FAO 2006). The largest amounts of forest loss are occurring in Cambodia, with approximately 166,000 ha decrease per year of forest area, with this rate being lower from 1990 to 2000 and increasing from 2000 to 2005 (Table 1a). It is the only one of the four countries where the loss is higher for the more recent dates. Nepal and Thailand show smaller annual decreases in forest cover, with these deforestation rates slowing in 2000–2005 when compared with the previous decade (Table 1a and b). Finally, India reveals a very different national trend, being the only one of the four countries with a trend of increasing forest area at the national level.

Some of these movements in forest cover relate to changes in forest plantations (Table 1b). In Cambodia, less than 1% of the total forest area is covered by plantations, while Nepal also reveals a very gradual increase in proportion of the forest area covered by plantations, from 1.0% to 1.3% to 1.5%. India also shows a gradual increase in area over time, from 3.1% to 4.2% and 4.8% of the total forested area. Finally, Thailand has a much different picture with plantations providing 16.5%, 20.8%, and 21.3% of the total forest area from 1990 to 2000 to 2005, a much higher percentage than the other countries.

The regional scale of analyses is also an important focus, and for each of the countries discussed nationally above, we also have more focused case study data which will now be discussed.

For Sisaket, Thailand, less than 10% of the landscape remains in stable forest cover, with a decrease in this category from 1994 to 2000 to 2005 (Figure 2b). Most of the

Table 2. Basic national-level data for the four countries of interest, showing populations and GDPs and the relative economic importance of the agricultural sector.

Country	Cambodia	Nepal	India	Thailand
Population	14,482,000	25,725,000	1,081,229,000	63,465,00
Per capita GDP	$309	$240	$538	$2,359
Per capita agricultural GDP[a]	$148	$98	$201	$413
Ownership of forested lands	100% public[b]	99.9% public, 0.1% private	98.4% public, 1.6% private	86.8% public, 13.2% private

Notes: [a]Agricultural GDP divided by agricultural population.
[b]However, extensive areas are allocated as logging concessions to private, usually foreign corporations, or logged through military operatives on behalf of a few individuals (De Lopez 2002; Le Billon 2002; Global Witness 2004).
Source: FAO (2006).

landscape is in nonforest cover and this value has increased over the same time period. About 4–6% of the area rotates from degradation to regeneration during each time period. Reforested areas have decreased over time, while deforestation shows first an increase, from 1994 to 2000, and then a decrease by 2005 (Figure 2b).

Spatially, some locations in Sisaket have experienced little change, including areas of rice production, the forested border escarpment, and riparian corridors. In other places, key changes have taken place, however. On the good soils associated with the extreme northeast, the escarpment foothills, and the three hilly areas to the southeast there has been considerable landscape dynamism, where upland crops, woodland, and – most recently – rubber plantations have emerged, as verified by field and interview data.

For Ordar Mean Chey, Cambodia, there are quite different values to Sisaket, Thailand, despite the spatial contiguity of the two provinces. In contrast to the national trend of decreasing forest cover across Cambodia from 1990 to 2005 (Figure 2a), at the study level of Ordar Mean Chey we see a different picture, largely because it was the area to which Pol Pot retreated, and peace came to this province much later. From 1989 to 1994, we see more reforestation and regeneration than deforestation and degradation (Figure 2a). This relates to a reduction in area under rice (nonforest cover) and large increase in woodland (reforestation), validated by interview data. Overall, the area in stable forest has decreased over time, while the area covered by stable nonforest has not changed much. Deforestation rates have increased over time, while degradation fluctuates from 11.7% to 22.3% to 17% by 2000–2005.

The area covered by reforestation has almost halved over time, from 16% to 11%, to 8%. Regeneration follows a more varied path, first decreasing and then increasing to 19% by 2000–2005. Most notable in terms of spatial arrangement is the development of what was in 1994 a narrow track through the dense forest in the southeast of Ordar Mean Chey, into a dramatic wedge of deforestation by 2005. The increase in open forest in 1994 occurred as a band around the dense forest core regions. The role of settlements in influencing forest change is also clear from the impact of growth at the villages of Anlong Veng and Trapeang Prasat. Although seemingly small in spatial extent, the wedge of deforestation associated with Trapeang Prasat and its access track has effectively fragmented the eastern portion of the dense forest.

In Nepal, the study area patterns of stable forest and stable nonforest are varied. The highest proportion of stable forest occurred in the community forests, while the largely unprotected surrounding landscape had the least amount of stable forest (Figure 2c). Stable nonforest cover showed an opposite distribution, with the greatest amount in the surrounding landscape and only negligible amounts in the community forests. Community forests were areas of transition, with over 30% in areas of land-cover modification, that is, regrowth and degradation, but less than 10% in conversion, that is, reforestation and deforestation. Buffer forests were dominated by reforestation over deforestation but also by degradation over regrowth (Figure 2c). The park periphery and surrounding landscape provide a contrasting view to the community forests and buffer forests, with greater degradation and deforestation – although even these locations show some reforestation and regrowth (Figure 2c).

Within the Indian study regions, the extent of forested and nonforested land cover in the MWS, BRF, and surrounding landscape during 1990 and 2000 is shown in Figure 2. As a percentage, most of the area in the MWS and the BRF is covered by open or dense forest, while the surrounding landscape is dominated by nonforest. Figure 2d describes the area occupied by the four change categories of stable forest, reforestation, deforestation, and stable nonforest, between 1990 and 2000, for the MWS, BRF, and the surrounding

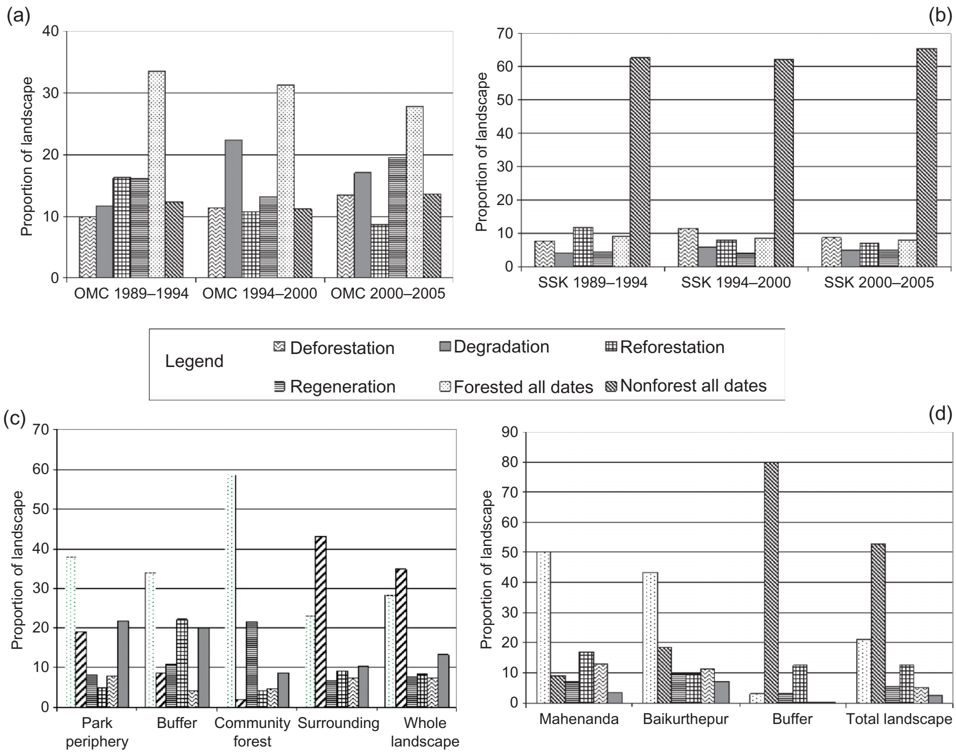

Figure 2. Graphs of four study sites and the land-cover trajectory results across dates and locations for (a) Cambodia, (b) Thailand, (c) Nepal, and (d) India.

landscape. Clearly, the overall landscape is experiencing a trend toward reforestation and regrowth (Figure 2d). The area within the surrounding landscape appears relatively stable, with much of the landscape distributed between stable forest and stable nonforest categories. In contrast, the MWS and BRF have experienced substantial change, with large areas experiencing some form of change. In the MWS, large patches of stable forest to the north occur in hilly areas with steep topography. There is only limited deforestation, and substantial reforestation and regrowth has taken place in the less hilly southern sections.

Discussion

Figure 3 (adapted from Kauppi *et al*. 2006) highlights the different positions of the four study areas within the context of forest transitions, standing forest biomass, and trends. As is clearly evident, the four study sites represent three of the four possible trajectories of reforestation, regeneration, deforestation, and degradation, the latter not depicted in this research (Figure 3).

The broad FAO classifications allow the major trends of forest change to stand out clearly. However, these generalized categories are to some extent over-simplified.

A more detailed understanding, derived from the case studies presented here, reveals that there is a far greater level of dynamism that is masked by the broad forest–nonforest categories. FTT appears to be applicable to each of the case study sites, with Cambodia's position along the pathway differing most from that of the other three countries. A detailed

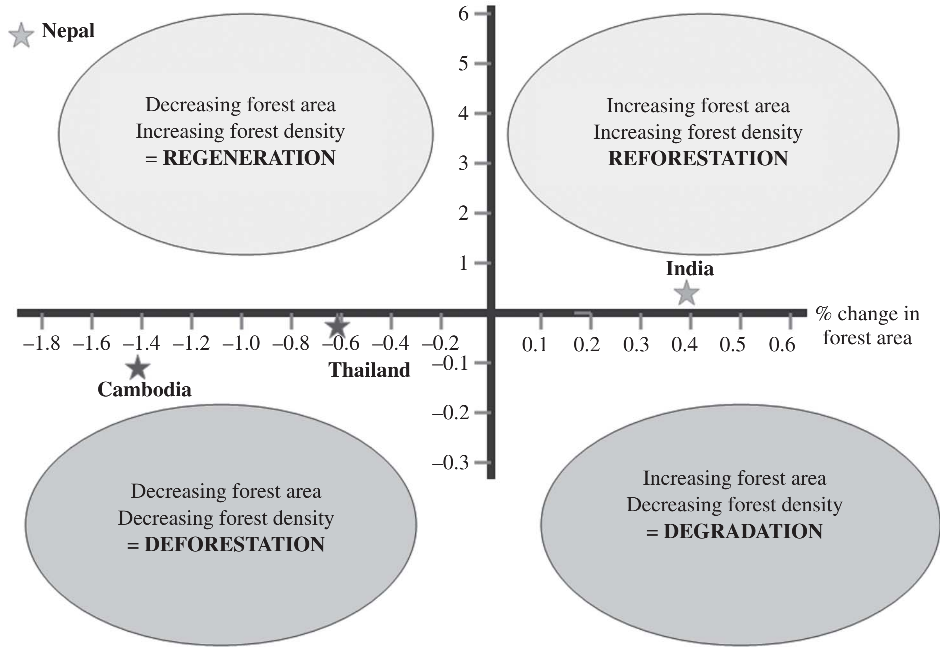

Figure 3. FAO data setting national-level context of trajectories of change for the four study regions and their resultant land-cover trajectory space.

assessment of conditions in each of the study sites provides understanding of each country's location along the curve in Figure 4.

The forest transitions in Sisaket, Thailand, reflect a well-developed economy emerging from stagnation where land use has been dominated by rice production (Felkner and Townsend 2004). Sisaket's low proportion of forest has persisted across the study period, reflecting the high human population density. There has been little variation in the location of forests, which have persisted only where they are afforded some protection, such as in riparian buffers, and on the rocky escarpment of the southern border, where military presence and protected areas have combined with biophysical attributes unsuited to paddy rice (slope and thin soils) to limit agricultural expansion.

In Cambodia, the increasing rate of deforestation since 2000 is in keeping with the national-level FAO data, with that province finally attaining more stable political conditions already in place in the rest of the country. However, during the earlier phase (1990–2000), this province experienced an increase in forested areas even though the rest of the country was experiencing net deforestation. The finer spatial and temporal resolutions reveal more of the underlying processes and drivers than are reflected in the FAO data.

Cambodia's anomalous conditions can largely be explained by political conflict, particularly during the first half of the study period, which was verified by interview data where political turmoil was mentioned. The country's mainly forested landscape is rapidly changing as it has opened up for development starting in 1993. This led to the reestablishment of rice fields (nonforest) and increased settlement in the east, as this Khmer Rouge hold-out area gradually returned to central government control after Pol Pot's death in 1998. Yet, as large areas remained inaccessible due to continued guerilla warfare up until 1998 and the presence of landmines to this day, Ordar Mean Chey is only now able to begin exploiting

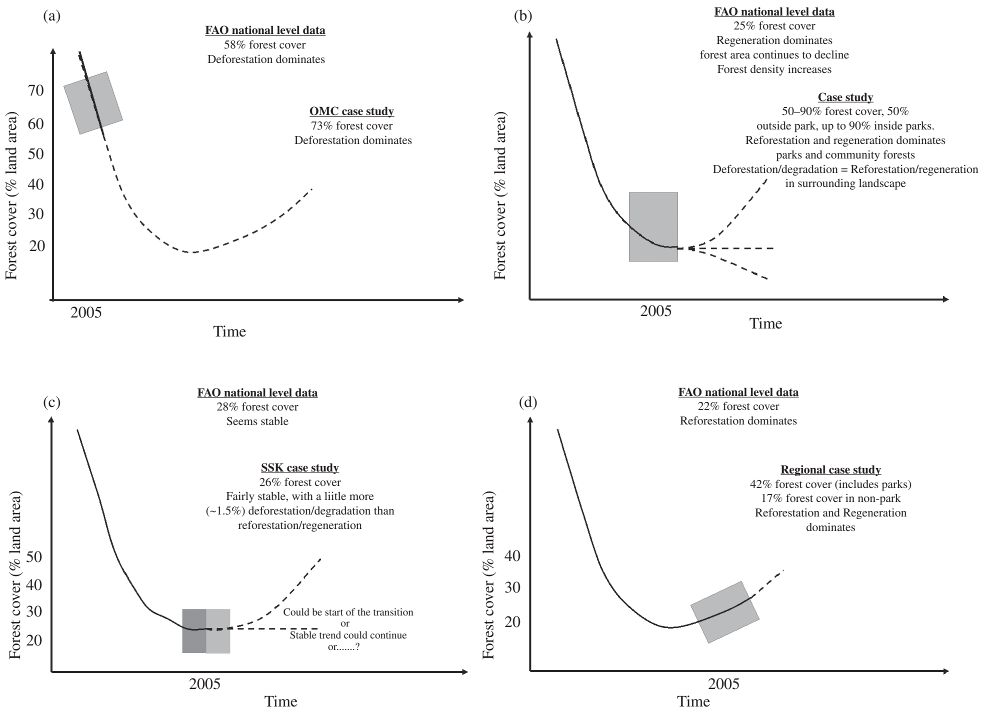

Figure 4. Forest transition location for each region, according to FAO national-level statistics, and the regional case studies for (a) Cambodia, (b) Nepal, (c) Thailand, and (d) India.

its resource base (De Lopez 2002) as was seen during field visits. The reforestation, particularly of woodland, between 1989 and 1994 is due largely to the laying down of landmines by both the new Vietnamese-backed government and the retreating Khmer Rouge factions.

In Nepal, the FAO data show that the rate of deforestation in Nepal slowed between 2000 and 2005, compared with the period 1990–2000. While this can be seen as capturing the influence of national-level schemes such as the tree-planting program, some of the dramatic differences in the Chitwan landscape occur at the local level. The buffer forests are located in accessible, fertile areas close to the Rapti River and experienced extensive land conversion to agriculture and urban uses up to the early 1990s, but there has been extensive tree plantation after the establishment of the park buffer zone program in 1993, resulting in reforestation in this fertile riverine area (Nagendra *et al*. 2005). In contrast, the community forests were mostly protected from land-cover clearing for agriculture and urban construction due to their location on higher elevations and steeper slopes, but were highly degraded due to grazing and forest extraction prior to the 1990s. Since then, community protection has led to an increase in vegetation density (regrowth) (Nagendra *et al*. 2005, 2008). There is degradation in the park periphery and the unprotected landscape surrounding the park due to fuelwood extraction and grazing (Heinen and Mehta 1999; Nagendra *et al*. 2008) as verified by extensive interview data within the surrounding communities.

At the national level, India's forests appear to have stabilized in terms of total area covered. However, the remote sensing data at the local level are able to reveal some of the dynamism masked by the broad-scale FAO data – there are still active areas of reforestation and deforestation, indicating both the pressure on the forested land and the efforts to protect it. Reforestation has taken place in the MWS after commercial timber extraction was discontinued in the 1990s, and in the landscape surrounding the park there has been reforestation in shade-grown tea gardens which are no longer cultivated as extensively. However, the tree planting by government-sponsored programs found elsewhere in the country is not seen much in this particular landscape. There has been substantial deforestation in the park periphery due to pressure from the densely populated villages and towns that surround this area. Again, extensive interview data allowed for the identification of pathways of change and highlight the importance of both local-level analyses of land cover and of household and regional dynamics. Based on the specifics discussed for each country and study area in the earlier paragraphs of this section, we note the importance of context to understanding the exact conditions experienced at each locality (Perz 2007). Nevertheless, it is clear that some commonalities exist. For example, the impact of human pressure can be noted in each site, as can the role of protected areas in mitigating these impacts – as also seen in other studies (Cropper *et al*. 2001; Southworth and Tucker 2001; Munroe *et al*. 2004; Nagendra 2008).

While we feel that much of the current configuration of the northeastern Thailand landscape will persist for some time due to the need to maintain high levels of agricultural production, the current trend of deforestation in the Cambodian province is likely to persist until its landscape resembles more closely the agriculturally dominated areas of the three other study areas. In Nepal, community forestry is likely to lead to a continued trajectory toward reforestation and regrowth, unless initiatives by the Nepali government to take back control over the timber-rich Terai forests gain momentum. In India, where significant areas are already covered by tree plantations, increased tree planting is likely to continue, but protected areas will continue to be impacted at the boundary with increased pressure from the surrounding settlements (De Fries, Karanth, and Pareeth 2010).

Conclusions

This research demonstrates the usefulness of a hierarchical approach that combines 'grand theory' (Perz 2007) with comparative studies that accommodate 'context-specificity' within the use of FTT (exemplified in Figure 4). Working at two different spatial resolutions provides another way of capturing some of the dynamics of a landscape while still understanding the dominant trends of persistence and change through an integrated use of local-scale analyses and field-based data collection (Pontius, Shusas, and McEachern 2004). Methodologically, estimating the real area and spatial location of forest transitions is key to a better understanding of forest dynamics and the potential for future forest transitions (Grainger 2008). Such an approach can expand our understanding of land-use change, enabling us to differentiate drivers of land-cover change such as reforestation (land abandonment or tree planting = changes forest area) from drivers of land-cover modification such as regeneration (protected areas undergoing regrowth = changes forest density) on a landscape. Such differences are key to identify as different drivers are at work and previous research looks mainly at absolute changes in land cover – missing the often critical modifications or within-class changes. Such within-class changes have been flagged as important to both monitor and understand better (Nagendra and Southworth 2010; Fries *et al*. 2010) and this research makes an important step in this direction. In addition, the linkage to FAO national-level data, which substantiate the local findings, also proves some extra value and validation from this hierarchical analytical approach.

Much is still needed in terms of the clarification, definitions, and future directions related to FTT. One major issue relates to the definition of forest cover within the FAO database. Clearly, a more detailed approach, with separation into different types of forest cover (such as old growth vs. secondary forest and plantations), will be very helpful and of increasing importance for issues such as biodiversity, carbon storage or loss, and climate change mitigation strategies. While recent FAO databases use satellite remote sensing-based estimates of land-cover change they are utilizing very coarse resolution data (given the national-level focus) and may be considerably underestimating deforestation or reforestation trends (Grainger 2008). Finally, one key issue when dealing with transitions is that the time frame is of paramount importance. The definitions of dynamics by time frames, meaning short-, medium-, and long-term changes in forest cover, can help refine the issues occurring in tropical developing countries, as many of the current 'transitions' are not permanent and so are confusing the forest transition debate. For policymakers, understanding the extent to which the observed transitions are an important part of the dynamics of a functioning social–ecological system, versus change that represents an irreversible loss of future options, is critical. This is particularly true with regard to both the impacts of climate change on forests and the role of forests in mitigating climate change.

Another interesting finding is that forest-cover loss does not seem to be decreasing to the low levels of 10% landscape cover prior to the start of recovery observed in many previous studies (Rudel *et al*. 2002, 2005), but rather may actually be between 20% and 30% of the landscape, which has important implications in terms of maintained biodiversity through the conservation of initial, natural forest cover, as well as for carbon storage and climate change mitigation. Some major stabilizations may also be permanent, changing the shape of the forest transition curve. This leads us to address the issue of the role of parks and protected areas within FTT, which may be very important, as for the Nepal and India landscapes (Nagendra 2008), and is currently rarely discussed.

In conclusion, the approach we have used linking FAO data with local-level case studies allows us to find a way to relate patterns at a country scale with drivers at a local scale (Figure 4); look for differences in pattern and process between the local and national levels (Figure 4); and find a way to separate out differences in land use at a higher resolution, from both remote sensing analyses and field-based interview data, thus enabling a better understanding of drivers of each type of land-cover change. This integration of methods within the hierarchical analytical approach is a major improvement over individual case studies and allows us to better evaluate commonalities: from local to regions to nations.

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Note

1. Fieldwork included interviews with local informants, development planners, and government officials, in order to get a qualitative understanding of the factors influencing land-use land cover in the study areas.

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