Tourism, forest conversion, and land transformations in the Angkor basin, Cambodia

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ABSTRACT

The Angkor basin of Cambodia, the site of the great Angkor temple complex, has experienced explosive tourism growth since the 1993 onset of national political stability and renewed international investment, which in turn has driven increasing demand for water, wood, and biomass fuel, and rapid and extensive land-use and land-cover change. We use multi-temporal Landsat imagery (1989–2005) to describe the rate and extent of land-cover change throughout the Angkor basin. While 50% of the landscape remained in rice agriculture it is notable that a larger proportion of the area was deforested (23.4%) than experienced forest regrowth (4.9%). Most forest loss occurred between the Angkor temple complex and Phnom Kulen National Park, and was due in part to charcoal production to serve the tourist industry, and also conversion to permanent agriculture. The small area of forest increase was concentrated along the eastern boundary of the main Angkor complex. The interplay among global (tourism, climate), regional (national policies, large-river management), and local (construction and agriculture, energy and water sources to support the tourism industry) factors drives a distinctive but complex pattern of land-use and land-cover change.

Introduction

Within the past fifty years tropical, forested landscapes in developing countries have been transformed by economic and social development (Lambin & Geist, 2003; Walker, 2004, Wright, 2005). These transformations are important components of global environmental change (Foley et al., 2005; Moran, 2005; Rindfuss, Walsh, Turner, Fox, & Mishra, 2004). The most rapid and significant include deforestation as a consequence of urbanization, agricultural expansion, logging, and pastoral expansion (Lambin & Geist, 2003). Deforestation remains the dominant mode of land-cover transformation in tropical, developing countries, but the causes of deforestation are diverse and idiosyncratic (Carr, 2004; Geist & Lambin, 2002; Lambin & Geist, 2003; Walker, 2004).

Forests in Southeast Asia are valued for their high biodiversity and commercially important Dipterocarpus hardwoods (Kummer & Turner, 1994). At the same time global projections of forest loss are highest in this region. Legal and illegal private and state-run commercial timber harvesting practices, large transmigration schemes, and weak governance have contributed to recent forest losses (Lambin & Geist, 2003). Agricultural expansion is the most commonly cited cause (Lambin & Geist, 2003; Lepers et al., 2005), and a myriad of other forms of economic development also contribute (Chomitz & Gray, 1996).

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In contrast to the economic development of other ASEAN (Association of Southeast Asian Nations) nations, the turbulent and politically unstable history of Cambodia over the last quarter of the 20th century limited infrastructure development, natural resource exploitation, and economic growth (Le Billon, 2000). The horrendous Khmer Rouge period from 1975 to 1979, followed by Vietnamese occupation until 1989, led to a near-total loss of both financial and intellectual capital.
UN-supervised elections in 1993, the death of the Khmer Rouge primary leader Pol Pot in 1998, widespread removal of remnant land–mine fields, and the beginning of relative peace, political stability, and international investment has resulted in rapid changes across the Cambodian landscape. Dynamic policy initiatives, including increasing emphasis on international tourism, have contributed to rapid land-cover transformations from national down to local scales.

Cambodia is one of the Southeast Asian countries identified as a “hot spot” of forest loss (Giri, Defourny, & Shrestha, 2003; Lambin & Geist, 2003) but only a few studies have described land-cover change quantitatively in Cambodia at a local scale (Fox & Vogler, 2005; Giri et al., 2003; Stibig, Achard, & Fritz, 2004). Large, regional-scale studies commonly use coarse spatial resolution in their analysis, which limits the abilities of such data to support statements of causality about local forest loss. Siem Reap province, the site of the great Angkor complex, has experienced a rapidly growing tourism industry (a major economic development engine for the nation) and increasing human population. This paper describes landscape transformation in the drainage basin that includes the Angkor complex. The trend of land-cover change within the Angkor basin is especially important because the basin includes three sites of global natural and cultural conservation importance: the UNESCO World Heritage Site of Angkor (est. 1992), part of Phnom Kulen National Park, and the Tonle Sap Lake Biosphere Reserve (Fig. 1), which together now draw millions of tourists each year.

Time-series land-cover descriptions are the first step in understanding the dynamic processes of land-use decisions (Turner et al., 1990) and a demand exists for accurate and precise measurements of the rate and change of land-cover transformation across the globe (Foley et al., 2005). The objective of this study is to describe land-cover change in the Angkor basin from 1989 to 2005 by determining the spatial and temporal land-cover dynamics of the basin and by examining possible drivers of change in the basin, including how tourism may play a role in driving shifts of forest to non-forest land cover.

Methods

Study area

The most important historical periods influencing existing patterns in the Angkor basin landscape are that of the Khmer Empire (9th–mid-15th century A.D.) and the Khmer Rouge reign from 1975 to 1978. The Khmers ruled an area that extended into present-day Thailand, Laos, Vietnam, and all of Cambodia and had a population that may have exceeded one million, mostly supported by widespread rice cultivation (Chandler, 2000; Coe, 2004). Remnants of intensive land use are still prominent in the landscape and recognizable from space (Casals-Carrasco, Kubo, & Madhavan, 2000; Fletcher, Johnson, Bruce, & Khun-Neay, 2007). Angkor Wat and the surrounding temples, remnants of the Khmer Empire, draw international attention and tourism to the country and to Siem Reap province.

The Khmer Rouge overthrew the existing Cambodian government in 1975, severing international ties, forcing the Cambodian population into communist agrarian labor, and killing an estimated two million Cambodians (Chandler, 2000). Cambodia was then invaded and occupied by Vietnam from 1978 until 1989 but since then Cambodia has established a stable, democratic government.

The Angkor basin (2986 km²), which includes the drainage basins of three small rivers (Puok, Siem Reap, and Rolous), is at the northern end of the Tonle Sap Lake (Figs. 1 and 2) and lies completely within the Siem Reap province of Cambodia. Elevation ranges from 6 m above sea level at Tonle Sap (the largest fresh water lake in Southeast Asia and a UNESCO Biosphere Reserve since 1997) to 469 m on Phnom Kulen (IUCN category II National Park, 37,500 ha). The landscape is a mosaic of both flooded and upland forests, rice fields, scrub land, shifting cultivation, urban areas, and designated protected areas. Forests within the basin are comprised of both deciduous and evergreen trees. Several species of the dominant tree genus Dipterocarpus supply timber. Both floating and recession rice varieties are cultivated in the floodplain of Tonle Sap while dry season irrigated rice and rainfed rice are grown on higher land farther away from the lake (Varis & Keskinen, 2003). Land mines were scattered throughout the uplands and were not cleared until 2002, making cultivation in some areas dangerous. The small city of Siem Reap and the Angkor complex (10,800 ha), which was named a UNESCO World Heritage Site in 1992, are located within this predominantly flat landscape.

The Tonle Sap is a reservoir for the larger Mekong River during the rainy season (May–November). Water from the rising Mekong River flows up the Tonle Sap River, raising the lake level and flooding the area around the lake. The lake's surface area can vary between 2500 km² and over 15,000 km² between the end of the dry season and the height of a very rainy season (Fujita & Fox, 2005). Annually flooded, nutrient–enriched floodplains surround the lake and sustain traditional livelihoods through paddy cultivation and fish harvesting.

Landscape patterns and especially vegetation phenology are influenced by inter- and intra-annual precipitation patterns (Green, Schweik, & Randolf, 2005; Jensen, 2005). Seasonal monsoons bring wet, moisture-rich air from the southwest from May to November while December to April is characterized by drier, cooler air that flows from the northeast. The majority of rainfall occurs during the wet season with an annual precipitation range from 1050 to 1800 mm.

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1 Forests surrounding Angkor Wat were designated as the first protected area in Southeast Asia in 1925, but all government collapsed during decades of civil strife (ICEM, 2003). With the end of conflict and onset of political stability in 1993, twenty-three protected areas were created comprising ~21% of Cambodia’s total area. Three protected areas are situated partly or wholly within the study region.
Data sources and pre-processing

A Food and Agriculture Administration (FAO) national roads dataset was used for the base rectification of the 2002 image. The meteorology station for Siem Reap provided precipitation data for 1981 through 2004. The delineation of the Angkor basin used 1:100,000 scale topographic maps provided by the Japanese International Cooperation Agency (JICA), a 50-m spatial resolution digital elevation model (DEM) provided by the Ministry Land Management, Urban Planning, and Construction (MLMUPC), which was re-sampled to match the 30-m resolution of the Landsat images, and an FAO vector file of both the natural and man-made waterways within the province. The DEM was registered to the 2002 Landsat image with an error of less than 0.5 pixels (<15 m) to standardize registration for all datasets. The DEM was used to separate the upland part of the Angkor basin from the flooded lowlands.

Three Landsat 5 TM images (WRS II Path 127, Row 51; 7 February 1989, 31 January 1995, 27 February 2005) were used. The time frame of the study (1989–2005) encompasses the time of emergence of Cambodia as a capitalist state in 1989, up to the year in which field work was conducted (2005). A 2002 Landsat 7 ETM+ scene (not used in this analysis but will be used in subsequent analyses) served as the base image and was registered to the FAO roads layer with a nearest-neighbor resampling (RMSE < 0.5 pixels, or <15 m). Image-to-image registration was performed on the other
images. After completing the registration, each image was radiometrically calibrated to correct for sensor related, illumination, and atmospheric sources of variance (Green et al., 2005).

Image classification

Two hundred and three training samples collected in the field, half of these helped establish land-cover classes and then to train the classification algorithm to recognize land covers in the 2005 scene covers. The remaining training samples were used to evaluate the accuracy of the created classification. Other images were classified by interpretation and knowledge of the 2005 spectral signatures, logical reasoning (an upland forest in 2005 was probably an upland forest in 1995), and informally interviewing local informants about the history of specific areas. A supervised classification was created for five classes which subsequently was folded into forest, non-forest, and water for a more specific focus on forest-cover changes. Forest was defined as >30% tree canopy closure to separate the dense forest area from scrub lands. Non-forested land includes an aggregation of the other lands covers water, bare (which at this time of year includes agriculture, which presents as bare soil, within this cover), built, and scrub.

The DEM was used to separate the upland part of the basin from the lower part of the basin, using 9 m as the upper elevation threshold for the floodplain. Field work and image analysis (specifically, inspection of the flood extent in 2002) determined that 9 m was the appropriate upper floodplain limit. The region below 9 m elevation, comprised of seasonally flooded forest and floodplain agriculture, was excluded from this analysis because interacting factors, different from the upland area, that influence the observed changes were not explicitly studied.

Change-trajectory analysis

A post-classification change analysis for the three image dates was performed to determine patterns of spatial and temporal changes in the upper basin. Twenty-seven trajectories are possible from the three-date, three-class change analysis, but we examined only the forest and non-forest change trajectories for 2-date and 3-date change respectively which occupied greater than 1% of the landscape area. Trajectories greater than 1% of the landscape area that involved water were below 9 m elevation, which is seasonally flooded forest and floodplain agriculture, and was excluded from this analysis.

Normalized Difference Vegetation Index (NDVI) calculation and change detection

The Normalized Difference Vegetation Index (NDVI) is calculated as \( \frac{(\text{NIR} - \text{red})}{(\text{NIR} + \text{red})} \), where red corresponds to Landsat TM band 3 and near-infrared to band 4. Continuous NDVI values range from -1 to +1 with values closer to +1 considered to correspond to the presence of healthy green vegetation and standing biomass. NDVI was calculated for each image date and using these images we then calculated standard normal deviates (Z-scores) to minimize the influence of seasonal variation and inter-annual differences (Jensen, 2005). The use of the standard normal deviates reduces much of the potential effect of inter-annual climate variation, which is necessary even when using anniversary dates and calibrated imagery, in a region influenced so heavily by rainy season precipitation amounts. Image differencing was performed for each NDVI image pair (1995–1989; 2005–1995; 2005–1989) (Guild, Cohen, & Kauffman, 2004). A threshold of ±1 standard deviation defined ‘significant’ change (DeFries, Hansen, Newton, & Hansen, 2005; Southworth, Munroe, & Nagendra, 2004).

Field data collection

A total of 203 training and reference samples were collected following the CIPEC protocol, a detailed method of ground referencing for satellite imagery (Green et al., 2005), in May 2005 using a systematic random sampling method along roads (Congalton, 1991). The chance of encountering undetected land mines was a major deterrent to walking too far from a road. An initial classification included five land covers and an accuracy assessment of the 2005 classified image had an overall accuracy of 83% with a kappa value of 0.75 based on over 100 training samples. To focus specifically on forest cover the classification was aggregated to a binary forest, non-forest classification. The non-forest land cover consists of bare, scrub, and built land covers with most of the urbanized areas constructed of natural materials that are spectrally similar to scrub and bare land covers. There was a bias in sampling towards NF land-cover because this was the most common landscape in the watershed (Congalton, 1991). We also wanted to make sure we collected enough representative samples to separate scrub from forest and focused the majority of training sample collection in the upland forest area as areas of forest in the floodplain were covered by water.

We visited the areas of maximum F–NF change north of the Angkor complex and south–southwest of Phnom Kulen on 28 February and 1 March 2007. A convenience sample (Bernard, 2006, p. 191 et seq.) of nine people, all charcoal sellers or their families, were interviewed by a native Khmer-speaking translator (who was also has been our driver for three years) with an informal approach that simply asked what they were doing and how long it had been going on (Bernard, 2006, p. 211). This small sample included every person that we saw in the area during the visit.

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Results

Land-cover change

Non-forested land makes up the largest percent of the Angkor basin with 56%, 53%, and 65% respectively for 1989, 1995, and 2005 (Fig. 3). Forest makes up the next largest land-cover, and occurs predominantly in the more upland areas with greater relief. Forest area increased slightly during the first half of the study period from 40% to 42% but then declined to 32% during the second half of the study. Water makes up less than 5% of the upland landscape for all years of the study, and is found mostly in the Western Baray, the reservoir to the west of the Angkor complex.

Overall accuracy of the forest–non-forest land-cover classification of the 2005 scene was 94%, with a kappa statistic of 0.91. No individual class had a producers or users accuracy below 70% and as such the classification was deemed satisfactory. The definition of forest cover was minimum 30% canopy coverage which provided a distinct delineation between scrub areas and denser forest areas. Follow-up field work was conducted in May and October of 2006 and in February of 2007 to determine ambiguous land-cover classifications and to visit areas of major change to determine causes of the changes with both

Fig. 3. Forest/non-forest classification for the Angkor basin for 1989, 1995, and 2005. The map includes the floodplain forest < 9 m elevation, which is not included in the analysis (see Figs. 2 and 4).
observation and informal interviews of local people. This also provided a secondary validation of the classification accuracy for the most current image date. We analyzed only the 2005 classification (Fig. 3) for the accuracy assessment because land-cover data for previous years do not exist.

Overall change trajectory

Non-forested land expanded in the upland portion of the basin from 1989 to 2005 (Fig. 4). Change trajectories between the years 1989, 1995, and 2005 were compared on a pixel-by-pixel basis to examine possible land-cover trajectories (Tables 1 and 2). Focus and analysis was on the upland part of the basin as different factors drive changes in the floodplain region. Two-date changes (1989–1995 and 1995–2005) show stable non-forest (NF–NF) areas cover over half the landscape while stable forest cover (F–F) drops from 34.8% to 22.5% (Table 1). Reforestation (NF–F) is higher than deforestation (F–NF) between 1989 and 1995 (7.1% compared to 5.3%) but then there is a substantial change during the second half of the study. From 1995 to 2005 reforestation is 2.8% while deforestation covers 19.7% of the landscape.

![Image of land-cover classification trajectories for 1989–1995–2005 in the upper part of the Angkor basin (elevation > 9 m), Siem Reap, Cambodia. "F" refers to forest and "N" to non-forest. Only trajectories that cover >1% of the landscape are shown. Protected boundaries delineated in white.](image-url)
The 3-date change trajectories allow us to determine a single pixel’s trajectory over time with more detail (Table 2). Fifty percent of the landscape remained in the same land-cover class from 1989 to 2005. Stable forest cover mostly was located in high upland areas of the basin, especially in Phnom Kulen National Park. Adding together non-stable trajectories that ended in non-forest nearly five times the amount of landscape was deforested (23.4%) than was reforested (4.9%). Four percent of the forest to non-forest change was from old and permanent clearing but recent forest clearing (from 1995 to 2005) totals 19.6% of the land area. There was a slightly higher increase in reforestation (7.2%) over deforestation (5.3%) from 1989 to 1995 (Table 2) but this is minimal compared to the 19.6% of forest cover changed to non-forest between 1995 and 2005 with the most concentrated area of forest decline located directly south of Phnom Kulen and north of the Angkor complex, as opposed to the 2.7% reforestation spread across the upper basin (Fig. 4).

One small area of important trajectories can be seen on the top of Phnom Kulen, in the northern edge of the basin (Fig. 4). Many small fields were cleared and then were reforested (F–N–F), while many other small areas had F–F–N trajectories. Our field observations demonstrated that these were smallholder fields of shifting agriculture that were growing maize, pineapples, or other cash crops that were probably used in restaurants in Siem Reap.

NDVI change

From 1989 to 2005 5.3% (24,289 ha) of the basin area had a significant (>1 standard deviation) NDVI decline while only 1.3% (6138 ha) of the upper basin’s area showed significant increase (Fig. 5). There was a much larger area with a decrease of 5% (23,052 ha) in NDVI values from 1995 to 2005 than the 1% (4176 ha) decrease from 1989 to 1995. Significant amounts of vegetation were removed in the second half of the study’s time period.

The spatial concentration of NDVI decrease (Fig. 5) along the southern border of Phnom Kulen is consistent with the areas of forest–to-non-forest trajectory from 1995 to 2005 (see Fig. 4 of land-cover trajectory). Areas with increases in NDVI values are mostly concentrated around the Angkor Wat complex and are most prevalent since the designation of World Heritage status implying an increase in vegetation as a result of conservation initiatives. There is also an increase in NDVI from 1989 to 2005 concentrated within the western barai (part of the Angkor complex) which contains variable amount of water that fluctuates with seasonal monsoons (Fig. 5).

Human population growth

Population growth in the Angkor basin is difficult to measure because the 1998 census is the only one in the past 40 years (see the National Institute of Statistics of Cambodia, http://www.nis.gov.kh/). The Cambodia Inter-censal population survey of 2004, which used a small subsample of villages nationwide, is not available at the village level in our study area. A census of

### Table 1

Upper basin land-cover changes in areas above 9 m elevation of forest (F) and non-forest (NF) for 1989–1995, 1995–2005 and 1989–2005. Numbers were derived from taking the total area (ha) of each conversion and dividing it by the total area of the upper basin (elevation > 9 m). The water class is not represented here as the analysis is concerned only with changes in upland forest cover.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>F–F</td>
<td>34.80%</td>
<td>22.50%</td>
<td>21.60%</td>
</tr>
<tr>
<td>F–NF</td>
<td>5.30%</td>
<td>19.70%</td>
<td>18.50%</td>
</tr>
<tr>
<td>NF–F</td>
<td>7.10%</td>
<td>2.80%</td>
<td>3.60%</td>
</tr>
<tr>
<td>NF–NF</td>
<td>51.50%</td>
<td>54.20%</td>
<td>55.10%</td>
</tr>
</tbody>
</table>

Source: Mertens and Lambin (2000).

### Table 2


<table>
<thead>
<tr>
<th>Category</th>
<th>Change trajectory</th>
<th>Description</th>
<th>Area (ha)</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Forest</td>
<td>Forest</td>
<td>Stable primary or secondary forest</td>
<td>45,290.35</td>
</tr>
<tr>
<td>2</td>
<td>Forest</td>
<td>Non-forest</td>
<td>Old and permanent forest clearing</td>
<td>8807.67</td>
</tr>
<tr>
<td>3</td>
<td>Forest</td>
<td>Non-forest</td>
<td>Old forest clearing with regrowth</td>
<td>2936.97</td>
</tr>
<tr>
<td>4</td>
<td>Forest</td>
<td>Non-forest</td>
<td>Recent forest clearing</td>
<td>32,415.00</td>
</tr>
<tr>
<td>5</td>
<td>Non-forest</td>
<td>Non-forest</td>
<td>Stable permanent agriculture</td>
<td>111,817.04</td>
</tr>
<tr>
<td>6</td>
<td>Non-forest</td>
<td>Non-forest</td>
<td>Forest regrowth with new clearing</td>
<td>11,122.29</td>
</tr>
<tr>
<td>7</td>
<td>Non-forest</td>
<td>Forest</td>
<td>Old and permanent forest regrowth</td>
<td>4799.25</td>
</tr>
<tr>
<td>8</td>
<td>Non-forest</td>
<td>Non-forest</td>
<td>Recent forest regrowth</td>
<td>3157.74</td>
</tr>
</tbody>
</table>

Source: Mertens and Lambin (2000).
Cambodia was underway as this paper was written in 2008 but no data are available. According to the 1998 census, the 350 gazetted villages of the entire Angkor basin consisted of 58,470 households and 323,417 total people. The 39 villages in the F–NF 1995–2008 deforested zone had 32,778 people in 607 households.

**Field observations and interviews**

The landscape of the 1995–2005 F–NF area was almost completely deforested and dominated by scrub, short grass, and burned tree trunks. There was no evidence of cultivated agriculture (Fig. 6a). At least 12 active charcoal-producing households were observed along the ~20 km main north-south road to the northwest of the Angkor complex (Fig. 6b). The informants stated that charcoal production had been an important source of household income “for a very long time” and that “there was a big forest here at the beginning of making charcoal.” They could not say exactly which year charcoal production started. The informants also stated that the buyer’s truck comes along about once a week, buys the bags of charcoal, and takes them to Siem Reap for fuel for cooking in the hotels and restaurants. While this is a small sample size of informants and non-rigorous approach, the complete and obvious conversion of the landscape dotted with abandoned charcoal kilns visible to the horizon suggests that the informants’ statements honestly indicate the cause of F–NF conversion from 1995 to 2005 in this area. The nature of the change, although not necessarily the duration of charcoal production, is so obvious to observers that this approach needs little elaboration.

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Fig. 5. Standardized NDVI change detection within the upper part of the Angkor basin (elevation > 9 m). One standard deviation away from the mean was calculated for each time period and then increases or decreases in NDVI of greater than/less than one standard deviation are plotted for 1995 minus 1989, 2005 minus 1995, and 2005 minus 1989.

Cambodia was underway as this paper was written in 2008 but no data are available. According to the 1998 census, the 350 gazetted villages of the entire Angkor basin consisted of 58,470 households and 323,417 total people. The 39 villages in the F–NF 1995–2008 deforested zone had 32,778 people in 607 households.

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Discussion

The use of two different remote sensing methods, post-classification trajectory analysis and analysis of changes of a continuous-field vegetation index, indicates that the greatest loss in forest cover in the Angkor basin over the past 20 years occurred between 1995 and 2005. While a large percent of the upper basin remained in the same land cover across all image dates as either non-forest or forested lands (\(\sim 70\%\)), the dominant change in the upper basin was the decline in forest cover. The majority of forest loss occurred between the Angkor Wat complex and Phnom Kulen National Park.

These changes may have resulted from multiple drivers including logging (legal and illegal), charcoal production and permanent clearing for agriculture. Of these, charcoal production (Fig. 6) is most important in the western half of the F–F–N areas of Fig. 4. Several traditional Khmer dishes, popular among tourists, are cooked on a charcoal hot pot and all grilled meats are cooked with charcoal. In other parts of the world, charcoal production has been shown to drive deforestation including several cases in Africa, especially near urban areas (Hofstad, 1997; Lusambo, Monela, & Katani, 2007; Sussman, Green, & Sussman, 1994; others) and also in Ecuador where deforestation results from charcoal production for use in restaurants (Wunder, 1996).

The rise in tourism in Siem Reap has been spectacular. In 1993, 34,000 people landed at the international airport near the Angkor complex, rising to 1.12 million in 2007 (Cambodian Ministry of Tourism, Tourist Statistical Report, http://www.mot.gov.kh/). The vast majority of these landings were tourists. Additional tourists arrive in Siem Reap by land and some by boat trips up the Tonle Sap River. Thus, the nearly 40-fold rise in tourism since 1993 created increasing demand for charcoal that has been met by production in the nearest wood source, as would have been predicted by Hofstad (1997).

Much of the eastern half of the change area was converted to permanent agriculture by smallholders. Our observations in 2006 and 2007 show that nearly all the land is used for smallholder agriculture. Informal interviews of people we encountered in February of 2007 indicated that many of the families had been given land in the late 1990s and helped by the

![Fig. 6. (A) Typical landscape of the major F–NF 1995–2005 region north of the Angkor Complex and south–southwest of Phnom Kulen, the far southwest corner of which can be seen in the background. No cultivated agriculture was observed in this area, and abandoned charcoal kilns (e.g. the small, light-colored pile of soil just to the right center of the photo and just below the house roof) were evident everywhere. (B) Charcoal-producer household along main north–south road between Phnom Kulen and the Angkor complex. Seventeen bags of charcoal, each weighing about 50 kg, are seen in the photograph. The two light-colored mounds with holes are charcoal production kilns. Photos taken 1 March 2007 by MWB.](http://www.mot.gov.kh/)
government with clearing and planting their first crops. We have no other corroborating evidence or more details of this settlement and forest clearance.

Most forest loss in the upper part of the Angkor basin happened since the 1992 declaration of the Angkor complex as a UNESCO World Heritage Site. Re-establishment of protected area boundaries is relatively recent in Cambodia (1993) and is closely tied to population distribution, movement, and direction of growth. Most parks in Cambodia were created in more remote regions with low human population density; the Siem Reap Province parks are notable exceptions.

There were some areas of increased forest cover in the upper basin. The increase in forest is mostly concentrated along the eastern boundary of the main Angkor complex (Fig. 4). The increase may be a result of conservation measures to increase tourist value of the ancient ruins although NDVI increase within the Western Barai is attributed to seasonal monsoon patterns. In addition, there was no large scale clearing evident inside Phnom Kulen's borders although pockets of scattered regrowth and deforestation are apparent across the time period. These alternating trajectories of forest and non-forest are from smallholder shifting cultivation, which is common in upland regions in Southeast Asia (Fox & Vogler, 2005). Indigenous communities still live within the borders of Phnom Kulen and our observations from 2005 to 2007 indicate that these pockets of rotational forest/non-forest land units are mostly due to the shifting cultivation practices. Phnom Kulen is an IUCN II protected area, meaning the ecological integrity of the park should be sustained and needs of local, indigenous communities should be taken into consideration for management decisions, so further study would be useful to define the relationships of the protected area with the communities inside and outside its boundaries.

The Angkor basin continues to experience significant landscape changes as international interest and tourism money flows into the region to support, develop, and exploit the Angkor World Heritage Site. We observed extensive construction on lands previously used for paddy cultivation near the Angkor complex. A little farther into the uplands where our change trajectory indicates a high degree of forest clearing both charcoal production and permanent conversion to agriculture dominated during the period from 1995 to 2007.

The dynamics of the Angkor basin's landscape are better understood by determining the trajectories of land-cover change over space and time. Classification methods highlight predominant changes in forest cover in the Angkor basin. Although using such a method results in some level of generalization, it provides important information on spatial trends in a landscape that then are verified with other methods, such as NDVI. The standardized NDVI analysis reinforces the change of land-cover classes over time using image differencing to describe biophysical vegetation changes. This combination of techniques was more powerful for detecting and describing the patterns of land-cover change. The use of classification combined with other types of analyses, such as vegetation indices, has been emphasized in other land-use/land-cover change literature as important to fully capture the dynamic processes on the landscape (Hartter, Lucas, Gaughan, & Aranda, 2008; Southworth et al., 2004). The combination of methods in our analysis emphasizes the decrease in forests in the upper part of the Angkor basin.

Despite the uncertainty, national policies have made international markets more accessible and, in turn, accelerated development within Cambodia, especially Siem Reap Province. Large decreases in forest cover have occurred in the basin and despite the quick income generated from forest clearing, the actions may dramatically alter the landscape patterns and processes in the basin. If loss of forest cover becomes permanent there may be significant and negative ramifications for hydrological functions in the basin. The Cambodian government, through the responsible APSARA authority, the International Coordinating Commission for the World Heritage Site, and scholars have expressed concern about the declining water table, reduced stream flow, and reduced availability of water that might have been caused by upland deforestation (ICC, 2007, Lemaistre & Cavalier, 2002). This altered hydrological system may affect water availability for tourism, the preservation of the Angkor complex, and overall sustainability of the enterprises in Siem Reap province.

At a larger scale, climate change and alterations in the Mekong River flows by upstream dams may influence LUCC in this area in the future. A time-series of annual precipitation shows no significant changes or trends over the period of 1980–2004 (Gaughan, 2006), and suggests that climate change over this short time is negligible. Likewise, the recent dams built on the Mekong River and its tributaries may have influenced flow regime. The only changes described in the literature are sparse evidence of a reduction in maximum discharge in the 1990s and dry season water level fluctuation have become larger and more frequent (Li & He, 2008; Lu & Siew, 2006). Lu and Siew (2006) also report a decrease in suspended sediment load at upstream stations. This paper is concerned with the upland area of the Angkor basin outside of the floodplain forest that is affected by Mekong flow, and while these changes could indirectly affect land in the uplands by altering the behavior of people dependent on Tonle Sap Lake, we believe that there are no data for inferring a relationship between large-river management practices and LUCC in the Angkor basin.

This research set out to describe land-cover change in the Angkor basin from 1989 to 2005 by determining the spatial and temporal land-cover dynamics of the basin and by examining possible drivers of change. The use of remote sensing and GIS allowed for analysis across the landscape, using both continuous and discrete approaches to the analysis, which combined provides a clearer picture of the changes to the landscape. While much of the basin area remained in stable non-forest cover, tied to permanent agriculture, the dominant process of change in upland areas was one of deforestation. Different drivers were found for these changes based on location in the basin, with charcoal production dominating the western portions of the landscape and clearing for agriculture and development in the eastern sections. Overall, there was little reforestation occurring with the most increase from 1989 to 1995, while deforestation rates increased significantly during the latter half of the study (1995 to 2005). These changes identified through remote sensing may be useful in policy and development strategies that seek to balance sustainable local livelihoods with the benefits and growth of tourism in Cambodia (Gatrell &
Jensen, 2002). The interplay among global (tourism, climate), regional (national policies, large-river management), and local (construction and agriculture, energy and water sources to support the tourism industry) factors drives a distinctive but complex pattern of land-use and land-cover change in this region.

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References


