LAND USE AND LANDSCAPE DYNAMICS IN NORTHERN THAILAND:

ASSESSING CHANGE IN THREE UPLAND WATERSHEDS SINCE 1954

by

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Abstract

The forests of Southeast Asia contain biologically diverse communities of vegetation and wildlife. These lands also support millions of tribal people who produce food and fiber for local and regional consumption. Today, traditional uses of forestland are being transformed by national market forces and changing national policies of landownership and land use. While tropical forest loss is recognized as a regional and global problem, little is known about the link between resource use at the local level and its effects on forest fragmentation and loss at the landscape scale. This study analyzed human-induced loss and fragmentation of tropical forests in three upland watersheds in northern Thailand between 1954 and 1992. During this 38-year period, forest cover declined, agricultural cover increased, population and population density grew, and agriculture changed from subsistence to cash crops. These changes resulted in forest fragmentation and loss, with implications for biological and cultural diversity, sustainable resource use, and the economic conditions of the region. By linking the outcome of individual land use decisions and measures of landscape fragmentation and change, we illustrate the hierarchy of temporal and spatial events that, in summation, result in global biome changes.

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Introduction

Humans have converted natural land-cover patterns in many areas of the world into mosaics of natural vegetation within matrices of human-dominated land uses (Curtis 1956; Krummel et al. 1987; Dunn et al. 1993; Green and Sussman 1990). Fragmentation of natural land-cover patterns affects plant and animal population dynamics, biodiversity, the movement of materials (e.g., soil and nutrients) and water in upland catchments, evapotranspiration rates, and primary productivity. These changes can limit the ability of a landscape to provide natural resources on a sustained basis and can result in long-term degradation of environmental quality (Pimentel and Krummel 1987).

With population growth and economic development in tropical regions, forest fragmentation and loss are becoming critical environmental problems with possible implications on a global scale (Turner, Moss, and Skole 1993). While tropical forest loss is recognized as a regional and global problem, little is known about the link between resource use at the local level and its effects on forest fragmentation and loss at the landscape scale (Turner and Meyer 1991; Blaikie and Brookfield 1987;

Tucker and Richards 1983). Indeed, most analyses of landscape change have addressed temperate regions of the globe (O'Neill et al. 1988; Turner et al. 1990; Zonneveld and Forman 1989). Because harvesting of tropical forests often originates in local communities, quantifying the interaction between village resource-use patterns and tropical forest landscapes may be useful for determining the dynamics and patterns of tropical forest loss and fragmentation. Knowledge of these patterns may also be useful for answering questions related to the long-term sustainability of human-forest interactions and for developing management policies that protect and enhance tropical forests.

Recent studies in northern Thailand (Yarnasarn 1990; Fox et al. 1994) present an opportunity to quantify tropical forest fragmentation and loss at the landscape scale. With results from these studies and the spatial data collected for this study, forest fragmentation patterns were mapped in three upland watersheds between 1954 and 1992. Villagers cleared forests in these watersheds to provide land for swidden (shifting) cultivation, rice paddies, traditional Thai tea (*miang*), and, more recently, fruit and vegetable cash crops. This study analyzed human-induced changes in landscape patterns through time and sought to quantify changes in land cover, forest fragmentation rates, and forest loss. By meeting these objectives, the study begins to address issues concerning the long-term sustainability of agriculture-forest interactions.

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Study Landscape

The study area (approximately 10,000 ha), located northwest of Chiang Mai, Thailand, is a mountainous landscape with elevations ranging from 750 to 1,850 m above sea level . The site has a monsoonal climate, with a rainy season beginning in May or June and lasting until October or November. Almost no rain falls during the cold season in December and January, or in the hot season beginning in mid-February and lasting until the rains start in May or June. Mean average rainfall is approximately 3,000 mm/year.1 Temperatures remain stable between 26 and 34 $^{\circ}$ C, with higher elevations several degrees cooler than lower elevations.

The natural vegetation community is two-storied lower montane forest. The upper story is composed of oaks (*Quercus* sp.), false chestnuts (*Lithocarpus* sp., *Castanopsis* sp.), laurels (*Cinnamomum* sp., *Neolitsea* sp.), birch (*Betula alnoides*), and others. The lower story is composed of laurels (*Lindera* sp., *Phoebe* sp., *Litsea* sp., *Machilus* sp.) and others. Epiphytes are abundant and include mosses, liverworts, and lichens; there are numerous epiphytic ferns and orchids. There are also a number of epiphytic shrubs (Smitinand, Sabhasri, and Kunstadter 1978; Collins, Sayer, and Whitmore 1991).

The three study villages are on land managed by the Thai Royal Forest Department. Ban Khun Sa Nai (Khun) is located in the Mae Nam Pai watershed at an altitude of 1,200 m. The village was settled approximately 30 years ago by people of the Hmong ethnic group. The traditional swidden system of Hmong and other opium-growing hill tribes includes long cultivation and very long fallow swidden or abandonment (Kunstadter, Chapman, and Sabhasri 1978, 7). Ban Pang Khum (Pang) is located in the Nam Mae Khan watershed at an altitude of 1,250 m. This 200-year-old village was originally settled by members of the Karen ethnic group. Approximately 15 years ago, people of the Lisu tribe migrated into the village. Unable to compete successfully with the more established Karen villagers, Lisu villagers began out-migrating in the early 1990s. The Karen and Lisu often practice short cultivation and long fallow, or "forest fallow" swidden (Kunstadter, Chapman, and Sabhasri 1978, 7). Ban Kiu Thuai (Kiu) is located in the Nam Mae Rim watershed at an altitude of 1,100 m. Until about 20 years ago, the village was a campsite for northern Thais who came to pick tea leaves during the rainy season. Northern Thais often practice short cultivation and short fallow swidden and permanent field tree crops, associated with the use of forest for swidden rice and fuel (Kunstadter, Chapman, and Sabhasri 1978, 7).

The swidden cultivation-also called slash- and-burn or shifting cultivation-practiced by households in all three villages involves cutting living vegetation in the dry season, letting it dry, burning it late in the dry season, and then planting a crop in the ashes early in the wet season. Declining crop productivity, due to weed competition or soil nutrient depletion, leads to the field being abandoned after 1-2 years. Abandonment results in the establishment of permanent vegetation cover and after a period of 10-15 years, the development of secondary, closed-canopy forest. As long as population density remains low and abandoned fields recover as forest succession proceeds, most swidden cultivators live in the forest on a sustainable (i.e., long-term) basis (Pelzer 1978, 271).

From an ecological perspective, swiddening can be viewed as a perturbation to a forested landscape that results in the formation of cleared patches, patches undergoing natural plant succession, and mature forest. The extent or severity of the perturbation is a function of the rate of patch formation, the size and shape complexity of the patches, the length of fallow or successional period for each patch, and the size and shape complexity of the mature forest. A key component of swidden systems-unlike the conversion of a forested landscape into a permanent agricultural landscape (Krummel et al. 1987; Dunn et al. 1993)-is the potential for recovery and the reliance upon the forested landscape to promote the recovery process. Thus, forest succession, biodiversity, and patterns of patch formation (the swiddens) are critical determinants in achieving sustainability.

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Database Development

The spatial database consisted of land-cover maps derived from aerial photographs, field surveys, and satellite images. Aerial photographs were available for the study area for 1954 (1:50,000), 1976 (1:15,000), and 1983 (1:15,000). Interpretation of these photographs produced land-cover maps classified in terms of closed-canopy forests, sparse forests, swiddens, fallow swiddens, fruit orchards, tea gardens, forest plantations, villages, grasslands, and paddy fields.2

In 1987, 1991, and 1992, researchers surveyed and sketched permanent and swidden agricultural fields on 1:50,000 topographic maps enlarged to a scale of 1:10,000. In addition to mapping agricultural fields, the researchers collected data on crop type and cropping system for each field. Data were analyzed to determine the proportion of agricultural activity classified as permanent (i.e., paddy rice or continuous crop land), subsistence swidden crops, and cash crops grown in swidden fields. Because forest mapping was not conducted, amounts and patterns of fallow swidden fields and forests were not calculated from these data.

The project acquired a Landsat thematic mapper scene and a SPOT scene of the study area for January 1989. Combined processing of these images resulted in the classification and delineation of various land covers. While the field-mapping activities provided training fields to assist in the classification, ground truthing was not conducted to determine the accuracy of the classification.

The land-cover classifications derived from the aerial photographs and the field surveys were digitized and placed into a geographic information system (GIS) database (ARC/INFO). The Landsat/SPOT classification, and a digital elevation model derived from a digitized 1:50,000 topographic map of the study region, were also included in the GIS database. The GIS provided a method to link raster and vector data collected at different spatial scales and times and mapped at different projections.

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Results

Changes in Population Density

Population growth in northern Thailand is due to both natural increase and migration from other parts of Thailand. Kunstadter (1990, 183) reports that while the overall birthrate in northern Thailand is now below 2 percent, birthrate and rates of natural increase remain high among the highland minority groups (3-3.5 percent among the Lua and Karen in the middle elevations, and even higher among higher elevation groups such as the Hmong).

In 1992 the population of the study area (three study villages and three other villages nearby) was 1,793 (Sam Mun Highland Development Project, unpublished data, 1992); in 1986/87, it was 1,683 (Yarnasarn 1990; Department of Public Welfare 1986). Oral histories collected in the villages, as well as the aerial photographs, indicate that the Hmong and the Lisu did not arrive until after 1954 and 1976, respectively. Using this information and an assumed annual population growth rate (in this case 3 percent), the population and population density can be estimated. Total population is estimated to have been 375, 960, and 1,492 in 1954, 1976, and 1983, respectively. Population density on land other than closed-canopy forest (i.e., paddy, swidden, fallow swidden, and sparse forest) is estimated to have been 0.26, 0.30, and 0.45 persons/ha in 1954, 1976, and 1983, respectively. In 1987 and 1992 population density on agricultural lands is recorded as having been 0.51 and 0.52 persons/ha, respectively. These figures indicate that population density doubled between 1954 and 1992.

Population densities in other swidden agriculture villages in northern Thailand in the late 1960s ranged from 0.33 (Kunstadter 1978, 78) to 0.44 (Keen 1978, 226) persons/ha. These values indicate that population density in the study area is approximately the same as that reported in similar villages. Dove (1982) calculated the territorial needs of swidden cultivators in West Kalimantan, Indonesia, to be approximately 640 ha per 100 people, or 0.16 persons/ha. By this measure, which may not be appropriate given differences in the physical environments, the population density of the study area exceeded the recommended rate in 1954 and was approximately three times that level in 1992.

Changes in Land Cover

Forest Cover. Summary statistics of changing land-cover conditions in this upland tropical-forest landscape appear in Table 1. Closed-canopy forest cover declined from 76 percent of the landscape in 1954 to 57 percent in 1976, and to 56 percent in 1983. The combined SPOT and Landsat thematic mapper classification provided information on land-cover conditions over 80 percent of the study landscape and was used to estimate forest conditions in 1989. Based on this classification, closed-canopy forest covered approximately 55 percent of the landscape.

Table 1: Northern Thailand study landscape summary statistics

	Year	*Number of patches*	*Total edge ($m \times 10^4$)*	*Mean patch size (h.a.)*	*Total area (ha)*	*% of area*
Forest:						

Dense forest	1954[a]	33	49	219	7210	76
	1976	64	60	85	5446	57
	1983	64	65	84	5345	56
	1989[b]	-	-	-	-	55
Sparse forest	1954	197	21	10	1029	11
	1976	135	32	13	1710	18
	1983	166	30	8	1324	14
Plantation	1954	0	0	0	0	0
	1976	4	2	27	109	1
	1983	22	4	13	274	3
Grassland	1954	65	11	11	738	8
	1976	69	11	8	557	6
	1983	55	8	8	444	5
Agriculture						
Paddy	1954	44	3	2	101	1
	1976	131	6	1	173	2
	1983	167	8	1	209	2
	1992[c]	130	6	1	150	2
Swidden						
(Including opium)	1954	82	4	2	128	1
	1976	256	13	2	393	4
	1983	350	17	1	498	5
	1987	342	-	1	388	4
	1992	88	3	1	60	1
Fallow	1954	86	5	2	186	2
	1976	359	25	3	971	10
	1983	435	33	3	1267	13
Tea garden	1954	11	2	11	124	1
	1976	18	4	11	200	2
	1983	18	4	11	198	2
	1992	26	3	7	182	2
Cash crop	1987	0	0	0	0	0
	1992	151	8	1	183	2

[a]Data for 1954, 1976, and 1983 compiled from arial photographs

[b]Data for 1989 compiled from an integrated Landsat/SPOT Image

[c]data for 1987 and 1992 compiled from field survey mapping

Thus, the period 1954-76 resulted in an annual rate of closed-canopy forest loss of 1.3 percent, and the period 1976-89 showed a loss rate of 0.27 percent per year. The rate of closed-canopy forest loss for the total 1954-89 period was approximately 0.9 percent per year. These figures indicate that sometime prior to 1976, the rate of deforestation slowed considerably, and that since 1976 the rates of forest removal and forest recovery have been relatively balanced.

Following closed-canopy forest cover through time was particularly interesting. In 1983 approximately 56 percent of the study area was covered with this forest classification. Of this, approximately 59 percent (33 percent of the study area) had been consistently mapped as closed-canopy forest in 1954 and 1976. While it is possible that during the 1954-76 period some forest was disturbed and reestablished, we can place an upper bound of 33 percent of the total study area as closed-canopy forest dating from before 1954 .

In terms of northern Thailand, between 1961 and 1985 forest cover declined from 68.5 percent to 49.6 percent, an annual loss of approximately 1.3 percent forest cover (Hirsch 1990, 168). Thus total deforestation, as well as the annual rate of deforestation, in the study area was approximately the same as for northern Thailand as a region during the period 1954-76, but has been less than that found regionally since 1976.

Agricultural Cover. Table 1 shows that agricultural cover (paddy, swidden, fallow, and tea) increased from 5 percent of the landscape in 1954 to 18 percent in 1976, and to 22 percent in 1983. During this period sparse forest, which may represent the effects of swidden agriculture, varied from 11 percent of the landscape in 1954 to 18 percent in 1976, and to 14 percent in 1983. From 1976 to 1983, sparse forests decreased in proportion to the increase in agricultural land.

The field survey and mapping of current agricultural crops conducted in 1987, 1991, and 1992 revealed a shift from subsistence crops to cash crops for regional and national markets (except for tea and opium, which were always produced for export). Table 1 shows that whereas in 1987, 388 ha of land were devoted to subsistence swidden crops and none to cash crops (villagers were growing some cabbages, but the amount was too small to measure), by 1992 newly introduced exotic crops such as peach, apricot, pear, and coffee and commercial crops such as cabbage, carrots, taro, and red kidney beans had grown to 182 ha, and subsistence swidden had dropped to 60 ha. Likewise, whereas opium poppies were grown on approximately 140 ha of land in 1987 (at least during some part of the year), by 1992 this had dropped to 3 ha.

Grasslands. An interesting feature of this landscape is the presence of grasslands, which are not actively managed by villagers and which oral histories do not record having ever been managed (Table 1). Grasslands existed in 1954 and were still present in the 1989 Landsat/SPOT image. An analysis of grasslands and topographic conditions showed no significant correlation with aspect or elevation. Smitinand, Sabhasri, and Kunstadter (1978, 38) suggest the effect of shifting cultivation on the promotion or suppression of grasslands as secondary climax vegetation depends on details of the cultivation methods, especially the length of cultivation. One system, long cultivation-very long fallow type (Hmong system)-promotes development of grasslands, whereas short cultivation-relatively long fallow (Karen system)-appears to suppress development of grasslands. A short cultivation period appears to allow the repeated development of forest or bush as secondary successions. This suggests that at some point in history, these grasslands were managed in a long cultivation system.

Transition Matrices. Transition matrices showing changes in land cover through time can be developed by overlaying grid-cell data for a given period with grid-cell data for each other period available (Horn 1981; Turner 1987). A grid program within the GIS was used to transform the classified polygonal data for the years 1954, 1976, and 1983 into a set of grid cells, each measuring 30 m by 30 m. These data were used to calculate transition matrices for the periods 1954-76 and 1976-83 (Table 2).

The results show both a continuing loss of tropical forest to crop production and a recovery of forest cover from previously disturbed lands. During the period 1954-76, 40 percent of the closed-canopy forest cover that existed in 1954 was lost. Closed-canopy forest was converted primarily to sparse forest (16 percent) or fallow swidden (11 percent), with lesser amounts in active swidden (4 percent) and grassland (5 percent). On the other hand, 62 percent of the sparse forest and 64 percent of the fallow land in 1954 were classified as closed-canopy forest in 1976. In addition, 24 percent of the grasslands that existed in 1954 were classified as closed-canopy forest in 1976.

While the majority (55 percent) of swidden in 1954 returned to closed-canopy tropical forest, 28 percent of these lands remained as fallow or active swidden in 1976. Approximately 22 percent of the fallow land in 1954 was classified as fallow or active in 1976. This indicates that many cleared and burned fields are maintained for crop production or under short fallow periods with little time to return to forest cover.

Paddy rice and "other" (tea fields and village settlements) are permanent features that remained relatively constant through the 1954-83 period. These land uses represent substantial labor and capital inputs for village households.

The transition matrix for the 1976-83 (Table 2.) period reveals a trend in the loss and recovery of tropical forest similar to that seen in the 1954-76 period. Closed-canopy forest continues to be converted to swidden fields, while regrowth of forest comes from sparse forest, fallow field, and grassland. In addition, forest plantations started by the Thai Royal Forest Department contribute to reforestation in this landscape.

Table 2: Transition matrices of land cover classess in northern Thailand study landscape

	Dense forest	***Sparse forest***	***Fallow swidden***	***Active Swidden***	***Paddy***	***Forest plantation***	***Grassland***	***others***
1954-1976	1976							
1954								
Dense forest	0.60	0.16	0.11	0.04	0.01	0.01	0.05	0.02
Sparse forest	0.62	0.20	0.07	0.07	0.01	0.00	0.03	0.00
Fallow swidden	0.64	0.11	0.16	0.06	0.01	0.00	0.00	0.02
Active swidden	0.55	0.09	0.13	0.15	0.04	0.00	0.01	0.03
Paddy	0.19	0.03	0.09	0.00	0.64	0.00	0.01	0.04
Forest plantation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Grassland	0.24	0.37	0.08	0.01	0.00	0.03	0.26	0.01
Others	0.19	0.04	0.01	0.00	0.01	0.00	0.01	0.74
1976-1983	1983							
1976								
Dense forest	0.72	0.07	0.12	0.05	0.01	0.01	0.01	0.01
Sparse forest	0.42	0.31	0.10	0.05	0.01	0.03	0.08	0.00
Fallow swidden	0.38	0.19	0.28	0.06	0.02	0.04	0.03	0.00
Active swidden	0.29	0.23	0.28	0.09	0.01	0.03	0.07	0.00
Paddy	0.23	0.03	0.05	0.02	0.64	0.00	0.01	0.02
Forest plantation	0.19	0.08	0.01	0.01	0.00	0.60	0.10	0.01
Grassland	0.22	0.18	0.09	0.05	0.00	0.15	0.31	0.00
Others	0.24	0.02	0.03	0.01	0.03	0.00	0.00	0.67

The transition matrices clearly demonstrate the dynamic character of swidden landscapes. With few exceptions, such as village and paddy, land use on any particular piece of land is not stable but constantly changes as swidden fields are moved throughout the landscape and as fallow swiddens return to forest cover.

Changes in Landscape Patterns

Patchiness. The total number of mapped landscape patches increased dramatically from 1954 to 1983 (Table 1). This was primarily a result of an increase in active and fallow swidden fields and the construction of permanent rice paddies. While the number of swidden, tea, and fruit orchard patches increased over time, the average size of each patch did not change significantly over the same time period (an exception to this trend is the average size of paddy fields, which decreased significantly between 1954 and 1983). Thus, it appears that at the scale of an individual farmer managing individual swidden fields, the dynamics of clearing and planting have not changed over time. Rather, as village populations have increased, the number of swidden fields have increased.

Forest clearing activities in support of swidden and permanent agriculture resulted in the fragmentation of large contiguous forest areas, as shown by the increasing amount of forest edge and the large increase in number and area of agricultural clearing activities (Table 1). Figure 2 shows the dramatic impact of human resource use on the shape complexity of the original closed-canopy forest cover, assuming that closed-canopy forest mapped in 1954, 1976, and 1983 at the same location remained undisturbed during the 1954-83 time period. In comparison with agricultural fields, however, forest patches were still large (98 percent of the forest patches were greater than the 1-ha average size of agricultural fields).

Fractals. To quantify the shape complexity of terrain and land-cover types in the study landscape, we used the fractal dimension as a measure of shape complexity. For lines, the fractal D value can vary between 1 and 2, where D = 1 implies that a line is so smooth it can be fully approximated by a polynomial, and in D = 2 the line is so "fuzzy" that it has, in fact, become an area (Lovejoy 1982). For surfaces, the D value ranges between 2 (completely smooth) and 3 (infinitely crumpled). By determining the shape complexity of land-cover types, inferences on the dynamics that produce shapes can be made. This is especially true if underlying forces that constrain land-cover shapes can also be measured (Krummel et al. 1987). For the study area, a major physical constraint to vegetation dynamics and land use is topography. To quantify the shape complexity of slope and elevation, we conducted an iterative fractal analysis of the three-dimensional digital elevation model. The measured fractal dimension of 2.31 is indicative of very irregular topographic conditions (Mandelbrot 1977).

Table 3: Fractal dimension of land cover classes in northern Thailand study landscape

	1954		***1976***		***1983***		***1991***
Dense forest	1.47	r^2=0.96	1.54	r^2=0.96	1.49	r^2=0.95	-
Sparse forest	1.39	r^2=0.91	1.38	r^2=0.93	1.34	r^2=0.90	-
Grassland	1.36	r^2=0.95	1.25	r^2=0.90	1.20	r^2=0.90	-
Tea garden	1.26	r^2=0.95	1.39	r^2=0.98	1.39	r^2=0.96	-
Paddy	1.25	r^2=0.96	1.23	r^2=0.95	1.24	r^2=0.96	1.25
Swidden	1.09	r^2=0.97	1.14	r^2=0.96	1.18	r^2=0.95	1.05
Fallow swidden	1.19	r^2=0.94	1.21	r^2=0.94	1.24	r^2=0.93	-
Terrain	2.31		2.31		2.31		-

Land cover fractals are a measure of the complexity of two dimensional lines. The terrain fractal is a measure of three-dimensional digital elevation model.

We used a perimeter area method to determine the average dimension of the ensemble patches of each cover type. An analysis of the fractal dimensions of land-cover classes for 1954, 1976, 1983, and 1991 reveals significant differences between patterns created by swidden agriculture and those created by paddy fields as well as by forest cover (Table 3). Closed-canopy forest cover has the highest fractal dimensions, ranging from 1.47 to 1.54. The construction of paddy fields for permanent rice production produces field shapes with the next-highest fractal dimensions, 1.23-1.25; paddies are constructed to allow natural flow of irrigation water and hence must adhere to the topographic dimensions of the landscape. Indeed, paddy fields represent a long-term, stable agricultural system that conforms to the physical features of the landscape.

Swidden agriculture causes the formation of small regular fields with a fractal dimension in the range of 1.1-1.2. Based on this topographic dimension, it is clear that the fractal dimensions of swidden fields do not match the natural physiographic features of this landscape. Swidden fields consist of simple shapes, rectangles and ovals, while topographic features are highly irregular. Indeed, swidden agriculture, like agriculture in the United States (Krummel et al. 1987), results in the production of simple shapes. These functions have little in common with the natural patterns that result from physical or biological processes operating under natural conditions.

Dominance and Contagion. Grid-cell data were used to calculate two indices of landscape pattern based on information theoretic measures. The dominance index, D1, measures how extensively one or a few land-cover types occur on the landscape (O'Neill et al. 1988). Large values of D1 indicate that the landscape is dominated by a few land-cover types, while smaller values indicate a more equal distribution of land-cover types. The contagion index, D2, measures the aggregation of land-cover classes (O'Neill et al. 1988). Higher values of D2 indicate the presence of large, contiguous patches of land cover, while smaller values indicate a landscape composed of many small patches.

The data show a decrease in the dominance index, D1, from 100 percent in 1954 to 65 percent in 1976, and to 60 percent in 1983. This decrease reflects the loss of forest cover and increasing agricultural activity in this landscape. The measure of contagion, D2, shows no change over the same time period. While it is evident that this landscape is becoming increasingly fragmented, this index is not sensitive to these changes. O'Neill et al. (1989) found that this index of contagion was not sensitive to changes in the dominance index and seems to be related to aggregation/disaggregation on a scale not captured in landscape-wide analyses.

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Discussion

Between 1954 and 1991, this upland, forested landscape has been increasingly transformed by the land-use practices of local people who have responded to local, regional, and national social and economic forces. During the period 1954-83, our data show a rapid expansion of traditional swidden agriculture to support local village needs, with few exports of commodities to the regional or national markets. As village populations increased and new immigrants moved to the area, the traditional clearing of closed-canopy forest to establish new crop lands resulted in a substantial net loss of closed-canopy forest cover. Under sustainable conditions, swidden systems should result in small yearly disturbances in total forest area with an equilibrium between closed-canopy forest loss and recovery. Our results show that during the period between 1954 and 1976, forest clearing was clearly not sustainable. Indeed, the situation could best be described as the opening of a frontier area with subsequent clearing and loss of tropical forest.

While the population continued to increase during the 1976-83 period, our analysis shows a slowing of the net loss of closed-canopy forest cover. However, demand for crop land did not decrease. Rather, swidden production began to rely more heavily on the use of sparse forest and fallow lands to support crop production. A number of events could have slowed the net loss of closed-canopy forest cover. This was a period when the Thai government, through the Narcotics Control Board of the Third Region Army, began to exert pressure to eradicate opium growing (Crooker 1988, 254; Shinawatra 1985, 42). In addition, the Thai Royal Forest Department, who claims title to this land, also initiated efforts to support reforestation and forest conservation. Finally, it appears that the most accessible or fertile lands had already been claimed in previous years and were being used more intensively (i.e., by a shorter fallow period).

When the village mapping exercise began in 1987, a few villagers were growing cabbages in fields along the dirt road, but otherwise agricultural land use remained dedicated to subsistence crops. In 1989 a new paved road was built with the support of the Thai Royal Forest Department, opening the village to markets in Chiang Mai and even as far away as Bangkok. Since then, cash crops have grown in volume to the point that they are now the dominant form of agricultural land use; opium poppies have almost completely disappeared. Shinawatra (1985, 171) notes that agricultural changes in the highlands of northern Thailand have taken place through increased interface between the highland and lowland economy in terms of the flows of ideas, information, and products. Highland farmers are moving toward wet rice farming and cash cropping, although elements of traditional farm systems persist.

Another major change since 1987 has been the out-migration of members of the Lisu community. As the most recent migrants to the area, the Lisu had access to the least amount of arable land. In addition, the rapid growth of the Thai economy, particularly in Chiang Mai, may have acted as a "pull factor" to encourage out-migration.

Finally, one factor that has not changed is land tenure. The study villages are on land claimed by the Thai Royal Forest Department. For historical reasons, land titles have been granted for only paddy and tea fields and not for fruits and vegetables or swidden crops. In addition, while there are a number of types of title available in Thailand, the frequency of each type was quite low in these villages. Thus the effect of land title on farmer decisions is not clear. Private title may have induced farmers to adopt better soil conservation practices. But in the absence of land title, farmers have clearly not been quick to adopt these practices.

While human use of this tropical forest landscape is driven by social and economic forces, these forces now drive the ecological dynamics of the landscape system. The continuing fragmentation of forest cover causes large increases in forest edge and irregular-shaped patches of forest. The increase in edge and the subsequent "edge effects" reduce the area of forest interior, with possible detrimental effects on species dependent on interior forest conditions. In addition, swidden agriculture compounds the effects of forest fragmentation by continually setting the forest succession "clock" back to zero. In essence, old-growth forest does not exist on this landscape. At maximum, only 33 percent of landscape is covered with closed-canopy forest dating from before 1954.

The pattern of topography and the different land-cover types, as measured by the fractal index, provided useful insights about how physical and human forces control landscape structure. Topographic complexity is a dominant physical parameter controlling ecosystem functions (e.g., water and soil movement, precipitation, and temperature) and biological diversity (e.g., aspect, exposure, and soil moisture availability) (Bormann et al. 1968). Our calculated topographic fractal dimension of 2.31 summarizes a landscape geometry of steep slopes and large elevation changes over relatively short distances.

With the topographic fractal as a baseline measure of landscape structure, forest cover, grasslands, and tea plantations, with the highest fractal measures, mirror the terrain structure. The structural shape of paddy fields also fits reasonably well with topographic conditions. However, swidden and fallow fields have low fractal measures that differ significantly from the shape complexity of the topographic conditions and other land-cover patterns. Of particular interest is that the shape complexity of the different land-cover types did not change over the period 1954-83.

We hypothesize that a combination of physical and human forces controls the shape complexity of landscape vegetation and that these forces do not change over time. Severe elevation and slope conditions provide a fundamental controlling force over forest cover and grassland. Elevation and slope place constraints on farmer accessibility and reduce the probability of forest removal. The highly irregular topographic conditions, in combination with swidden systems that also enhance shape complexity, result in a continued pattern of highly complex forest cover. The shape complexity of paddy rice is determined by water flow and storage and thus must mirror topographic complexity. Finally, the shape complexity of swidden fields is a function of labor forces (i.e., cost and efficiency to clear and burn new fields) and the minimization of edge effects (invasion by pests and weeds) that results in simple shapes.

If these hypotheses are true, we can then make some statements on sustainability, land cover, and landscape pattern. First, extreme slope and elevation conditions will continue to act as a barrier to forest clearing and serve, except under severe land use needs, to protect a portion of the forest cover. Second, paddy fields and tea gardens, which are both long-term productive agricultural systems in this landscape, have relatively complex shapes adapted to the topographic conditions. Third, the shape complexity of swidden fields appears to be invariant, even given increasing population density and the changing market conditions for cash crops. Swiddening is a system designed to be sustainable because of its distribution through time (short periods of disturbance and long fallow periods) rather than its distribution through space. Under low population pressure, swiddening is a sustainable agricultural system, but under increased population pressure and shorted fallow periods the system becomes unsustainable (Bandy et al. 1993). As the period of cultivation is shortened, the shape of the fields should evolve to reflect the landscape. Because the shape of swidden fields does not mirror the topographic conditions, continued soil loss, excessive water runoff, and land degradation could result from the development of a cash crop economy. If soil conservation practices (e.g., contour farming and terracing) are introduced, we would expect to see an increase over time in the shape complexity of agricultural fields.

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Conclusions

While tropical forests of Southeast Asia have been occupied and used to meet human needs for thousands of years, traditional forest management systems are currently being transformed by rapid and far-reaching political, economic, and environmental changes. The dynamics of population growth, migration into remaining frontiers, and responses to national and international market forces result in a demand for land that produces food and fiber even if only for a temporary period. Our results illustrate the mechanisms that cumulatively drive current land use changes, especially in the tropical forest frontiers of Southeast Asia. By linking the outcome of individual land use decisions and measures of landscape fragmentation and change, we begin to show the hierarchy of temporal and spatial events that in summation result in global changes to sensitive biome conditions.

This study developed a spatial information database to document changes in land cover and landscape patterns through a 38-year period. Our analysis showed that both rates and patterns of change are necessary indicators of the long-term condition of a tropical forest and the sustainability of the cropping system. In addition to quantifying changes in land cover and land-cover patterns, this study traced the connection between these changes and the forces that caused them. These included local and discrete events such as the building of an access road, as well as national forces such as forest protection policies, and international forces such as commodity prices. There is no one single driving force causing land use change, and the human response in terms of land use practice has many variables relating to culture, local economy, traditional land tenure systems, etc.

Perhaps the two most interesting findings of this study can be summarized as follows. First, sometime between 1954 and 1976 villagers stopped wholesale clearing of forestlands, and the amount of closed-canopy forest cover began to stabilize. While the total amount of closed-canopy forest has remained relatively constant since then, forest cover on any given piece of land has remained dynamic. Still, 33 percent of the landscape in 1983 was covered with closed-canopy secondary forest that was at least 35 years old.

Second, fractals were useful for assessing land-cover categories according to how well they fit the landscape (i.e., forest/grassland/tea fit closely; paddy fit well; and swidden/fallow fit poorly). Yet each of these categories showed little change through time despite landscape fragmentation. We hypothesize that different, fundamental forces affect the shape of each land-cover category: landscape-scale forces (slope and terrain) affect the shape of forest/grassland/tea patches; forces of terrain and water flow affect the shape of paddy; and labor forces (i.e., cost and efficiency) affect the shape of swidden/fallow fields. By quantifying the spatial and temporal patterns of tropical forest change, we have attempted to show how the landscape in these upland tropical forests is controlled by physical and biological, as well as social and economic, parameters. A time series of spatial data shows that the value of some of these parameters is changing over time with a resultant change in the tropical forest landscape. The consequences of these parameter changes can be debated, but not ignored. Our study, along with others that assist in quantifying landscape dynamics, should help lead to reasoned debate on human use of tropical forests.

Notes

1. Rainfall data were recorded at Doi Mon Ang Get in Amphoe Mae Taeng, Chang Wat Chiang Mai, by the Watershed Development Project Unit 3 between January 1977 and December 1982 at an elevation of 1,300 m above mean sea level. This site is near one of the study villages, Ban Kiu Thuai.

2. The same person manually interpreted all three sets of photographs. Dense forest cover implies that the canopy was dense but says nothing about the age of the forest cover. Study results show that dense forest may be as little as 7 years old (see Table 2).

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