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Impact of land use and land cover changes on ecosystem services in Menglun, Xishuangbanna, Southwest China

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Abstract Changing the landscape has serious environmental impacts affecting the ecosystem services, particularly in the tropics. In this paper, we report changes in ecosystem services in relation to land use and land cover over an 18-year period (1988–2006) in the Menglun Township, Xishuangbanna, Southwest China. We used Landsat TM/ETM and Quickbird data sets to estimate changes in ten land use and land cover categories, and generalized value coefficients to estimate changes in the ecosystem services provided by each land category. The results showed that over the 18-year period, the land use and land cover in the study area experienced significant changes. Rubber plantations increased from 12.10% of total land cover to 45.63%, while forested area and swidden field decreased from 48.73 and 13.14 to 27.57 and 0.46%, respectively. During this period, the estimated value of ecosystem services dropped by US $11.427 million (~27.73%). Further analysis showed that there were significant changes in ecological functions such as nutrient cycling, erosion control, climate regulation and water treatment as well as recreation; the obvious increase in the ecological function is provision of raw material (natural rubber). Our findings conclude that an abrupt shift in land use from ecologically important tropical forests and traditionally managed swidden fields to large-scale rubber plantations result in a great loss of ecosystem services in this area. Further, the study suggests that provision of alternative economic opportunities would help in maintaining ecosystem services and for an appropriate compensation mechanisms need to be established based on rigorous valuation.

Keywords Rubber expansion · Tropical forest · Remote sensing · Ecosystem services · Valuation · Biodiversity hotspot

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Introduction

Land use and land cover (LULC) are the main determinants of the structure, functions, and dynamics of most landscapes throughout the world (Wu and Hobbs 2002, Fu et al. 2001). These have primarily been studied when there occur severe environmental problems (Bürgi et al. 2004). As a consequence, changes in land use, particularly in ecologically important land use categories, may significantly affect ecosystem processes and services. Although consequences of LULC changes have been studied at a global level, yet the coarse-scale of these models does not capture important land use changes occurring at finer spatial resolutions such as patchy tropical deforestation, forest plantations, and logging. Finer scale models are, however, required to investigate the implications of land use change for ecosystem services at local and regional scales (DeFries and Bounoua 2004).

Economists are increasingly recognizing that environmental functions or 'ecosystem services' support and protect economic activity and thus have an economic value (Aylward and Barbier 1992). The economic valuation of ecosystem services is becoming an effective way to understand the multiple benefits provided by ecosystems (Guo et al, 2001). A few studies have tried to estimate the values of a variety of ecosystem services. Peters et al. (1989) presented an assessment of the economic value of a tropical Amazon rainforest in Brazil and proposed a strategy for sustainable use of rainforest in the region. Most notably, Costanza et al. (1997) attempted to estimate the global biosphere values of 17 ecosystem services provided by 16 dominant global biomes. Thereafter, Kreuter et al. (2001), Zhao et al. (2004), Wang et al. (2006) and Li et al. (2007) used the generalized coefficient to evaluate ecosystem services at regional level in their studies.

Worldover, the tropics, are witnessing some of the most intensive LULC changes (Bawa and Dayanandan, 1997). Tropical forests are the most biologically diverse and ecologically complex of terrestrial ecosystems, and are disappearing at alarming rates (Laurance 2007a). The Xishuangbanna prefecture in southwestern China, located in one of the biodiversity hotspots (Myers et al. 2000), is experiencing a dramatic change in LULC since 1950s, the forests in this area have now either been denuded or converted into rubber plantations or other tropical cash crops, or used for shifting cultivation (Zhang and Cao 1995). The change in the primary forest cover of the area has shifted the focus on the imbalance between conservation and development. These changes in the primary forests may have altered the ecosystem services resulting in severe impact on environment. It is thus essential to evaluate such ecosystems with a view to understand impact of changing land use patterns on the economic aspects of ecosystem services.

In the present study we propose to estimate the annual economic value of services provided by the ecosystems of Menglun, a township in Xishuangbanna, identified as one of the key sites for the Millennium Ecosystem Assessment Program (Millennium Ecosystem Assessment 2005). We used Geographical Information System (GIS) techniques to determine LULC changes within the study area. The objectives of the study include: (1) to examine the changes in ecosystem services in relation to LULC changes in the study areas during the period from 1988 to 2006; (2) to determine if generalized coefficients can be used to evaluate changes at local level; (3) to provide suggestions for future conservation and development strategies.

Materials and methods

The study area

Xishuangbanna, a Dai Autonomous Prefecture covering 19,200 km^2 in the southern part of Yunnan province borders on Myanmar to the southwest and with Laos to the south and southeast (Fig. 1). The Lancang River (the upper course of the Mekong) crosses the prefecture from north to south. The region is controlled by a typical tropical monsoon climate characterized by a distinct rainy season (May–October) with peak precipitation occurring in July–September, followed by a cool dry season (November–January) and a hot dry season (February–April) (Cao et al. 2003). Due to its transitional geographic location and climatic conditions, straddling the tropics and subtropics, Xishuangbanna is well known for its rich biodiversity and still maintains the most represented and the best conserved tracts of tropical rain forest in China (Zhu 1997). Although it covers only 0.2% of the land area of China, it supports nearly 16% of its higher plant species (Zhang and Cao 1995), and more than 23% of China's animal species. Presently, about 14% of the total land area in Xishuangbanna is protected in nature reserves. The local economy is based on cash crops such as tea, rubber, and fruits, as well as tourism, rubber production accounts for approximately 30% of the regional economy. We selected Menglun Township from the prefecture's 37 administrative areas for this case study.

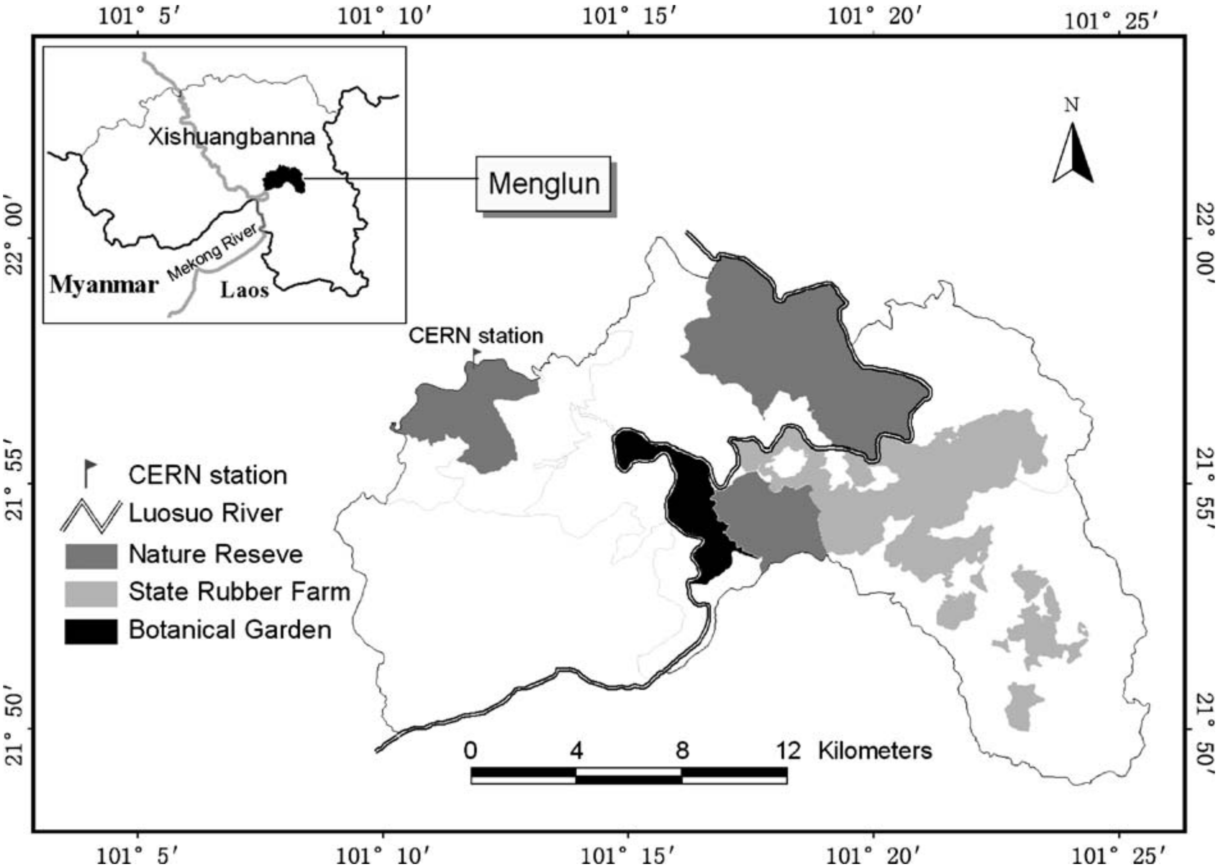

Fig. 1 Location of Menglun in Xishuangbanna, SW China

Menglun (101.15°E–101.43°E, 21.81°N–22.00°N) is a typical township representative of the environmental and socio-economic conditions of Xishuangbanna. It covers 334.88 km^2 with altitudes ranging from 540 to 1,400 m above mean sea level. The Luosuo River, a major tributary of the Mekong, winds from the north to the southwest of the township. Within the boundary of the township, there are six administrative villages, a state farm oriented to the production of rubber, a nature reserve (part of Xishuangbanna National Nature Reserve), and a botanical garden with a field station belonging to the Chinese Ecosystem Research Network (CERN).

There are more than ten ethnic groups in Menglun Township, including *Dai*, *Hani*, *Han*, *Yi*, *Ji'nuo*, *Lahu*, *Wa*, *Yao*, *Hui*, and *Bulang*. The *Dai* and the *Hani* are the dominant ethnic groups in this area accounting for 56.3 and 22.4% of the total population, respectively. Traditionally, the *Dai* people live in the lowland area near rivers, and paddy cultivation is their major agriculture activity; The *Hani* live in mountainous areas, and slash-and-burn farming was their major way of food production along with hunting before 1990. Between late 1950s and early 1980s state farms were established in this area for rubber production replacing large areas of tropical forests. Since 1982, the rural economic reform in China has resulted in re-allocation of land to individual households and the villagers have the freedom to use their land for more desirable economic activities. Consequently, orchards for tropical fruits, tea gardens, as well as rubber plantations began to expand rapidly. During the period from 1988 to 2006, the gross domestic product increased from US $3.11 million to US $11.20 million.

Estimation of LULC changes using satellite images

The spatial database was developed from: (1) The LULC maps derived from independent supervised classifications of a February 1988 Landsat TM (Thematic Mapper) image and a March 2003 Landsat ETM (Enhanced Thematic mapper) image (both with

30-m spatial resolution); the data for 2006 was delineated from two Quickbird images of April 2006 based on the results of 2003; (2) Records from field surveys. Geometric rectifications used a pre-rectified image to confirm all the TM/ETM images in the same coordinating system (with root mean square (RMS) error less than 1 pixel).

To enable post-classification analysis of the images, LULC maps of the three periods used the same classification system (including ten classes of LULC type). The classification system is based on the technical guide to land use status survey devised by the Agricultural Division Committee of China (China Agricultural Division Committee 1984). The classification accuracies exceed 80% according to several sources of reference: our analyses of ground-truthed GPS points; a 2002 Ikonos image covering the western part of the study area; the land use map of the 1990s, and Quickbird images of 2006 covering the entire area. These data showed that the classified images generally agree with actual LULC. The ten LULC categories were:

(1) paddy field;
(2) orchards, including plantations of fruit trees, tea, vanilla, other cash crops;
(3) rubber plantations;
(4) special land uses including arboretum, nursery, experimental fields;
(5) swidden fields referred to 'slash and burn field' or shifting cultivation land, including land cultivated and fallowed within 1 or 2 years;
(6) shrub land (with woody bushes greater than 20% and tree cover less than 20%);
(7) logging area, referring to land patches newly cleared for other purposes;
(8) rivers;
(9) forested area including nature reserves, primary and secondary forests;
(10) settlement and road including urban and rural settlements with buildings, national highways and expressways.

Assignment of ecosystem service value

To obtain ecosystem service values for various ground cover types, the ten LULC categories used to classify satellite images were compared with the 16 biomes identified by Costanza et al. (1997) in their ecosystem service valuation model, similar approaches were applied by a number of researchers (Kreuter et al. 2001, Zhao et al. 2004, Wang et al. 2006, Li et al. 2007). The most representative biome was used as a proxy for each LULC category including: (1) cropland for paddy field and orchard, (2) forest for special land use (arboretum, nursery, experimental fields), (3) grass/rangelands for swidden field, shrub land and logging area, (4) lakes/river for rivers, (5) tropical forest for forested area, (6) urban for settlement and road, and (7) Service value of tropical forest for raw materials applied to rubber plantation, as shown in Table 1.

The total value of ecosystem service in the study area in 1988 and 2006 was obtained as follows:

$$\mathrm{ESV} = \sum (\mathrm{A}_k \times \mathrm{VC}_k) \tag{1}$$

where ESV is the estimated ecosystem service value, A_k is the area (ha) and VC_k the value coefficient (US \$ ha^{-1} yr^{-1}) for LULC category k. The change in ecosystem service value was estimated by calculating the differences between the estimated values for each LULC category in 1988 and 2006.

In addition to estimating LULC change effects on the total value of ecosystem services, we also estimated the impacts of such changes on 17 individual ecosystem functions within the study area. The values of services provided by individual ecosystem functions were calculated using the following equation:

$$\mathrm{ESV}_f = \sum \left(\mathrm{A}_k \times \mathrm{VC}_{fk}\right) \tag{2}$$

where ESV_f is the estimated ecosystem service value of function f, A_k is the area (ha) and VC_{fk} the value

Table 1 Costanza et al. (1997) biome equivalents for land categories, and corresponding ecosystem values

Land use and land cover categories	Equivalent biome	Ecosystem service coefficient (US \$ ha^{-1} yr^{-1})
Paddy field	Crop land	92
Orchard	Crop land	92
Special land use	Forest	969
Swidden field	Grass/rangelands	232
Shrub land	Grass/rangelands	232
Logging area	Grass/rangelands	232
River	Lakes/river	8,498
Forested area	Tropical forest	2,007
Settlement and road	Urban	0
Rubber plantation	[a]	315

[a] Service value of tropical forest for raw materials is applied to rubber plantation

coefficient of function f (US \$ ha^{-1} yr^{-1}) for LULC category k.

The biomes used as proxies for the LULC categories were not perfect matches. Specifically, rubber plantations differed from Costanza et al.'s biomes of forest or tropical forest. Because rubber plantations consists of rubber trees of regular age and size, they do not have the same vertical structure as natural forests and lack the spectrum of ecosystem services provided by forests (climate regulation, soil formation and water treatment). Similarly, swidden fields are not represented by any of the biomes in Costanza et al., although they are used to produce food through extensive farming and covered with trees and shrubs or grasses when lying fallow. Swidden fields therefore have the ecological functions of grassland/rangeland.

Due to these uncertainties, we conducted sensitivity analyses to determine the dependence of our estimates of changes in ecosystem service values on the applied coefficients. The ecosystem coefficients for the major types of LULC including rubber plantation, swidden field, shrubland were each adjusted by 50%. Even though the forested area category matches Costanza et al.'s definition here, we also adjusted its value coefficient by 50% in the sensitivity analysis. To test the robustness of our analysis, we substituted a rubber plantation value coefficient to the coefficients of forest.

In each analysis, the coefficient of sensitivity (CS) was calculated using the standard economic concept of elasticity, i.e. the percent change in the output for a given percentage in an output (Stigler 1987):

$$\mathrm{CS} = \frac{\left(\mathrm{ESV}_j - \mathrm{ESV}_i\right)/\mathrm{ESV}_i}{\left(\mathrm{VC}_j - \mathrm{VC}_i\right)/\mathrm{VC}_{ik}} \qquad (3)$$

where ESV is the estimated ecosystem service value, VC is the value coefficient, i and j represent the initial and adjusted values, respectively, and k represents the LULC category. All these values were calculated with the help of Microsoft Excel.

If the ratio of percent change in the estimated total ecosystem service value (ESV) and the percent change in the adjusted valuation coefficient (VC) is greater than one, then the estimated ecosystem value is elastic with respect to that coefficient, but if the ratio is less than one, then the estimated ecosystem value is considered to be inelastic. The greater the proportional change in the ecosystem service value relative to the proportional change in the valuation coefficient, the more critical is the use of an accurate ecosystem value coefficient.

Results

Land use and land cover changes

Land use and land cover in this area have changed dramatically (Fig. 2 and Table 2). The largest changes in area occurred in rubber plantations, forested area and swidden fields. Rubber plantations increased from 12.10% (4,051.39 ha) of total LULC in 1988 to 45.63% (15,280.67 ha) in 2006, while forested area decreased from 48.73% (16,318.26 ha) to 27.57% (9,233.62 ha) and swidden field from 13.14% (4,400.24 ha) to 0.46% (153.13 ha). These land use shifts indicate drastic decrease in the ecologically important tropical forest (by 21.16% of total land area) and swidden field (by 12.68% of total land area) and a concomitant increase in economic production due to rubber plantation (by 33.53% of total land area). The dominant type of land use shifted from naturally forested area in 1988 to man-made rubber plantation in 2006.

Estimation of changes in ecosystem service values

Using the estimated change in the size of each LULC category together with the ecosystem service value coefficient by Costanza et al. (1997), we found that drastic changes in these in Menglun Township resulting in a net decline of ecosystem services value of US \$11.427 million from US \$41.200 million in 1988 to US \$29.752 million in 2006 (Table 3). The major contribution to change in the total ecosystem service value is the loss of forested area.

The ecosystem service values for individual ecosystem services are presented in Table 4. Compared to the ESV of 1988, the total ecosystem service value decreased by 27.73% in this area during the 18-year period. Breaking down the total change, the most important components were nutrient cycling (−15.85%), raw material (+3.17%), erosion control (−4.52%) and climate regulation (−3.83%). Although the valuation coefficient for the ecosystem service of 'habitat/refugia' is not available, it must inevitably

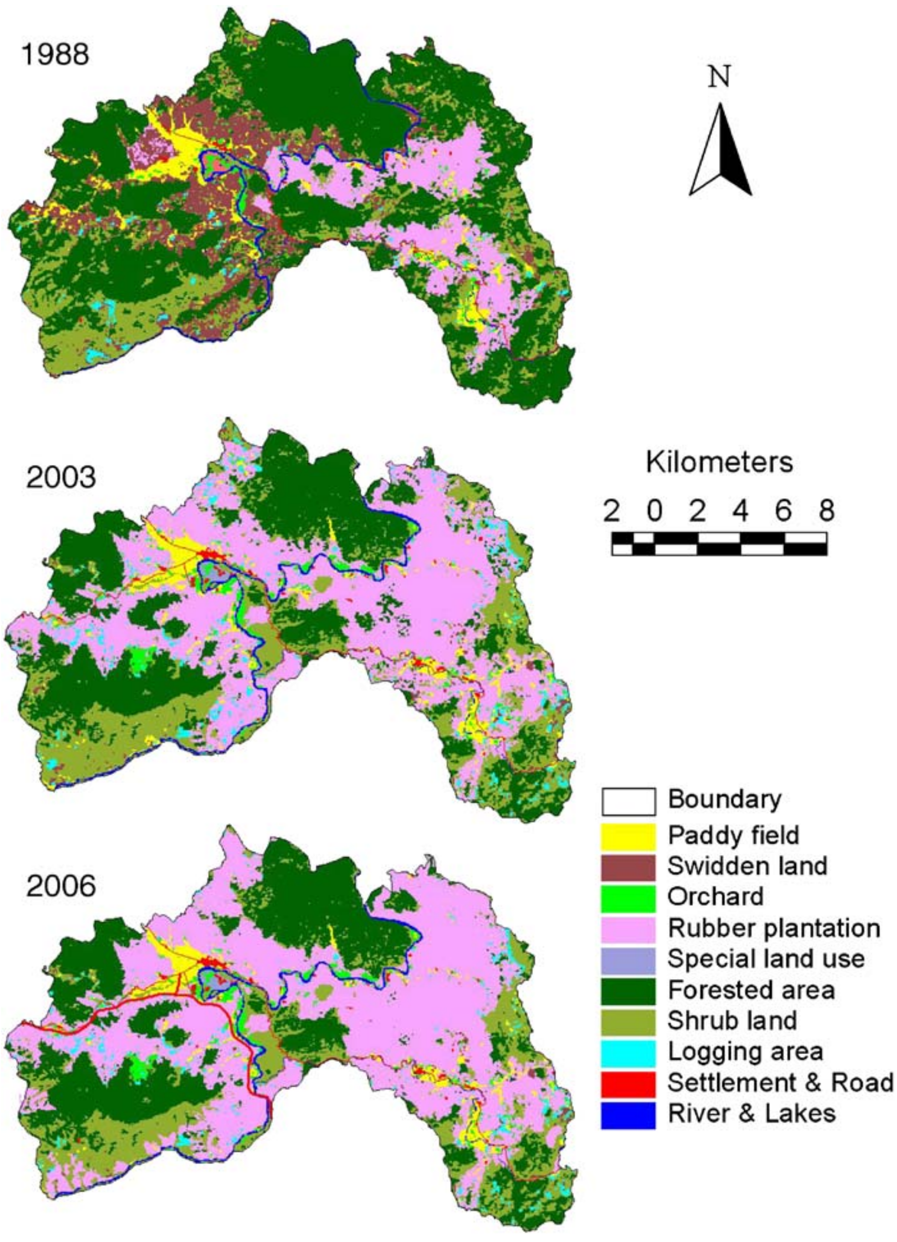

Fig. 2 Changes in land use and land cover from 1988 to 2006 in Menglun, Xishuangbanna, SW China

have decreased drastically due to the loss of forested area. The contributions of changes from other services are minimal.

Ecosystem service sensitivity analyses

In 1988, 48.73% of Menglun Township was covered by forested area, but this land type decreased to 27.57% in 2006. The value coefficient assigned to this land type is almost 6.37 times that of rubber plantation, 8.65 times that of swidden field (Table 1). Consequently, it is not surprising that the decline in forested area has a dramatic effect on the estimated value of ecosystem service in the area. To determine the robustness of our ecosystem service value estimate, we conducted a sensitivity analysis by adjusting the coefficients of the ecosystem services provided by major LULC categories.

Table 2 Changes in land use and land cover from 1988 to 2006 in Menglun, Xishuangbanna, SW China

Land use	Area (ha)			Composition (%)		
	Y1988	Y2003	Y2006	Y1988	Y2003	Y2006
Paddy field	1,419.88	1,392.59	1,197.69	4.24	4.16	3.58
Swidden field	4,400.24	246.86	153.13	13.14	0.74	0.46
Orchard	461.44	774.98	701.33	1.38	2.31	2.09
Rubber plantation	4,051.39	13,087.71	15,280.67	12.10	39.08	45.63
Special land use	70.67	72.84	72.84	0.21	0.22	0.22
Forested area	16,318.26	9,848.97	9,233.62	48.73	29.41	27.57
Shrub land	5,791.78	6,362.69	5,375.15	17.29	19.00	16.05
Logging area	302.04	879.32	626.12	0.90	2.63	1.87
Settlement and road	147.85	263.77	290.77	0.44	0.79	0.87
River	524.78	558.60	557.00	1.57	1.67	1.66
Sum	33,488.34	33,488.34	33,488.34	100	100	100

The effects of using alternative coefficients to estimate ecosystem service value in 1988 and 2006 are shown in Table 5. The CS of these analyses was less than unity at all cases. The estimated value of the ecosystem service for the study area increased from a low of 0.2–0% for 1% increase in the value of swidden field coefficient, to a high of 0.80–0.62% for a 1% increase in forested area coefficient. This indicates that the total ecosystem value estimated for the study area is relatively inelastic with respect to the ecosystem service coefficients. This implies that our estimates were robust and higher or over-valued coefficients can substantially affect the veracity of estimated changes in ecosystem service values over time even though the CS are less than unity. For this reason, we also studied the effect of large variations in coefficient values on the estimated value of land use related changes in ecosystem services. When the value coefficient of rubber plantations was adjusted upwards from the assigned figure (raw materials of tropical forest: US \$315 ha^{-1} yr^{-1}) to the figure for forest (equal to US \$969 ha^{-1} yr^{-1}), the estimated total ecosystem service value increased between 6.43 and 33.57%. Nevertheless, the value of the loss of ecosystem service due to the decline in this land type is still high. The result emphasizes the importance of

Table 3 Total ecosystem service values estimated for each land use and land cover category and changes from 1988 to 2006 in the study area using Costanza et al. coefficient

Land use	ESV (US \$ million)		Change	
	Y1988	Y2006	ESV	CC_k[a] (%)
Paddy field	0.131	0.110	−0.020	−0.05
Swidden field	1.030	0.036	−0.994	−2.41
Orchard	0.042	0.065	0.022	0.05
Rubber plantation	1.276	4.813	3.537	8.59
Special land use	0.068	0.071	0.002	0.01
Forested area	32.767	18.541	−14.226	−34.53
Shrub land	1.355	1.258	−0.097	−0.24
Logging area	0.071	0.147	0.076	0.18
Settlement and road	0	0	0	0
River	4.460	4.733	0.274	0.66
Sum	41.200	29.773	−11.427	−27.73
	100%	72.27%	−27.73%	
GDP[b]	3.11	11.20		

[a] Contribution of change in ESV: $CC_k = (ESV_{2006} - ESV_{1988}) / \sum ESV_{1988}$

[b] Discounted to Net Present Value for the purpose of comparison

Table 4 Estimated annual value of ecosystem functions (ESV_f in US $ million per year)

Ecosystem services	ESV_{f1988}	ESV_{f2006}	Change	CC_f^a (%)
1 Gas regulation	0.073	0.043	−0.03	−0.07
2 Climate regulation	3.649	2.069	−1.58	−3.83
3 Disturbance regulation	0.082	0.046	−0.04	−0.09
4 Water regulation	2.987	3.107	0.12	0.29
5 Water supply	1.242	1.253	0.01	0.03
6 Erosion control	4.309	2.448	−1.86	−4.52
7 Soil formation	0.174	0.099	−0.08	−0.18
8 Nutrient cycling	15.071	8.540	−6.53	−15.85
9 Water treatment	2.688	1.716	−0.97	−2.36
10 Pollination	0.289	0.180	−0.11	−0.26
11 Biological control	0.287	0.187	−0.10	−0.24
12 Habitat/refugia	–	–	–	–
13 Food production	1.246	0.775	−0.47	−1.14
14 Raw material	6.426	7.732	1.31	3.17
15 Genetic resources	0.670	0.380	−0.29	−0.70
16 Recreation	1.974	1.179	−0.79	−1.93
17 Cultural	0.033	0.019	−0.01	−0.03
Sum	41.200	29.773	−11.43	−27.73

[a] Contribution of change in ESV_f: $CC_f = \left(ESV_{f2006} - ESV_{f1988}\right) / \sum ESV_{f1988}$

this land type in the provision of ecosystem services and underscores the substantial reduction in annual ecosystem services as a result of the expansion of rubber plantation. However, the result of our sensitivity analysis also emphasizes the importance of obtaining accurate value coefficients for dominant land types in order to quantify accurately the ecological economic effect of LULC shifts.

Discussion

Over the 18-year period (1988–2006), the LULC in the study area experienced significant changes. The increase in rubber plantation was at the expense of ecologically important tropical forests and traditional swidden farming. Mono-culture of rubber plantation has become the dominant LULC in the local economy.

Table 5 Ecosystem service value after adjusting ecosystem service valuation coefficient (VC) and coefficient of sensitivity (CS)

Change in valuation coefficient (VC)	ESV[a](US $ Million)				Effect of changing CV from original value[a]			
	Y1988	Y2006	Change	%	Y1988		Y2006	
					%	CS	%	CS
Rubber plantation VC +50%	41.838	32.730	−9.658	−23.08	1.55	0.03	8.08	0.16
Rubber plantation VC −50%	40.562	27.367	−13.195	−32.53	−1.55	0.03	−8.08	0.16
Swidden field VC +50%	41.715	29.791	−11.924	−28.58	1.25	0.02	0.06	0.00
Swidden field VC −50%	40.685	29.755	−10.930	−26.86	−1.25	0.02	−0.06	0.00
Shrub land VC +50%	41.878	30.402	−11.475	−27.40	1.64	0.03	2.11	0.04
Shrub land V −50%	40.522	29.144	−11.378	−28.08	−1.64	0.03	−2.11	0.04
Forested area VC +50%	57.584	39.044	−18.540	−32.20	39.77	0.80	31.44	0.62
Forested area VC −50%	24.816	20.503	−4.314	−17.38	−39.77	0.80	−31.44	0.62
Rubber plantation VC = Forest VC	43.850	39.767	−4.083	−9.31	6.43	0.03	33.57	0.16

[a] Total Ecosystem service values of Menglun Township before adjustment were US $41.200 million and US $29.773 million in 1988 and 2006 respectively

According to spatial analysis by Liu et al. (2005), over 95% of rubber plantations in Menglun occur at elevations of less than 900 m in areas of tropical seasonal rain forest. This increase in rubber plantation and decrease in forested area and swidden field occurred on the 15–25° slopes, although mountain habitats produced the lowest yields for rubber (Cao et al. 2003).

The estimated ecosystem service value (ESV) of the township dropped by US $11.427 million (27.73%) over the same period. Assuming a trend of linear decline in ecosystem service value, a cumulative loss of US $102.843 million might have occurred over the 18-year period of our study. In an agriculture-based economy such as Menglun Township, it would appear that an US $1 increase in GDP is at the cost of at least US $1.39 decrease in ESV.

Tropical forests play an important role in the provision of ecosystem services and processes in this area and the abrupt shift in LULC has resulted in an aggregate decline of ecosystem services. Significant changes have occurred in the ecological functions such as nutrient cycling, erosion control and climate regulation, provision of raw materials and habitat or refugia for wildlife.

A number of studies substantiate these observations. According to Cao and Zhang (1997), the tropical seasonal rain forest contains the highest tree diversity in China, as in an area of only 2,500 m^2, 81 tree species were recorded. However, in the rubber plantations, there is only one tree species i.e. *Hevea braziliensis*. Li and Sha (2005) showed that rubber plantations and upland rice fields had very low nitrogen storage and mineralization rates and exhibited significant variation compared to other land use patterns. Zhang et al. (1997) compared the runoff characteristics between tropical rainforest and rubber plantation and found that the water runoff in rainy season occurred deeper in the soil of the rubber plantation than that of the tropical rainforest, due to lack of ground cover in the rubber plantation. Liu et al. (2003) reported that rubber plantations are less capable of intercepting the dry season fog that compensates for rainfall deficits in this area. Li (2001) and Zhang (1986) described the climate changes also in this area over the last 40 years and concluded that the climate has become warmer and drier due in part to changes in tropical forest cover. Zhu et al. (2004) reported habitat change and biodiversity losses in Xishuangbanna due to forest fragmentation. Loss of traditional swidden fields has also resulted in the loss of agro-biodiversity according to Guo et al. (2002). Moreover, the valuation coefficients estimated by Costanza et al. (1997) were incomplete and lacking information on habitat/refugia services provided by forest ecosystems. In our study, however, we have taken into account these aspects and can draw meaningful conclusions about the ecosystem services in the study area.

Common understandings of the causes of LULC change are dominated by simplifications which, in turn, underlie many environment oriented development policies. It is peoples' responses to economic opportunities, as mediated by institutional factors that drive LULC changes (Lambin et al. 2001). The changes in ecosystem services as a result of shifts in land use in the study areas are attributable to policy effects and market conditions. Sustainable land-use policies must also assess and enhance the resilience of different land-use practices (Foley et al. 2005). In order to maintain the ecosystem services in this region, efforts to conserve tropical forest ecosystems should be enhanced through provision of alternative economic opportunities, particularly for private rubber growers. The experience of Puerto Rico where forests recovered as the economy shifted from agriculture to industry could serve as a model (Helmer 2004; Grau et al. 2003). Appropriate ecological compensation mechanisms, e.g., to use carbon trading for tropical forest conservation (Laurance 2007b), and to judge the effects of public policy (Boyd 2007), should be established on the basis of a rigorous valuation of these ecosystem services.

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