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Forest transition, its causes and environmental consequences: empirical evidence from Yunnan of Southwest China

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Abstract: China is experiencing forest transition with its associated environmental and geopolitical impacts. This paper examines forest transition with empirical evidences experienced over the last half century at five sites in Yunnan Province of Southwest China. Results suggest that the forest transitions in Yunnan were mainly driven by economic growth that created off-farm opportunities. It was also supported by state policies favourable for environmental conservation that secured tenure and provided technical assistance and financial compensation. The forest transition in China contributes to global carbon sequestration, biodiversity conservation and in improving local and regional environment. The forest transition was also useful in understanding people and land interactions in the coupled human-environment systems in Yunnan of the eastern Himalayas; this also provided potential policy understandings for regional application specifically when it comes to environmental conservation and economic development.

Resumen: China está experimentando una transición forestal que tiene asociados impactos ambientales y geopolíticos. Este artículo examina la transición forestal a partir de evidencias empíricas acumuladas durante el último medio siglo en cinco sitios de la Provincia Yunnan, en el suroeste de China. Los resultados sugieren que las transiciones forestales en Yunnan fueron motivadas principalmente por el crecimiento económico que creó oportunidades fuera de las granjas. También fueron apoyadas por políticas estatales favorables para la conservación ambiental que aseguraron la tenencia de la propiedad y brindaron asistencia técnica y compensación económica. La transición forestal en China contribuye al secuestro mundial de carbono, la conservación de la biodiversidad y el mejoramiento del ambiente local y regional. La transición forestal también fue útil para entender las interacciones entre la gente y la tierra en los sistemas acoplados humano-ambiente en Yunnan en el oriente de los Himalaya; también proporcionó entendimientos potenciales de políticas de aplicación regional, específicamente cuando se trata de conservación ambiental y desarrollo económico.

Resumo: A China está experimentando uma transição florestal que tem impactos ambientais e geopolíticos associados. Este artigo examina a transição florestal a partir de evidências empíricas acumuladas durante o último meio século em cinco estações da província de Yunnan, no sudoeste da China. Os resultados sugerem que as transições florestais em Yunnan foram principalmente motivadas pelo crescimento económico que criou oportunidades fora das fazendas. Elas foram também apoiadas por políticas públicas favoráveis à conservação ambiental que asseguraram a posse da terra e proporcionaram assistência técnica e compensações financeiras. A transição

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florestal na China contribui para o sequestro mundial de carbono, para a conservação da biodiversidade e melhoria do ambiente local e regional. A transição florestal foi também útil para entender as interacções entre a população e a terra nos sistemas conjuntos homem-ambiente em Yunnan nos Himalaias orientais; esta também proporcionou entendimentos potenciais quanto a políticas de aplicação regional, especificamente quando se trata de conservação ambiental e desenvolvimento económico.

Key words: Environmental impact, geopolitics, land use dynamics, transition drivers, watersheds.

Introduction

China today is often seen as an environmentally destructive nation, quickly becoming the globe's most rapacious resource consumer for forest products (Diamond 2005; Kahrl *et al.* 2005; Sun *et al.* 2004). China is, however, also one of the countries that enjoy forest transition or forest re-growth (Kauppi *et al.* 2006; Zhang 2000). An increase in forest area mainly through plantation to the tune of more than 4 million hectares per year during 2000-2005 was recorded in China (FAO 2007). Recently, China instituted the largest and highest-funded afforestation program in the world (Zhang *et al.* 2000). The turning point from deforestation to net reforestation was redefining and developing progressive understanding on the forest transition (Kauppi *et al.* 2006; Mather & Needle 1999; Rudel *et al.* 2005). The forest transition in China contributes to global carbon sequestration (Fang *et al.* 2001), biodiversity conservation (Xu & Melick 2007) and further improving local and regional environment (Blaikie & Muldavin 2004). The path and rates of forest transition were mostly determined by the combinations of factors such as socioeconomic and enforcement of forest laws (Kauppi *et al.* 2006; Rudel *et al.* 2005) that were influenced by cross-cutting elements of globalization and economic liberalization processes (Lambin & Geist 2001). The forest transition was also regarded as socio-economic transformation that predicts non-linear response (Rudel *et al.* 2005). Understanding forest transition and its application to ecosystem management and economic development might need to be linked with the people, place, policy and geopolitics in the historical perspectives of human-environment interactions and systems (Axinn & Barber 2003; Menzies 1997; Xu *et al.* 1999). Given the potential of forest transitions for slowing soil erosion, improving water quality and slowing climate change through carbon sequestration; challenges could be posed to decision-makers and forest managers for speeding up the transitions or ensure continuity to such transitions. Economic incentives and alternative livelihoods established for conservation in China show examples of policy practices of politico-economic impetus for reforestation in the region.

Forests have multiple functions, they harbor biodiversity, present landscape beauty, anchor soil and water, sink carbon, regulate climate and tempers stream flow, and in addition also directly supply forest products (timber, firewood, raw material for paper, non-timber forest products and others) for local livelihoods and economy. Natural forests show multiple structures with a combination of species at different 'niches', habitats and in different evolutionary stages. Stakeholders and actors have their own identification of forest, for example, the decision-makers cite forests for services, ecologists care for biodiversity, foresters look at the living stock volume, engineers value the fuel energy, and climatologists measure carbon sequestration. The Global Forest Resources Assessment of 2005 integrates those identifications into Forest Identity Index for comparing forest transition status in 50 nations (Kauppi *et al.* 2006). Net forest cover in Asia is increasing mainly due to large investments in forest plantation such as in China and Vietnam (FAO 2007). However, the growth in plantation does not support the negative impacts of continued loss of natural forests and deterioration of environment.

Equally important is the conversion of forest area into agricultural land for food production and rangelands for livestock grazing. Farmers and herders as well as shifting cultivators nurture and manage biomass by applying traditional ecological knowledge systems for centuries if not millennia, across the world (Alcorn 1990; Conklin 1957).

Although overall forest transition has been recorded in China there was not much information on the questions of how, why and when such transitions happened at different locations (Ediger & Chen 2006; Liu *et al.* 2006; Willson 2006; Xu *et al.* 2005a; Xu *et al.* 2005b). This paper analyzes forest transition through the lens of land-use/cover changes that has happened and provides a better understanding of the dynamics of forest transition in southwest China. The study believes that the existence of tree plantation and watershed protection could conserve water, sequester carbon and prevent biodiversity loss, but the empirical bases for such claims remain weak (FAO 2007).

This paper deals with comparison of rate of land cover change in the five study sites in Yunnan over the last 50 years. It analyzes driving factors of land use dynamics in the light of forest transition in the broader historical and contemporary contexts of China. The study also considers local environmental impacts and regional geopolitical application, including methodology for comparison, key results of analysis, discussion for linking case studies to regional economic and ecological sustainability. Finally the paper presents the key findings of the case studies specifically on the overall forest transition processes in China.

Study area

The Himalayan region forms the source of nine large river systems that provides the greatest variations in climatic zones and forest ecosystems with differences in longitude, latitude and altitude. Almost 1.5 billion of the world populations live in these river basins that depend on the Greater Himalaya for their ecosystem services (Xu *et al.* 2007). Yunnan Province of Southwest China in the eastern Himalaya is the source of headwaters and major tributaries feeding into several major rivers including the Yangtze, Salween, Irrawaddy, Mekong, Black, Red, and Pearl Rivers. These rivers have reach and impact on the lives of more than 600 million people in central and southern China as well as Montane Mainland of Southeast Asia (Fig. 1). Yunnan is the home for about 45 million people including 15 million ethnic nationalities based on the latest census of 2005. Substantial land use/ cover changes have occurred in Yunnan during the last century driven by population dynamic, state policies and economic development (Xu *et al.* 1999).

Forests in China have been used, managed and regenerated many times in the history. Rather than being ancient natural forests that need protection, China's forests belong not to nature but culture. Forests in Yunnan has no exception which have been managed by different ethnic groups through the swidden farming (shifting cultivation) or sequential agroforestry This system was built around patchy and pulsed removal of trees but not of the forests that included largely integrated secondary successional vegetation - everything from grass and bushes, to young open-canopy tree communities, and to mature closed-canopy tree communities.

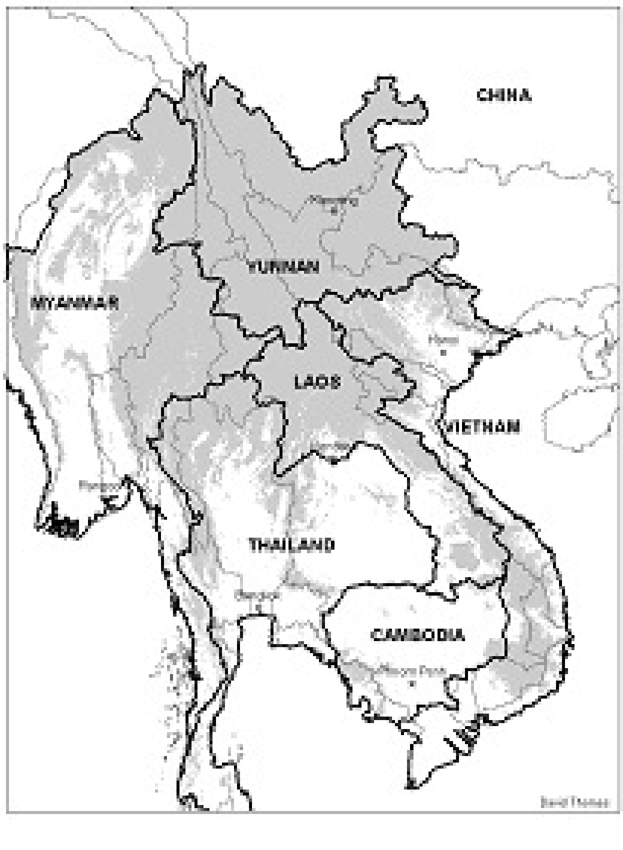

Fig. 1. Location map showing Yunnan of China in connection with Montane Mainland Southeast Asia.

Table 1. Biophysical characteristics and socio-cultural features of the five case study sites.

Region	Alpine ecosystem in Diqing Prefecture of Northwest Yunnan	Montane broad-leaved forest in Baoshan Municipality of Western Yunnan		Montane rainforest in Xishuangbanna Prefecture of Southern Yunnan	
Study site	Xiaozhongdian	Xizhuang	Yangliu	Menglong	Menglun
Area (km²)	880	34.4	42.35	108	335
Elevation (m)	2890-4600	1750-3100	1120-2790	650 -1350	540-1400
Annual rainfall (mm)	700	1013	1200-1700	1362	1555
Ethnicity	Tibetan	Han Chinese	Yi and Han Chinese	Dai, Hani, Bulang, Han Chinese	Dai, Hani, Han Chinese, Jinuo
Total population	9267 (in 2000)	4273 (in 2002)	1573 (in 2002)	1339 (in 2002)	18860 (in 2000)
Land use practices	Agro-pastoral	Upland agriculture	Paddy and upland agriculture	Paddy rice, shifting cultivation, rubber plantation	Paddy rice, shifting cultivation, rubber plantation
Major forest vegetation	Pine (*Pinus densata*), Spruce (*Picea likiangenis*), oak (*Quercus* spp.), fir(*Abies georgei*)	Pine (*Pinus armandii, Pinus yunnanesis*), *Schima* sp., *Castanopsis* spp., *Alnus nepalensis*	Pine (*Pinus armandii, Pinus yunnanesis*), *Alnus nepalensis*, wild walnut, *Camellia reticulate*	Tropical montane rainforest (*Phoebe megacalyx, Parachmeria runnanensis, Gymnnmhes remota*)	Tropical montane rainforest (*Tetramelus nudiflora, Duabunga grandiflora, Terminalia myriocarpa*)
Tree plantation	Pine, fir and spruce	Walnut, Pine, Eucalyptus and tea	Walnut, chestnut, pear	Rubber	Rubber and tea
Shrub vegetation	*Quercus* spp., *Pinus* spp., *Rhododendron* spp., may include also young tree plantation	*Rhododendron* spp., *Vaccinium fragile*, *Myrica nana*, *Engelhardtia* sp., etc.	*Litsea cubeba*, *Rhododendron* spp., *Rhus chinensis*, *Mahonia fortunei*, etc.	*Macaranga denticulate*, *Croton* spp., *Wendlanddia scabra*, *Aporosa yunnanensis*, *Phyllanthus emblica*, etc.	*Macaranga denticulate*, *Croton* spp., *Litsea glutinosa*, *Mallotus philippinensis*, *Phyllanthus emblica*, etc.
Grassland	Various grasses and forbs surrounding village, improved pastures, alpine meadow (>3600m)	Various grasses and forbs after logging for grazing	Various grasses and forbs, managed for grazing livestock	*Alpinia* spp., *Eupatprium odoratum*, etc., early stage of swidden-fallow	*Eupatprium odoratum*, etc., early stage of swidden-fallow
Cultivated farmland	barley, buckwheat, potato, turnip, rapeseed.	Rice, corn, wheat, tobacco, vegetables	Rice, corn, potato, wheat, vegetables	Paddy and upland rice, sweet potato, vegetables	Paddy and upland rice, sweet potato, vegetables, beans
Related forest transition	Logging ban in 1998 and natural forest protection afterward	Tree plantation and watershed conservation since 1980s	Spontaneous tree plantation in 1980s and "Sloping Land Conversion Program" since 1999	State rubber plantation during 1960s and small-holder rubber plantation since 1980s	Established protected areas in early 1980s and large rubber plantation in 1990s

Biophysical and socio-economic environments of the five study sites, traditional forest management and their relevance to forest transitions are summarized in Table 1. Elevations of study sites ranged from a low (500-1500 m) in Xishuangbanna Prefecture of Southern Yunnan to a high (1100-3100 m) in Baoshan of Western Yunnan, and to the high plateau (2900-4600 m) in Shangrila County of Diqing Prefecture in Northwest Yunnan.

Rainfall averaged around 1200 mm across the study sites with the highest value of 1700 mm at Yangliu and the lowest of 700 mm at Xiaozhongdian. Major forest types range from sub-alpine forests, to cool temperate conifer forests, to broadleaved and pine mixed forest in sub-tropics and to montane rainforest in tropical areas of Yunnan. Both the land use and livelihoods varied from agro-pastoralism practiced by Tibetans in Diqing, upland agriculture by Yi and Han Chinese in Baoshan, to shifting cultivation and paddy cultivation by multi-ethnic groups such as Dai, Hani, Jinuo, Bulang and Han Chinese.

Methodology

Socioeconomic databases were developed using secondary sources and through interviews of local residents and government officials. Changes in national and regional policies influencing land use, forest resource management and infrastructure (roads and markets) were documented. Researchers conducted semi-structured informal interviews for identifying the socioeconomic and institutional factors influencing forest access and management decisions. Information on the methods used, types of spatial data collection and sources are given in Table 2.

Spatial databases were developed using topographic maps, GPS, aerial photographs, Landsat Thematic Mapper and Enhanced Thematic Mapper images, and ASTER image (Table 2). For generating comparable land use/cover data across sites, both aerial photographs and satellite images were manually interpreted and supervised classified into 4 classes - forestland, shrub-land, grassland and farmland, and miscellaneous. For forest transition analysis, rubber plantation was separated from forest by field ground truthing. The grassland category included alpine meadow, grazing and improved pasture surrounding villages in northwest Yunnan, and early stages of swidden-fallow (shifting cultivation) succession in southern Yunnan. Both photographs and satellite images were registered to topographic base maps and the land-cover categories were digitized, attributed and entered into a geographic information system (GIS) database. Table 2 provides more information on the types of remotely sensed data and methods of analyses used in each of study sites.

In order to quantify the land change across the sites, the following formula (Xu *et al.* 2005b) was used to calculate annual land use dynamics.

$$LC = \frac{Ub - Ua}{Ua} \times \frac{1}{T} \times 100\%$$

In the formula, LC represents the degree of

Table 2. Specification of spatial data used for analyses in the five case study sites with region details.

Region	Alpine forest in Diqing Prefecture of Northwest Yunnan	Montane broad-leaved forest in Baoshan Municipality of Western Yunnan		Montane rainforest in Xishuangbanna Prefecture of Southern Yunnan	
Data / Study site	Xiaozhongdian	Xizhuang	Yangliu	Menglong	Menglun
First set	1981 Landsat MSS pixel size 57m	1987 aerial photo Scale: 1:40,000	1989 Landsat TM pixel size 30m	1965 aerial photo Scale: 1:35,000	1988 Landsat TM pixel size 30m
Second set	1990 Landsat TM pixel size 30m	2002 ASTER pixel size 15 m	2001 Landsat TM pixel size 30m	1992 aerial photo Scale: 1:35,000	2003 Landsat TM pixel size 30m
Third set	1999 Landsat ETM pixel size 30m		2002 Aster for visual interpretation	1993/TM	
Scale of Rectified topographic map	1:50,000	1:10,000	1:50,000	1:25,000	1:25,000

land use change, Ua represents the area of the particular land use at beginning of year 'a', and Ub the area at the end of year 'b', and T represents the length of time. When the unit of T was set as a year, LC indicated the degree of annual individual land use dynamics. The degree of integrated land use change was defined by the integrated numeric changing of all the categories of land use during the length of time of the study in the area. Its formula used was as follows:

$$LC = \frac{\sum_{i=1}^{n} \Delta LU_{i-j}}{2\sum_{i=1}^{n} LU_i} \times \frac{1}{T} \times 100\%$$

LUi represents the area of category i at the beginning year of the study, ΔLUi-j represents the amount of category i converted to other categories; T represents the length of the study. When the unit of T was set as a year, LC indicated the degree of annual integrated land use dynamics.

Given the long history of swidden cultivation and human activities throughout this region, we considered it unlikely that forest conditions in any of the sites were to a large extend 'primary.' We assumed that nearly all forests in southwest China have been modified, managed, regenerated and reused many times (Xu & Melick 2007). The current vegetations, consisting of a wide variety of vegetation types, were the results of many generations of cultivation and succession. Species composition and structure of secondary forest vegetations changed rapidly in the course of succession, and only experienced observers were able to distinguish mature secondary forests from primary forests. Young secondary forests and other formations such as grass, weeds, bamboo, and bushes were recognized more easily as products of human pressure (Brown & Lugo 1990; Schmidt-Vogt 1998). The above experiences were extensively used in this study.

Results

Land cover changes

Land use/cover change and annual rates of change are provided in Table 3. Grasslands and shrub-lands were the stable land-use forms being converted from farmlands in high plateaus of northwest Yunnan and mid-hill watersheds of western Yunnnan (annual loss of 2.1% of farmlands). Mid-hill watersheds in Yangliu and Xizhuang demonstrated increase in forest cover (7.4% and 0.7% annually, respectively). In Menglong, both shrub-land and forestland contributed to increased area of rubber plantation. However, majority of rubber plantations were resulted from the conversion of the swidden-fallow succession vegetation. If we consider rubber plantation as forest cover then all sites showed substantial increase of land cover by woody vegetation, however, at the cost of agriculture land conversion both from intensive cultivated upland and active swidden-fallow fields.

Land use dynamics

Land use dynamics in the case studies at different sites reflect the local political economy, ecological succession, and people and resource interactions in the coupled human-environment system. These are briefly described below for each of the five sites.

Xiaozhongdian

The most dramatic land use change in the Xiaozhongdian since 1981 was the decline of forestland and their conversion into shrub-land due to commercial logging activities up until the ban in 1998 (Willson 2006). The mid-1980s represents the peak period of timber extraction from the Diqing Prefecture (Xu & Wilkes 2004). From the 1990 to 1999 the area of forest continued to decline at a much slower rate, converting to shrub-lands or rangelands. Although the rangeland remained nearly the same in the coverage, most of the rangelands were invaded by *Azalea* bush resulting from Government's ban on prescribed burning. Inappropriate species used in reforestation programmes and insect attacks have slowed down the forest re-growth. Cutting for firewood and fencing substantially impacted on forest biomass and regenerating forests adjacent to villages (Xu & Wilkes 2004; Melick *et al.* 2007). Observation on the spatial distribution and socioeconomic information helped in understanding the significant transition from forest to shrub and grassland, from shrub and grassland to re-growth of forest. This also showed relationships to logging and other human induced activities where forest regeneration was context-

Table 3. Land use/cover, change in area over time and annual change index in the five study sites.

	Xiaozhongdian				
	Year	Forest land	Shrub-land	Grassland	Farmland
Land use/cover (ha)	1981	52800	10560	16720	7040
	1990	44000	19360	21120	5280
	1999	41360	25520	16720	4400
Change in area (ha) over time		-11440	14960	0	-2640
Annual change index (LC %)		-1.2	7.8	0	-3.5

	Xizhuang				
	Year	Forest land	Shrub-land	Grassland	Farmland
Land use/cover (ha)	1987	1818	408	44	1050
	2002	2007	542	121	543
Change in area (ha) over time		189	134	77	-507
Annual change index (LC %)		0.7	2.2	11.7	-3.2

	Yangliu				
	Year	Forest land	Shrub-land	Grassland	Farmland
Land use/cover (ha)	1989	720	518	903	2089
	2001	1360	439	865	1567
Change in area (ha) over time		640	-79	-38	-533
Annual change index (LC %)		7.4	-1.2	-0.3	-2.1

	Menglong					
	Year	Forest land	Rubber plantation	Shrub-land	Swidden fallow	Farmland (paddy)
Land use/cover	1965	5499	832	2852	263	1275
	1992	4337	2875	1579	390	1448
Change in area (ha) over time		-1162	2043	-1273	127	173
Annual change index (LC %)		-0.8	9.8	-1.7	1.8	0.5

	Menglun					
	Year	Forest land	Rubber plantation	Shrub-land	Swidden fallow	Farmland (paddy)
Land use/cover	1988	16331	4042	5730	4408	1426
	2003	9859	13104	6139	249	1407
Change in area (ha) over time		-6472	9062	409	-4159	-19
Annual change index (NC %)		-2.6	14.9	0.5	-6.3	-0.1

ualized in the coupled human-environment systems. Such forest dynamics suggested considerable structural changes that occurred even during the 1990s when reduction in overall forest cover slowed significantly. It is evident that forest cover statistics alone give a partial picture of forest status (Willson 2006; Melick *et al.* 2007).

Xizhuang

The importance of the Xizhuang watershed area for maintaining good quality water supplies has led to Baoshan Municipal Government and local communities in making great efforts to re-vegetate degraded areas of the watershed. Logging operations in the watershed have been greatly reduced since the early 1980s. Changes over the 15- year period experienced by the Xizhuang watershed shows forestland continued to be the principle land cover that increased from 44% of the total area in 1987 to 54% in 2002 (Xu *et al.* 2005a). Land use dynamics showed mostly conversion of significant area of farmlands into forest, while some area also experienced the reverse of forestland conversion to farmland. Paddy cultivation was abandoned because of water scarcity which triggered conversion of paddy-lands into rainfed upland or tea gardens. Large areas of tea gardens established in the 1950s were recently regarded as non-productive and these were converted into food crop cultivation or replaced by fruit trees or new variety of productive tea were introduced in the late 1990s. The increase in forest cover at this site resulted from the conversion of high elevation buckwheat fields. The afforestation programmes implemented in the Xishuang watershed used aerial seeding of *Pinus yunnanensis* during 1985 and 1991. These programmes were state subsidized tree planting by local farmers being implemented in China for the past two decades. The establishment of pine monoculture plantations has increased the soil acidity and reduced the biodiversity. Farmers also reported loss of their grazing grounds for livestock from conversion into pine plantations. Many farmers of this watershed have taken the off-farm employment opportunities that resulted from improved access roads to the urban cities (Xu *et al.* 2005b).

Yangliu

Local forestry bureau had made great efforts to re-vegetate the watersheds in Yangliu since 1990s. The image classification showed that farmland area decreased during the period between 1989 and 2001 by 522 ha (25%). The land conversions were mostly categorized into grass and shrub because trees planted in the late 1990s were not yet classified as forest. The forested area of the watershed over those 10 years increased by 89% contributed from shrub, grassland and farmland conversion. Grasslands and shrub-lands respectively declined by 4 and 15% in the watershed (Ediger & Chen 2006). Tree plantations were mostly individual household activities. Local farmers planted timber species on the distant uplands since early 1980s without external subsidies. However, planting of economically valuable trees such as walnut, chestnut and pears started from the late 1990s when the government supplied planting material and provided technical assistance and food compensation as part of nation wide the "Sloping Land Conversion Programme". The impacts of farmland conversion policies in the Yangliu sub-watershed definitely affected immediate resource availability and livelihood options, but they also influenced long-term economic changes. The reduction in arable land was contributing to greater economic integration of the rural household economy with the market economy including access to cash and cash crops for meeting basic needs through out-migration and off-farm employment opportunities (Ediger & Chen 2006). On the other hand the impacts of forestations on hydrological processes such as conservation of soil and water were still uncertain.

Menglong

Menglong Township is located in Jinghong County in southern Xishuangbanna, bordering Myanmar in the south. The county in the past had the largest tropical rainforest of the region. The low elevation and gentle sloped forestland were cleared by state farmers (often Han Chinese immigrated from Central China) for rubber plantation in late 1950s and 1960s. The rubber plantation was promoted by the state as 'legible' landscape for substitution of shifting cultivation (Xu 2006). The major land-cover changes documented between 1965 and 1992 comprised of forestland loss from 36% to 24%, bush/grassland loss from 26% to 14%, and increased rubber plantation area from 8% to 27% of the total land (Xu *et al.* 2005a). The mosaic, diverse and flexible landscapes of swidden-fallow vegetations and natural forests existed earlier were replaced by landscapes dominated by rubber trees. Shifting cultivators (such as Hani and Bulang groups) together with valley based paddy farmers (the Dai people) were transformed from subsistence-based livelihoods to market-oriented production systems.

Menglun

Menglun Township, although surrounded by Xishuangbanna Nature Reserve, experienced a rapid expansion of rubber plantations between 1988 and 2003. Over this period the total area under rubber increased from 4,042 ha to 13,104 ha showing expansion by 324%. The image classification showed that the majority of these new rubber plantations were derived from forested areas (4150 ha, 42%), and swidden-fallow succession vegetation (3001 ha, 23%) (Liu *et al.* 2006). Spatial variation demonstrated the correlation between accessibility (road, processing, market and technology) and rubber plantation distribution. Varieties suitable for higher elevations are being introduced recently that is expected to further encourage expansion of rubber plantations in new areas. The road network links all the administrative villages facilitating access and communication. Another dimension of economic booming in the Menglun Township is high volume domestic tourism. Urbanization is unprecedentally happening in the township while engaging youth mostly in off-farm employment. The farmers including those shifting cultivators in the uplands have experienced a three-fold increase in incomes largely coming from rubber plantation supplemented by tourism since the establishment of the famous botanic garden in this township. Menglun looks 'greener' mainly because of large areas under evenly spaced rubber plantations and also contributed by surrounding nature reserve.

Discussion

Transition and contemporary drivers

Houghton (2002) estimated the original forest areas were 4.3 million km^2 in China. By 1850, 44% of China's forests were cleared, and another 27% was lost between 1850 and 1980. Carbon emissions from forest clearing peaked in the late 1950s that left China with just 13% forest cover of the total area. Majority of the forestlands initially cleared for agriculture are no longer croplands but converted into fallows or degraded shrub-lands. Historically, Chinese authorities tried to bring ethnic minorities and people living on the geographical periphery of the country under central control. These included settlement programmes by converting forestlands into cultivable lands under agriculture while reducing taxation levels. The demand for agricultural land and timber following human settlement in remote areas were the main causes of forest loss (Menzies 1994; Xu & Ribot 2004). In the nineteenth century, during the latter part of the Qing Dynasty, the central government was less interested in conservation of natural resources *per se* than in exerting sovereignty over peripheral territories and benefiting financially from the exploitation of their resources (Menzies 1992). Therefore, rather than controlling the timber industry by regulating its growth, logging, marketing and production, as it does today, it reaped the benefits through taxation. Large areas under forests in remote locations were managed by customary institutions until the middle of the twentieth century. After the People's Republic of China was founded in 1949, all lands including forest resources were owned either by the state or converted into collective resources. The most deforestation occurred after the 1950s which had started during the World War II followed by the 'Great Leap Forward' in 1958 and the 'Cultural Revolution' during 1966-1976 in China (Xu & Ribot 2004).

It is estimated that 80% of the total population in Yunnan use firewood for cooking, winter heating and tobacco curing that has the annual demand of 27 million m^3 of firewood (Xu 2002). Since the early 1980s, Yunnan embarked into forest transition initiated by a chaotic forest tenure shift from the state to collective resources that further got converted into private individual lands in 1981. Tree plantations and conservation programmes were implemented in the mid-hills of Yunnan such as Xizhuang and Yangliu watersheds resulting from the decentralization policies in forest management since early 1980s. In early 1990s with emerging market incentives and reinforcement of new forest tenures favouring the privatization, farmers converted forests into economically valuable fruit trees and rubber. The largest historical flood in Yangtze River stimulated state to pay for environmental conservation through land use conservation commonly known as "Grain for Green" program. The latest forest inventory showed that the forest cover in Yunnan increased significantly from 26% in 1978 to 34% in 1997, and to 50% by 2006 (YPFI 2006). The results of the five case studies discussed in this paper confirm that the forest transitions in remote areas of China are real and reliable. Rural reform, economic liberalization and globalization are the major factors of booming economic growth in China. This evident success has differential situations at different places in the country and most importantly it has increased the economic disparity between rural and urban populations. Increasingly rural populations are abandoning their agricultural land or forestry activities for higher-paying off-farm employments. However, miracle in economic growth enabled the Chinese government afford compensation for environmental service through watershed conservation and forestry programmes. Scarcity in timber resources and the secured tenure rights stimulated the private sector for planting fast-growing trees. The above drivers and policies promoted forest plantation that significantly increased the forest area from the late 1970s to the early 2000s (Kauppi *et al.* 2006). China taking the benefit of free trade imports timber products from other neighbouring countries (Zhang 2000). Energy technology and economic growth also leads to substitution of forest resources. These are evident as more and more rural households adapting to biogas, small hydropower and solar energy, which are directly reducing community reliance on firewood from forest (Li *et al.* 2005). In the decentralized forest policies economic instruments for management and conservation are used and can be seen in the "Sloped Land Conversion Programme" and "Natural Forest Protection Programme". Resulting from these programmes and forest promoting policies China has been able to develop the largest planted forest in the world that totaled to 71 million hectares in 2005 (FAO 2007). Three case studies in Xiaozhongdian, Xizhuang and Yangliu demonstrated good increases in forest coverage.

The environmental impact

The significance and value of forest transition largely depends on the effects of the transition on the environmental service that these forests provide. There is a need to develop understanding on the impacts of forest transitions especially in relation to changes in hydrological cycles, soil and water conservation, climate change, and, to lesser degree on the possible biodiversity crisis (Rudel *et al.* 2005). The interactions of land, forest and water have long been discussed and debated. Land use/cover is intrinsically linked with the freshwater hydrological cycle; therefore, a land use decision is often a water decision (Bosch & Hewlett 1982; Falkenmark 1999). The effects of forest expansion on stream flows and water quality appear to vary with the type and structure of vegetation as well as conditions of catchment. In Xizhuang watershed, both farmers and researchers report the negative effects of eucalyptus and pine plantations on both water quality and quantity, largely attributed to increased soil acidification and higher rate of evaporation by these tree species. Standard practices for "Sloped Land Conversion Programme" are not adequately addressing land management issues of clearing natural vegetation, tillage for tree plantation, weeding and non-intercropping which might be contributing to soil erosion and water runoff. Out of 71 million hectare plantation, the productive or economic plantation account for 54 million hectare (FAO 2007).

The study of the hydrological consequences of forest transition is complicated by great spatial and temporal variability of land use/cover changes and hydrological systems. Although contribution of rubber monoculture to runoff is still debatable, there are evidences strongly supporting conclusions that the long-term rubber farming caused soil acidification, soil compaction, and depletion of organic matter and nutrients (Zhang & Zhang 2005). Much of current understandings of land use effects on hydrology are derived from controlled experimental manipulations of the land surface at particularly scale and within a limited time period. There are few examples for controlled long-term studies on permanent land 'conversions' (e.g. forest to agriculture, agriculture to urban, etc.) at multiple scales (DeFries & Eshleman 2004). Advance in satellite remote sensing technology and availability of new data (e.g. hydro-meteorological data within catchment) together with progress in computation and statistics have significantly enhanced modeling capabilities for predicting hydrological consequences of land use change and forecasting ecosystem change at multiple scales (Clark 2001). The complexity theory by Messina & Walsh (2001) calls for a multidisciplinary approach with comprehensive view towards the hydrologic process that maintains environmental services. This approach provides credible, salient and legitimate knowledge to decisions that must balance trade-offs between the positive benefits of land use/cover change and potentially negative consequences. The impact of a forest transition on biodiversity needs to be reexamined. Monoculture plantation does not contribute positively to biodiversity richness and related benefits. Introduced fir (*Abies* sp.) plantation in Xiaozhongdian of northwest Yunnan is vulnerable to insect (*Cosmotriche saxosimilis*) attack. Since 1986 more than 20,000 ha of *Abies* forest have been pest-affected in Shangrila County of Diqin Prefecture (Xu & Wilkes 2004). In many places endemic species have been replaced by invasive species in the disturbed habitats and it's seen that low levels of biodiversity persisted in the early periods of transition.

Geopolitical impacts

Forest transition supports that when the declines in forest cover cease the beginning of the re-growth forest starts. However, there are some exceptions like a situation of highly populated areas combined with poverty tend to drive deforestation particularly in the absence of enforcement of policies and laws. Corruption might be another factor for delay of forest transition which is quite evident in Myanmar (Rudel *et al.* 2005). The economic growth and forest transition in China has also geopolitical implications beyond the national boundary (Grumbine 2007). Converting arable land to urban construction and tree plantation directly affects domestic food security with the potential to influence global commodity markets. China imported 5.8 billion US dollars worth of animal feed with average annual change of 57% in value during 1999-2003, out of which 94% was soybeans largely imported from Latin America including Brazil and Argentina (Stevens & Kennan 2006). Such imports have potential implication to land use/cover in the countries outside China like in biodiversity rich Amazon (Brown *et al.* 2005). Free trade can export the impacts of one nation's timber consumption to anther nation that harvests the timber (Mayer *et al.* 2005). With the implementation of "Natural Forest Protection Programme" or logging restrictions in 1998 and tariff reductions on forest products in 1999, China's annual timber product imports from Myanmar have more than tripled between 1997 and 2002 (Kahrl *et al.* 2005; Sun *et al.* 2004). China imported 134 million m^3 of forest products with a total value of 16.4 billion USD in 2005 (Sun *et al.* 2004). There are increasing instances of exported impacts or leakage of one nation's timber consumption to the forests of other countries in Asia (Kauppi *et al.* 2006). From ecological point of view, trade logically flows from warmer, moister climate, where tree grow fast, to cooler or drier ones where they grow slowly. Exports from fast-growing plantations decrease the global forest area harvested (Kauppi *et al.* 2006). The case studies in Menglong and Menglun of Xishuangbanna show great expansion of rubber plantation from conversion of either forestland or shrub-land or secondary successional vegetation. There is no more land left for rubber plantation inside China. Chinese investors are searching more lands for rubber plantation in neighboring countries such as Laos and Myanmar. Conversion of secondary forest areas to rubber is considered as economic opportunity both for local decision-makers and farmers. Rubber plantation will eventually become predominant landscape in Montane Mainland Southeast Asia. Following China, two developing nations with tropical forest, the India and Vietnam had reached turnaround of forest transition, both enjoy forest expansion and strong economic growth (Kauppi *et al.* 2006).

Conclusions

The case studies of forest transitions in Yunnan illustrate the experiences of 'the stick and the carrot' approach where combination of law enforcement and economic incentive for forestation were demonstrated. Decentralization in forest management is often a pre-condition in the forest transition although many cases show that insufficient transfer of powers and decision-making process to local institutions hampers successful transition. The experience of Joint Forest Management in India (e.g., Forest Protection Committees) and Community Forestry in Nepal (e.g., Forest User Groups) show that it is important to recognize the customary laws and access to forest resources, and legal and judiciary systems for conflict resolutions. The local participation in the forest transition is critical to sustainable forest management and regeneration.

Understandings on the historical trajectory of transitions can be used as entrance points in developing policy-relevant land-use scenarios and for predicting sets of local and regional pathways of transitions. Developing pathways that will be useful for policy development and forest management in a region requires collection of information on (a) historical land-use patterns, (b) climatic, economic and ecological constraints on forest areas, and (c) what causes change, how different causes act together (synergies), and how resulting land-use activities provide feedbacks on the causes. Once basic functional understandings of the pathways are developed then the relevant policy interventions for promoting sustainable forest management in specific areas will emerge. Understanding the pathways can also help land managers and policy makers in anticipating changes and coping with uncertainties.

Multi-functionality attributes of forest ecosystems change over time and space. Various actors have their own expectations over certain forest areas and resources therein. Forestry programmes that combine poverty reduction and nature conservation are often rare, but new efforts are emerging that expects to evaluate and monitor these often opposing goals in the future. Economic development and off-farm opportunities are one of the pathways facilitating forest transition in China.

Impact of forest transition is often beyond biophysical and sociopolitical boundaries. The Yunnan cases clearly demonstrated the export of impacts to the nations of economic regionalization and ecological efficiency. The ecological efficiency between the region of fast and slow tree growth combined with economic growth showed potential. Increased access by the improvement of road transportation has shortened the connectivity between people and environment, people from one place to other place, and the people and market. It is evident from this study that the forest transition could positively switch environmental services over time and space.

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