

Increasing tree cover while losing diverse natural forests in tropical Hainan, China

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Abstract To protect biodiversity and improve environmental conditions, China has invested billions of dollars in reforestation and payments for ecosystem service programs. Here, we examine the Sloping Land Conversion Program, the largest such program in the world and found that after 13 years of implementation at our study site, it has had negative impacts on natural tropical forests. GIS and remote sensing techniques revealed that both natural forests and natural shrub and grasslands were replaced by non-native monocultural plantations on Hainan Island, China, a key tropical biodiversity hotspot. Under current Chinese policy, these plantations are classified simply as “forests”, with the assumption that

they are equivalent to natural forests. This lack of a distinction in forest quality has led to substantial deforestation and plantation expansion, including encroachment into protected areas on Hainan. Additional social and economic drivers of these changes were identified by examining the participants in this program and their actions. Without a new ecologically based definition of forests and new goals for reforestation, such programs designed to improve ecosystem services, and forest quality may actually threaten remaining natural forests and other vegetation types in Hainan and in other areas of mainland China.

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Keywords Forest restoration programs · Sloping Land Conversion Program · Deforestation · Rubber plantation · Monoculture pulp plantation

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Introduction

China has undergone a forest transition from net forest loss to net gain primarily due to reforestation programs (Meyfroidt and Lambin 2009). However, China's tropical areas still suffer from deforestation and plantation expansion (Li et al. 2009; Zhai et al. 2012). Since 1999, the central government has invested more than 298 billion RMB (USD 47.82 billion) (The Central People's Government of the People's Republic of China 2012) in a payments-for-ecosystem services and restoration program called the Sloping Land Conversion Program (SLCP) (Groom et al. 2010; Li et al. 2011). Largely initiated as a response to the 1998 floods in the Yangtze River watershed, the SLCP has restored marginal cultivated lands (on slopes >25°) to forests or grasslands and has led to increased forest cover and generally improved ecosystem services (Liu et al. 2008; Chen et al. 2009a).

Hainan Island's forests have also undergone a transition in land-use change from previous deforestation to net reforestation (Zhang et al. 2007). The history of the island's tropical forests in the last 100 years has been a history of deforestation, degradation, and recent regrowth. Forest cover had decreased to 50 % at the beginning of the 1930s, and then fell to 15 % by the end of the 1970s (Zhang et al. 2000). The trend was then reversed due to decades of forest conservation and reforestation/afforestation, and by the 1990s, it was estimated that more than 20,000 ha of land had been reforested (Zhang et al. 2000). However, by the 1990s, deforestation, driven largely by plantation expansion, had again increased (Zhang et al. 2010; Zhai et al. 2012). Through the SLCP about 170,000 ha of forest had been replanted by the end of 2008, increasing Hainan's forest cover by 5.2 % (Hao et al. 2009). However, a recent Greenpeace report found that during this period, a quarter (72,000 ha) of Hainan's natural tropical rainforest had been destroyed (Greenpeace 2011).

To investigate these conflicting claims between increasing forest area and loss of natural forest on Hainan Island, we used remote sensing and GIS data to investigate changes in different land-use types in the upper Changhua watershed. The results from this analysis would allow us to distinguish between the conversion of natural forests into plantations and the reforestation of degraded areas into production forests. If the SLCP is actually driving local smallholders to replace natural forests with monoculture plantations, instead of restoring degraded areas into forests, then the policy is not serving its purpose of improving the ecosystem function of the landscape. Therefore, we asked a simple question: did plantations replace degraded or natural areas? Finally, we attempted to identify underlying factors that may impact Hainan's remaining tropical rainforest in the future.

Materials and methods

Study area

Hainan Island (18°10'–20°10'N and 108°37'–111°03'E, Fig. 1a), the largest tropical island in China with an area of 33,920 km² and is also the largest island in the Indo-Burma biodiversity hotspot (Francisco-Ortega et al. 2010). The island's tropical rainforests are located at the northern margin of Tropical Asia (Zhu and Zhou 2002) and are known for their high biodiversity (Zheng et al. 2002). This research was conducted in the upper Changhua Watershed (Fig. 1b), south of the Hainan Island, which is one of eight plant conservation hotspots in China (Zhang and Ma 2008). Hainan's Changhua River (Fig. 1c) has been identified as a center of endemism for plants and birds (Chen 2008).

Data sources and methods

Land-cover classification was performed using three Landsat thematic mapper (TM) images and six Satellite Pour l'Observation de la Terre 5 (SPOT5) images for three separate years: 1988, 1995, and 2005 (Table S1). The TM and SPOT images of 1995 and 2005 were purchased from Beijing Spot Image Co., Ltd. and were corrected for atmospheric and radiometric distortions. The Landsat TM image for the year 1988 was downloaded from Earth Explorer (<http://edcsns17.cr.usgs.gov/EarthExplorer/>), which has been pre-processed according to a standardized set of parameters and has been orthorectified using geodetic and elevation control data to correct for positional accuracy and relief displacement. The data were topographically corrected to a digital elevation model (DEM) (Ekstrand 1996). The DEM was derived from topographic maps (scale = 1:50,000) that were provided by the State Bureau of Surveying and Mapping. The TM images were rectified to Pulkovo_1942_Transverse_Mercator projection system, and then, an image-to-image registration was used to register the TM images to another TM image in 2000, with the rectification RMS error less than one pixel. To enhance image resolution, image fusion was made between multispectral TM and the SPOT panchromatic band to get a 10-m-resolution multispectral image. This was done by principal component analysis (PCA) on PCI software (Chavez and Kwarteng 1989; Antunes 2000).

Final images for each year were classified into six land-cover types: (1) natural forests; (2) natural shrub and grasslands; (3) tropical crops; (4) rubber plantations; (5) pulp plantations; and (6) open areas. "Natural forests" included primary forests and naturally regenerating secondary forests, characterized by closed canopy structure. "Natural shrub and grasslands" represent a transition between abandoned agricultural land and forest after the removal of natural forest. A data layer for this land-cover type was provided by Hainan Environmental Science Institute and was used in initial classification efforts. "Tropical crops" consisted primarily of *Cocos nucifera*, *Areca catechu*, *Anacardium occidentale*, *Litchi chinensis* plantations, and *Camellia sinensis* gardens. "Rubber (*Hevea brasiliensis*) plantations" were identified by their characteristic image texture, land form and landscape terracing. These areas were mostly confined to State Farms. "Pulp plantations" were distinguished by their special image color in combination with a reference data layer provided by Jinhua Forestry Co., Ltd. (Jinhua Company). "Open areas" included shifting cultivation, paddy rice, cultivated lands, rivers, pools, cities, villages, and industrial lands.

All the non-thermal channels of the fused images were used in further classification efforts. The classification of

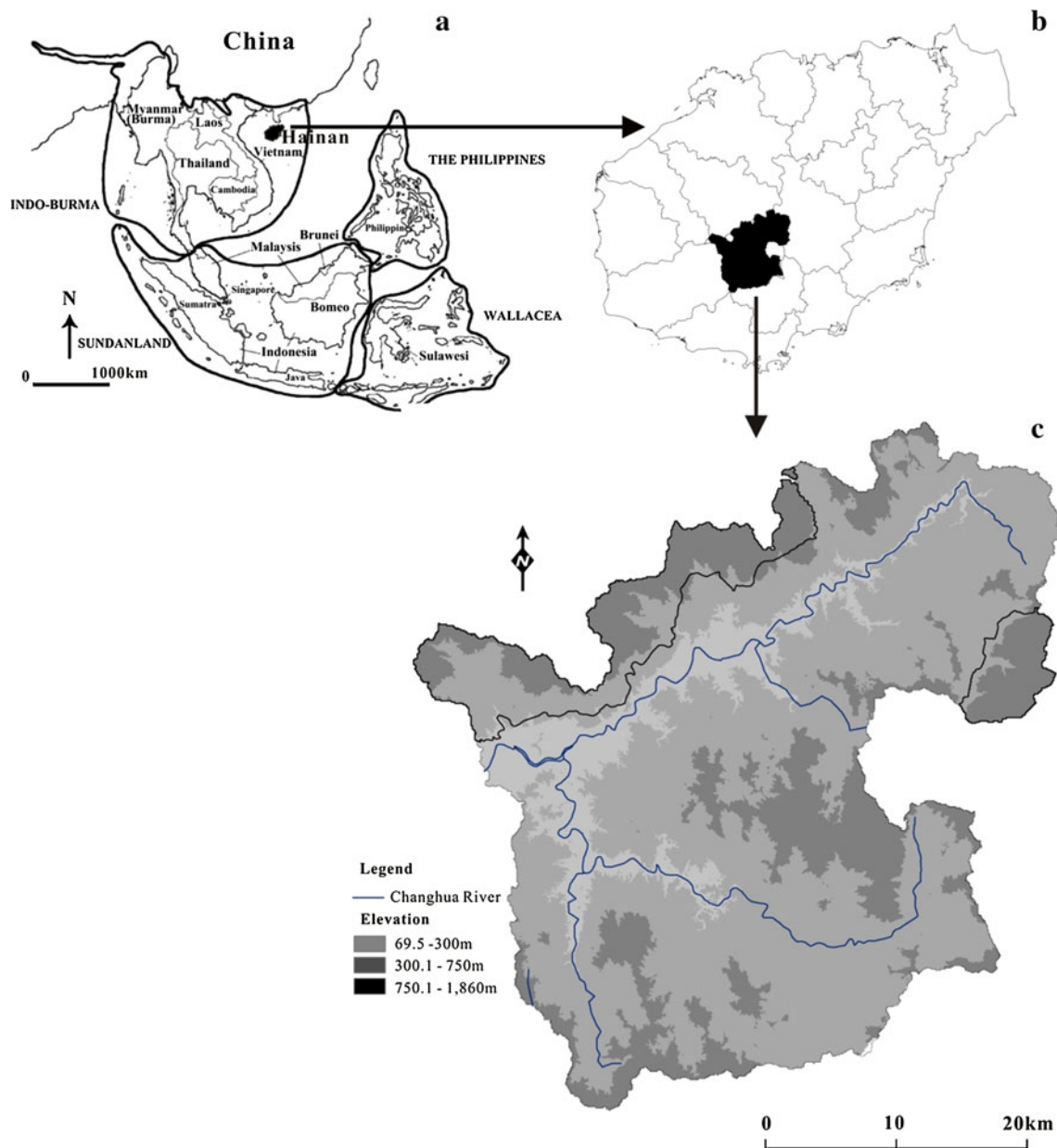


Fig. 1 The Changhua watershed on the island of Hainan, China: **a** image of China showing the position of tropical areas (*black areas*) and their locations in the biodiversity hotspots (*thick black lines*)

according to Mittermeier et al. (2004); **b** Hainan with the location of the study area indicated by *black*; **c** the upper reaches of Changhua watershed with the Nature Reserves

the land-cover classes was performed through a supervised maximum likelihood classification method (Jensen and Lulla 1987) on ERDAS 9.0. The classification results were converted into vector for later further editing in ArcGIS. The results were manually edited in ArcGIS (Version 9.3.1, Environmental System Research Institute, USA) by visual interpretation when necessary (e.g., areas of new clearings for pulp plantation, and areas covered by cloud). Interpretation was aided by a farm layer, pulp plantation plan layer, residential area layer and Hainan grass distribution layer, as well as expert local knowledge.

To minimize classification errors caused by difference in the resolution of the three satellite images, we continued to do clump and elimination after classification; polygons <900 m² equal to 1 cell were eliminated (Li et al. 2007). Training areas for the TM were generated by the Hainan Environmental Science Institute in 2005 and 2006. Large homogeneous areas were selected as training areas (Schowengerdt 2007). For each land-cover class, at least 10 training areas (Li et al. 2007; Schowengerdt 2007) were selected to reflect variation due to topography and growing conditions.

Classification accuracy was evaluated in terms of producer's accuracy, user's accuracy, and overall accuracy, which is commonly calculated by an error matrix (or confusion matrix) (Congalton and Green 1999; Foody 2010). For accuracy assessment, six hundred points were randomly sampled during field surveys in 2006 and 2007. The 2005 land-cover map was found to be generally reliable (overall classification accuracy and Overall Kappa Statistics were 83.5 and 80.8 %, respectively, Table S2). The classification accuracy assessment of 1995 was based on the assumption that the same resolution satellite images' processing can achieve the same accuracy. While the absence of accuracy assessment of the 1988 classification was for no higher resolution images, ground truth data and other reference data are available. But since multiple kinds of ancillary data were used after supervised classification by visual interpretation to achieve a confidential classification map, we assumed that this achieved a level of accuracy similar to 2005. We did not update the thematic maps by buying the SPOT images from more recent years, because first, we wanted to test the SLCP's impacts on natural forests, and second, more than 96 % of the areas reforested by the SLCP in Hainan (Table 2) were planted between 2002 and 2005.

The association of the different land-use classes with slope was examined for each year, using random permutation tests (Webb 2000). For the slope tests, we used four different classes to consider soil erosion and law: 0°–10°; 11°–25°; 26°–40°; and >40° (Wang and Jiao 1996). To remove any possible effects of spatial autocorrelation in the association between land use and the environmental factor, we performed permutation tests on a 15 % random subsample of the image. We performed 250 permutations to generate distributions for the observed and expected values. We then compared the mean values for these two distributions to determine whether the observed values were significantly different

from the expected values, given a random spatial distribution of land-use types.

To compare the changes in different land-use types between different time periods, we calculated the area of each land-use type for each time, along with changes in area during the study period, change ranges, and R-index (Liu et al. 2006).

We also collected official decrees, local government reports and documents, and socioeconomic data on the agents implementing and managing the SLCP projects on Hainan to assess the potential drivers for their actions. The socioeconomic data included individual and company names, location of the SLCP projects and species planted on both area and on annual basis. Informal field interviews were undertaken in September–October, 2011, to “ground truth” the above information. These data would improve our insight into the relationships between state policy through the SLCP, the agents who were managing the projects, and the economic cost and benefits experienced by these actual agents performing the reforestation.

Results

Plantations have replaced natural vegetation

Both natural forests and natural shrub and grasslands decreased greatly during 1988–2005, with natural shrub and grasslands losing a larger percentage (65 %) and natural forests losing a larger amount (21,603 ha). During the study period, natural forest loss corresponded to 22 % of natural forest cover in 1988. Of all land-use types, natural shrub and grasslands conversion into pulp plantation was more than 70 % of all the areas converted from natural shrub and grasslands. The R-index of natural shrub and grasslands (−0.48) was larger than that of natural forests, indicating that natural shrub and grasslands lost a larger

Table 1 Land-use/land-cover distribution (1988, 1995, and 2005) and the absolute and relative area of each category

Land-use/land-cover categories	1988		1995		2005		1988–2005		
	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)	Area changes (ha)	Change ranges (%)	R-index
NF	97,909	66.37	104,023	70.51	76,306	51.7	−21,603	−0.22	−0.12
NS&G	18,895	12.81	13,345	9.05	6,579	4.5	−12,316	−0.65	−0.48
TC	3,155	2.14	4,035	2.74	9,112	6.2	5,957	1.89	0.49
RP	8,329	5.65	12,926	8.76	26,776	18.2	18,447	2.21	0.53
OA	19,236	13.04	13,177	8.93	13,455	9.1	−5,781	−0.3	−0.18
PP	5	0.003	22	0.015	15,301	10.4	15,296	3,059.2	0.999
Total	147,528	100	147,528	100	147,528	100	0	–	–

NF natural forest, NS&G natural shrub and grasslands, TC tropical crops, RP rubber plantation, OA open area, PP pulp plantation

amount of land compared to 1988. Natural forests had a slight increase during 1988–1995 with larger amounts of natural shrub and grasslands converted to natural forests, but this was followed by a sharp decrease from 1995 to 2005 with substantial conversion of natural forests into rubber and pulp plantations and tropical croplands (Table 1; Fig. 2).

Rubber plantation displaced natural forests on slopes of $<25^\circ$, while pulp plantation displaced natural forests and natural shrub and grasslands on slopes of 11° – 40° (Figs. 2, 3c, d). Pulp plantation showed the highest R-index (proximity to 1.0) (Table 1); this indicates a sharp increase in pulp plantations from 1988 to 2005. Rubber plantation and tropical

croplands also significantly increased during the study period with indices of 0.53 and 0.49, respectively, mainly on flatter ($<25^\circ$) slopes (Fig. 3c, e). Additionally, the expansion of pulp plantation showed the highest index due to its limited presence before 1995 (Fig. 3d) with more than 60 % of this land-use type replacing natural forest (Fig. 2).

Plantations expanded faster on slopes steeper than 25° , and natural regeneration of forest was slower in 1995–2005

Between 1988 and 1995, natural forests regenerated mainly from natural shrub and grasslands and open areas (Table 1;

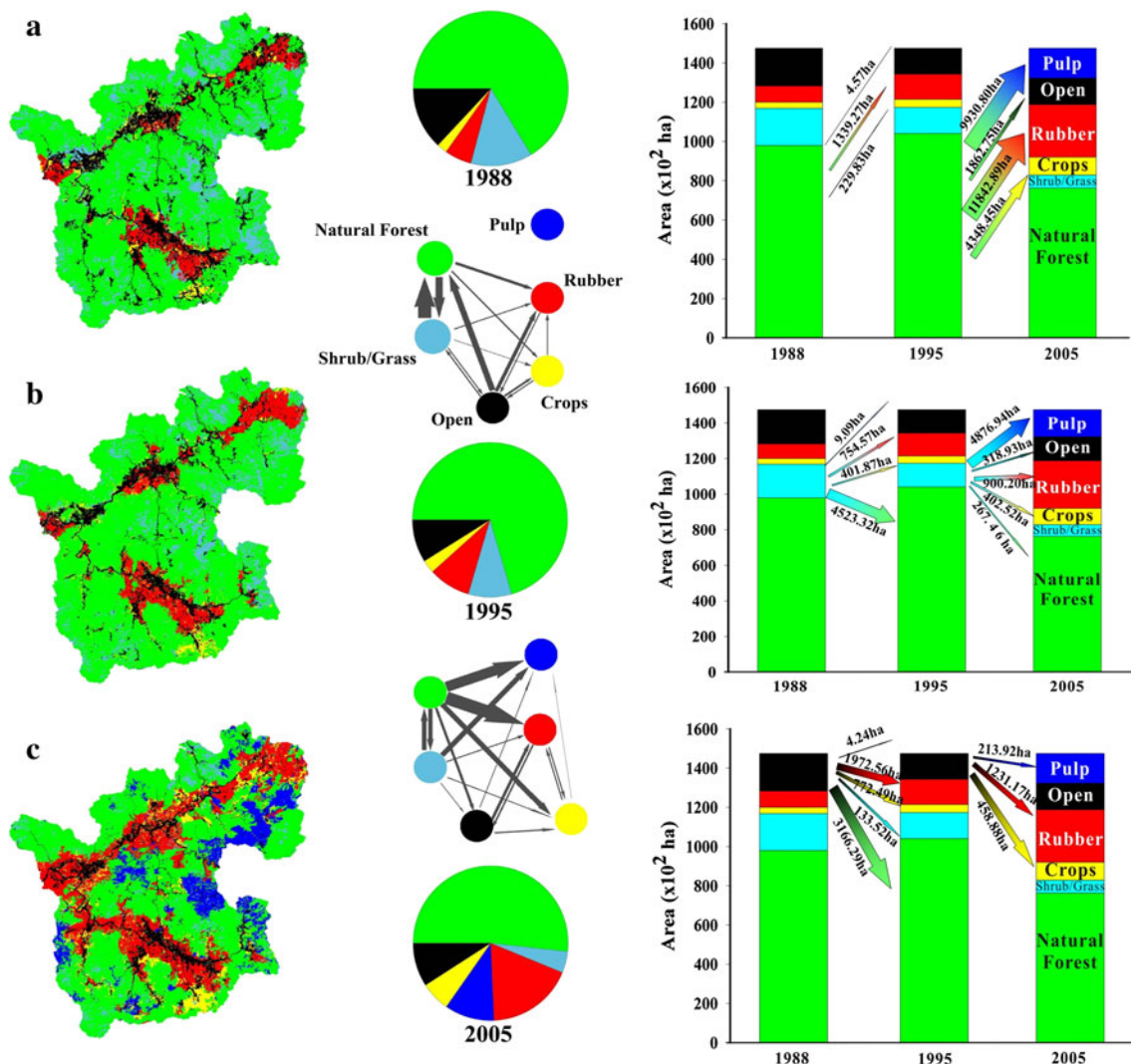


Fig. 2 Land-cover change in the Changhua watershed from 1988 to 2005. Maps shown in the left column illustrate the distribution of land-use classes: **a** 1988; **b** 1995; and **c** 2005. Pie-charts in right column indicate the relative proportion of each land-use class for each time period. Transition matrices separating each pie-chart indicate the change between land-use types, with the thickness of the arrows

indicating the relative amount of change. The histogram at the right of the pie-charts indicate the area converted from natural forests, natural shrub and grasslands, and open areas to other land-use types, and the number on the arrow means the area being converted. Color-coding follows the labels on the first transition matrix (color figure online)

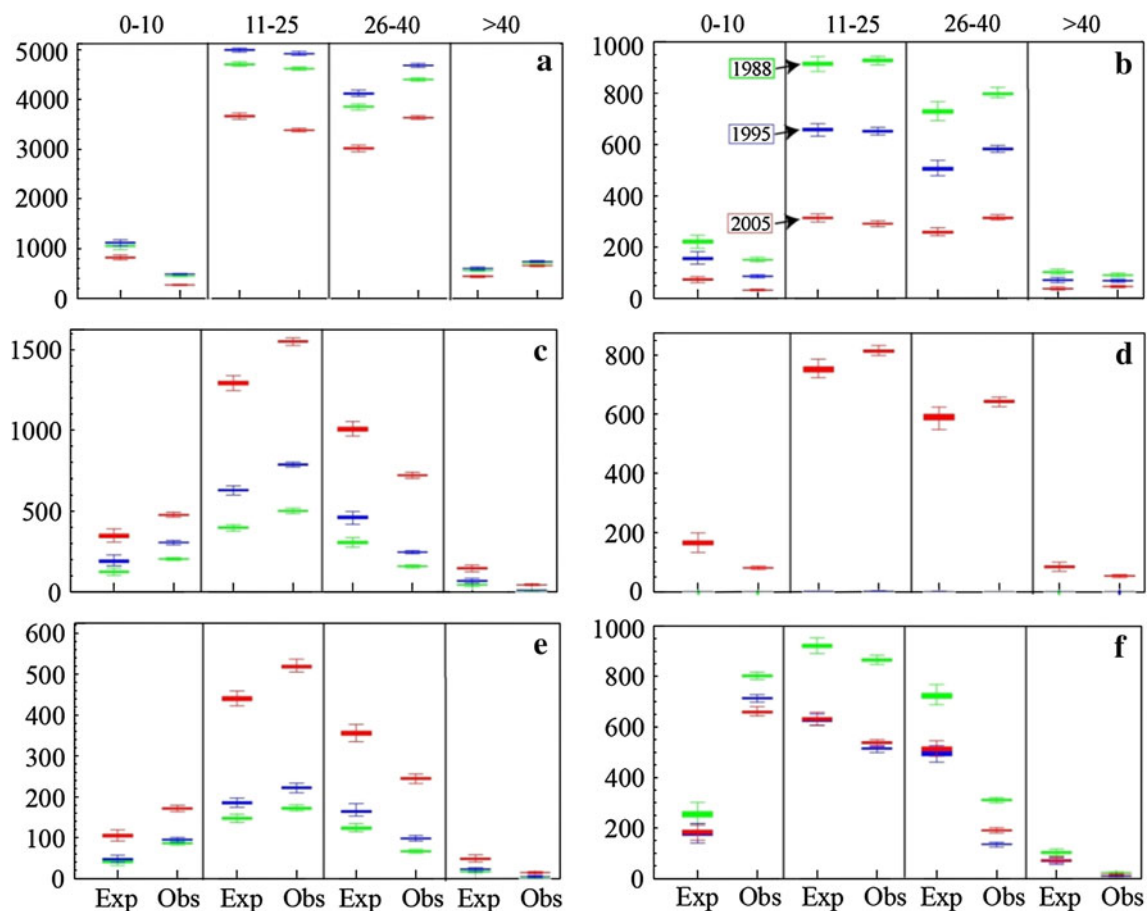


Fig. 3 Changes in area for each land-use type according to slope in the Changhua watershed. **a** natural forests; **b** natural shrub and grasslands; **c** rubber plantations; **d** pulp plantations; **e** tropical crops; and **f** open area. Observed (*Obs*) and Expected (*Exp*) values for each slope class represent means, 1 standard deviation and 95 %

confidence limits for 250 randomizations given a 15 % sub-sampling rate. Values for each year are *color-coded* as labeled. For the slope tests, we used four different classes: 0°–10°; 11°–25°; 26°–40°; and >40° (color figure online)

Fig. 2). Natural regeneration continued in some areas in 1995–2005, but only 2 % of natural shrub and grasslands' area in 1995 were converted to natural forests, while an equal proportion of these land-cover types were also converted to plantations (Fig. 2).

During 1995–2005, only 214 ha (1.6 % of open area in 1995) of open area was converted to both rubber and pulp plantations. One quarter of natural forests in 1995 were converted into pulp plantations, tropical croplands, and rubber plantation by 2005 (Table 2; Fig. 2). By 2005, 65 % of the area of pulp plantation, 48 % of tropical croplands, and 44 % of rubber plantation were converted from natural forests. No conversion from rubber to pulp plantations took place. As of 2005, very little natural vegetation remained on flat areas (Fig. 3a, b). This was due in large part to the predominance of tropical crops, rubber plantations and open area in low elevation flat areas. Rubber plantations, open areas, and tropical crops were almost non-existent on

the steepest slopes (Fig. 3c, e, f). Pulp plantation mainly occurred on steeper slopes (Fig. 3d). The appearance of pulp plantations between 1995 and 2005 did not displace rubber plantations in the lowlands.

No open areas were restored to natural vegetation during 1995–2005

Between 1988 and 1995, 3,166 ha of open areas were converted into natural forest, representing more than 50 % of this land-use type (Fig. 2) but that trend changed between 1995 and 2005 during which no open areas were converted into either natural forests or natural shrub and grasslands (Fig. 2). During this period, more than 2.4 % of natural shrub and grasslands were converted into open areas. Open areas were replaced mainly by rubber plantation, tropical croplands, and pulp plantation on less steep slopes (<25°) (Fig. 2, 3f).

Table 2 Reforestation areas allocated to Wuzhishan County in the Sloping Land Conversion Program during 2002–2008, and the actually reforested areas

Years	Reforested area allocated (ha)	Sloping land reforestation (ha)	Bare land reforestation (ha)	Hainan Government's documents	Actually planted forestlands (ha)
2002	966.7	286.7	680	QJNJ [2003] 107	969.3
2003	3,866.7	2,133.3	1,733.3	QFNJ [2003] 647	3,876.1
2004	666.7	0	666.7	QFGNJ [2004] 481	666.7
2005	1,333.3	0	1,333.3	QFGNJ [2005] 889	1,333.3
2007	133.3	0	133.3	QFGNJ [2007] 1,369	133.3
2008	133.3	0	133.3	QFGNJ [2008] 1,310	133.3
Total	7,100	2,420	4,680	–	7,112

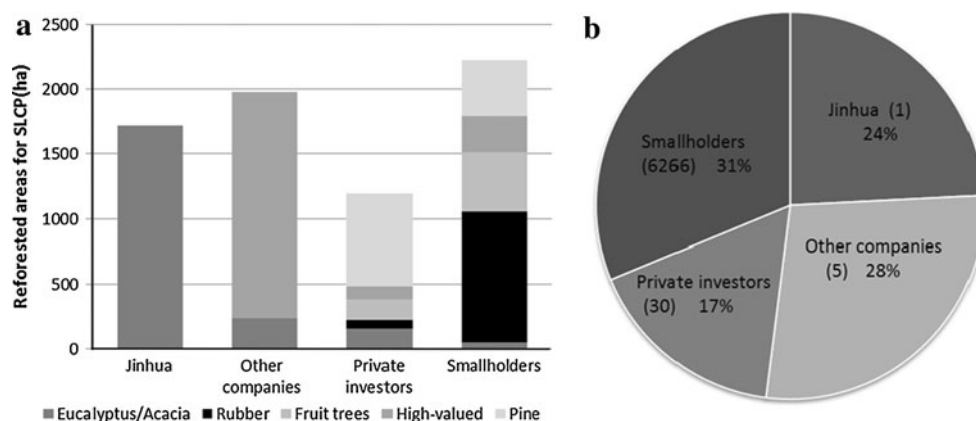


Fig. 4 **a** Reforested area of different species during the SLCP by each agent. *Eucalyptus* and *Acacia* includes *Eucalyptus grandis* × *Eucalyptus urophylla*, *E. urophylla* × *E. grandis*, *Eucalyptus* 12ABL, *Acacia mangium*, and *Acacia crassiparva*. *Rubber* indicates *H. brasiliensis*. *Fruit trees* refer coconut (*C. nucifera*), areca (*A. catechu*), mango (*Mangifera indica*), longan (*Euphoria longana*), litchi (*L. chinensis*) and so on. The high valued trees are largely well-known species with high timber values, which includes PNG basswood (*Eudosperrum*

chinese), redwoods (*Dalbergia odorifera* and *Dalbergia hainanensis*), Chinese eaglewood (*Aquilaria sinensis*), Yellow cheesewood (*Nauclea* sp.), and rattan (*Daemonorops margaritae*, *Calamus simplicifolius*). *Pine* plantation refers as *Pinus caribaea* in the study area. **b** Percentage of each agent's management of the SLCP lands. Four agents are involved in the SLCP: Jinhua Co., Ltd., other five companies, thirty private investors, and 6,266 smallholders

Four different groups of agents participated in the SLCP

From our limited data set, we discovered that four different groups of agents were involved in the SLCP (with percentage of total SLCP lands in parentheses): 6,266 smallholders (31 %); five private companies (28 %); the Jinhua Company (24 %); and 30 private investors (17 %) (Fig. 4). The Jinhua Company is separated from other agents as it is only involved in pulp plantation. The five private companies are mainly involved with high value economic species (Fig. 4). The smallholders directly control the lands they manage under the SLCP while the private investors must rent lands under the SLCP. Each group is subject to different management incentives and also has a distinct relationship with the local government, but more detailed analyses of these relationships go beyond the current study.

Discussion

The Sloping Land Conversion Program promotes expansion of plantations on marginal lands

The SLCP is implemented through multiple government quota systems from the central government down to the village level. These quotas promote legal reforestation activities on marginal slopes (25°–40°), including the planting of monoculture tree crops, but these lands would be better restored following ecologically sound principles (Zhang et al. 2000; Xu et al. 2009; Zhai et al. 2012). Coinciding with the initiation of the SLCP in Hainan, Zhai et al. (2012) found that plantation expansion was the main cause of deforestation in the upper Changhua watershed. Another study found that local villagers, through the SLCP, replaced previous swidden lands and natural shrub and

grasslands with rubber plantation and tropical crops (Umezaki and Jiang 2009). Swidden agricultural activity has been one of the most important traditional land-use systems in Southeast Asia (Mertz et al. 2009) and has been blamed as the main historical cause of deforestation in Hainan (Zhou 1995). In Xishuangbanna, another tropical area of China, local villagers also replaced their swidden lands, secondary forest, and natural forests with monocultural rubber plantation during the implementation of the SLCP (Li et al. 2007; Xu et al. 2009; Fu et al. 2010). The SLCP program seems to be changing this dynamic, replacing the relatively diverse and ecologically balanced swidden systems with plantations, particularly on marginal lands (Umezaki and Jiang 2009; Xu et al. 2009). In this study, we found that rubber, pulp and tropical croplands expanded significantly faster on slopes steeper than 25° in 1995–2005, compared to 1988–1995. Natural regeneration of forests was also slower in 1995–2005 compared to 1988–1995 (Fig. 2), providing further indirect evidence of the undesirable effects of the SLCP on natural forests (Xu 2011; Zhai et al. 2012). There should be concern when a national program designed to improve ecosystem services and stabilize marginal lands contributes to the replacement of natural forests with monoculture pulp and rubber plantations.

Large-scale monoculture plantations have also developed in other Chinese regions during the SLCP with serious ecological consequences (Cao 2008a, b; Gao et al. 2011). Some researchers in these areas of China posit that low precipitation caused problems with species suitability and poor survival rates (Liu 2008; Cao et al. 2011). However, in Hainan, even with higher precipitation and better survival rates, there were still serious ecological consequences as a result of this program (Cai et al. 2009).

A broad definition of “forests” can lead to the replacement of natural forests with plantations

The Chinese government defines rubber and pulp plantation as forests; from a policy perspective, this makes them equivalent to natural forests. But this definition is not based on ecological principles and has contributed to the expansion of plantations at the expense of natural forests (Xu 2011; Zhai et al. 2012). Official definitions of “ecological” forests combined with government planting programs that provide subsidies for participants to plant rubber, pine, *Eucalyptus* spp. and *Acacia* spp., leads to the expansion of plantations (Chen et al. 2009b; Xu 2011).

This is the government policy driver of the land-use conversions that our work revealed, but other factors also play a role. Survey data found that 69 % of the SLCP lands were controlled by companies and other private investors instead of smallholders (Fig. 4). In Hainan, the agents implementing (and benefitting from) the SLCP policy are

more often companies than villagers. In addition, unlike swidden agriculture lands and natural shrub and grasslands, plantations are assumed to have positive economic and ecological benefits (McElwee 2009; Xu et al. 2009). This may be true for both profit-seeking companies and smallholders seeking higher incomes. However, there are no cost/benefit analyses available on Hainan to test these assumptions and the limited data we collected were not sufficient to explore this further. The government policy definition of natural shrub and grasslands as “bare hills” is also ecologically problematic (Xu 2011). Equating plantations with natural forests in forest management policies has also contributed to the conversion of nature reserves, national protected areas, and important reservoir areas into monoculture plantations, causing serious environmental problems (Li et al. 2007; Xu et al. 2009; Greenpeace 2011; Zhai et al. 2012). The problem of equating natural forest with plantations is not unique to China and has affected forest dynamics and land-use change in tropical areas worldwide (Aziz et al. 2010; Putz and Redford 2010). To properly conserve and protect natural forests on Hainan, the next generation of studies should explore and link together three areas-policy, agents, and economic incentives. In policy, clear distinctions must be made between “production forests” and “ecological forests”, particularly for monoculture plantations comprised of exotic species. For agents, there should be better understanding of who specifically benefits from policies and how state policies help and/or hinder these agents. Third, the benefits and costs of policies should be calculated more carefully for both commercial agents and smallholders.

Reforestation programs on Hainan may continue to impact remaining natural forests

In Hainan, there are multiple ongoing reforestation projects with the purpose of increasing forest cover by 2015. These include the 100,000 ha Greening Hainan Island (Haikou Land Resources government web 2012) program, and the more than 100,000 ha “Pulp Plantation Base Project” (Zhai et al. 2012). Based on our research results in Hainan, we expect that about half of these new plantations will likely replace natural forests. In addition, production overcapacity of the pulp mill on Hainan Island with its shortage of raw material from local sources combined with growing Chinese demand for rubber (Li et al. 2007; Zhai et al. 2012) also adds conversion pressure on Hainan’s remaining natural forests. By 2016, the Hainan government plans to increase the island’s forest cover from 60.3 to 62 % (Hainan Government 2010). But this may well lead to more natural forest reduction since ongoing policies include rubber and pulp plantations in the definition of “forest” (Li et al. 2007; Viswanathan 2008).

Conclusion

To adequately protect Hainan's natural forests and to create ecologically sound reforestation policies, several issues need to be addressed. First, a more scientific definition of "forest" must be created to distinguish between profoundly different types of forest based on species composition and ecosystem function, including contributions to the conservation of biodiversity. This change should be a priority in the development of future forest policies in China. Continued use of the current definition will likely jeopardize tropical natural forests and their associated biodiversity functions (Xu 2011). Again, this issue affects tropical forests globally, given that a similar definition of forest is used by the United Nations Framework Convention on Climate Change, the Clean Development Mechanism of the Kyoto Protocol, and the FAO (Sasaki and Putz 2009). China could become a global leader in forest policy by creating ecologically meaningful definitions; in turn, these improvements could affect policy development in numerous types of forest in and beyond China.

Second, since 2000, the Hainan government has invested 57.28 million RMB (USD 9.19 million) to protect its natural forests and develop the island's nature reserves (State Bureau of Forestry Protection Division 2011). Currently, protected areas cover 7.1 % of the province's terrestrial area (Zhang et al. 2011) but if forest policies create conflicting incentives for different groups of agents, "reforestation" may cause declines in natural forests even while protected areas increase. Certainly, changing the current "forest" definition will help the efforts of the local government to protect natural forests and support natural regeneration. But it is also important to look more closely at which groups benefit from state policies and how this may contribute to loss of natural forests, and our study is limited in this regard.

Third, while the SLCP was designed to restore ecosystems and reduce poverty, regional market trends in Southeast Asia will continue to place major conversion pressure on natural forests in Hainan (Rudel et al. 2009). Rubber plantations are likely continued to expand as smallholders gain more economic benefits and commercial demand for rubber grows (Li et al. 2007; Manivong and Cramb 2008). There are also many government subsidies available for rubber and pulp plantings (e.g., the SLCP and Greening Hainan Island). In Xishuangbanna, China's other tropical forest region, demand, price, and government policies have also driven the expansion of rubber plantations and replacement of natural forests (Li et al. 2007; Liang et al. 2010; Xu et al. 2013). Our study area in Hainan has been identified as a priority protection area due to its high biodiversity, water and soil, and threatened species conservation values (Xiao et al. 2011; Zhang et al. 2011). However, Xishuangbanna also has high

conservation value, but this did not help to protect its natural forests. On the positive side, the Hainan government has recently passed the Hainan Non-commercial Forest Development Program (2010–2020), which aims to increase the area of non-commercial natural forest (The Central People's Government of the People's Republic of China 2012). This may lead to all current natural forests being protected and much of the remaining natural shrub and grasslands being restored or regenerated. Both rubber and pulp plantations as well as natural shrub and grasslands could also be managed as potential carbon sinks (Cao et al. 2011; Gao et al. 2011). The value of these lands should not be discounted and more concern should be paid to their regeneration and ecosystem-service benefits.

Last, the economic costs and benefits of spending billions of dollars on reforestation using non-native species in monocultural plantation should be more carefully explored. Hainan's reforestation and plans for payments for ecosystem services have major implications for future tropical rainforest conservation in both China and the world.

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References

- Antunes A (2000) Thematic resolution assessment merging Landsat and SPOT 10 m. *Int Arch Photogram Rem Sens. Spatial Inform Sci* 33 (B2; PART 2):52–55
- Aziz SA, Laurance WF, Clements R (2010) Forests reserved for rubber? *Front Ecol Environ* 8(4):178
- Cai Y, Liang C, Liang W (2009) Negative effects of plantations on bird diversity in Yinggeling Nature Reserve, Hainan Island. *Sichuan J Zool* 28:764–767 (in Chinese with English abstract)
- Cao S (2008a) Response to comment on "Why large-scale afforestation efforts in China have failed to solve the desertification problem". *Environ Sci Technol* 42(21):8166
- Cao S (2008b) Why large-scale afforestation efforts in China have failed to solve the desertification problem. *Environ Sci Technol* 42(6):1826–1831
- Cao S, Sun G, Zhang Z, Chen L, Feng Q, Fu B, McNulty S, Shankman D, Tang J, Wang Y, Wei X (2011) Greening China naturally. *Ambio* 40(7):828–831
- Chavez P, Kwarteng A (1989) Extracting spectral contrast in landsat thematic mapper image data using selective principal component analysis = Extraction du contraste spectral dans des images Landsat TM utilisant l'analyse sélective de composante principale. *Photogr Eng Rem Sens* 55(3):339–348
- Chen YH (2008) Avian biogeography and conservation on Hainan Island, China. *Zool Sci* 25(1):59–67 (in Chinese with English abstract)
- Chen X, Zhang X, Zhang Y, Wan C (2009a) Carbon sequestration potential of the stands under the Grain for Green Program in Yunnan Province, China. *For Ecol Manag* 258(3):199–206
- Chen XD, Lupi F, He GM, Ouyang ZY, Liu JG (2009b) Factors affecting land reconversion plans following a payment for ecosystem service program. *Biol Conserv* 142(8):1740–1747

- Congalton R, Green K (1999) Assessing the accuracy of remotely sensed data: principles and practices. Lewis, Boca Raton
- Ekstrand S (1996) Landsat TM-based forest damage assessment: correction for topographic effects. *Photogr Eng Rem Sens* 62(2):151–161
- Foody GM (2010) Assessing the accuracy of land cover change with imperfect ground reference data. *Rem Sens Environ* 114(10):2271–2285
- Francisco-Ortega J, Wang FG, Wang ZS, Xing FW, Liu H, Xu H, Xu WX, Luo YB, Song XQ, Gale S, Boufford DE, Maunder M, An SQ (2010) Endemic seed plant species from Hainan Island: a checklist. *Bot Rev* 76(3):295–345
- Fu Y, Chen J, Guo H, Hu H, Chen A, Cui J (2010) Agro biodiversity loss and livelihood vulnerability as a consequence of converting from subsistence farming systems to commercial plantation-dominated systems in Xishuangbanna, Yunnan, China: a household level analysis. *Land Degrad Dev* 21(3):274–284
- Gao G, Ding G, Wang H, Zang Y, Liang W (2011) China needs forest management rather than reforestation for carbon sequestration. *Environ Sci Technol* 45(24):10292–10293
- Greenpeace (2011) Disappearing tropical rainforests: Hainan tropical rainforests changes study in 2001–2010. Greenpeace. Accessed from <http://www.greenpeace.org/china/zh/publications/reports/forests/2011/hn-forest-2001-2010/> (in Chinese)
- Groom B, Grosjean P, Kontoleon A, Swanson T, Zhang S (2010) Relaxing rural constraints: a ‘win-win’ policy for poverty and environment in China? *Oxf Econ Pap New Ser* 62(1):132–156
- Haikou Land Resources Government Web (2012) Haikou has already collected 500 billion yuan for the Green Hainan Island Project, and this year will be plant 620,000 mu
- Hainan Government (2010) Hainan International Tourism Island Construction Scheme (2010–2020) (in Chinese)
- Hao Q, Liu Q, Zhong Q, Xin K (2009) 5 years vegetation restoration for key areas of conversion of crop land to forest in Hainan Province. *Protect Forest Sci Technol* (05):5–8 + 53 (in Chinese with English abstract)
- Jensen J, Lulla K (1987) Introductory digital image processing: a remote sensing perspective. *Geocarto Int* 2(1):65
- Li HM, Aide TM, Ma YX, Liu WJ, Cao M (2007) Demand for rubber is causing the loss of high diversity rain forest in SW China. *Biodivers Conserv* 16(6):1731–1745
- Li HM, Ma YX, Liu WJ (2009) Clearance and fragmentation of tropical rain forest in Xishuangbanna, SW, China. *Biodivers Conserv* 18(13):3421–3440
- Li J, Feldman MW, Li S, Daily GC (2011) Rural household income and inequality under the Sloping Land Conversion Program in western China. *Proc Natl Acad Sci USA* 108(19):7721–7726
- Liang J, Zhu H, Ma YX (2010) Land use, land cover change and conservation in the Dipterocarp rain forest area of southern Yunnan, China. *Gard Bull (Singapore)* 61(2):343–357
- Liu X (2008) Comment on “Why large-scale afforestation efforts in China have failed to solve the desertification problem”. *Environ Sci Technol* 42(21):8165
- Liu W, Hu H, Ma Y, Li H (2006) Environmental and socioeconomic impacts of increasing rubber plantations in Menglun township, southwest China. *Mt Res Dev* 26(3):245–253
- Liu J, Li S, Ouyang Z, Tam C, Chen X (2008) Ecological and socioeconomic effects of China’s policies for ecosystem services. *Proc Natl Acad Sci USA* 105(28):9477–9482
- Manivong V, Cramb RA (2008) Economics of smallholder rubber expansion in Northern Laos. *Agrofor Syst* 74(2):113–125
- McElwee P (2009) Reforestation “Bare Hills” in Vietnam: social and environmental consequences of the 5 Million Hectare Reforestation Program. *Ambio* 38(6):325–333
- Mertz O, Padoch C, Fox J, Cramb RA, Leisz SJ, Lam NT, Vien TD (2009) Swidden change in Southeast Asia: understanding causes and consequences. *Hum Ecol* 37(3):259–264
- Meyfroidt P, Lambin EF (2009) Forest transition in Vietnam and displacement of deforestation abroad. *Proc Natl Acad Sci USA* 106(38):16139–16144
- Mittermeier RA, Robles-Gil P, Hoffmann M, Pilgrim J, Brooks T, Mittermeier CG, Lamoreaux J, da Fonseca GAB (eds) (2004). *Hotspots revisited: Earth’s biologically richest and most endangered terrestrial ecoregions*. CEMEX, Monterrey; Conservation International, Washington DC; and Agrupación Sierra Madre, Mexico
- Putz FE, Redford KH (2010) The importance of defining ‘Forest’: tropical forest degradation, deforestation, long-term phase shifts, and further transitions. *Biotropica* 42(1):10–20
- Rudel TK, Defries R, Asner GP, Laurance WF (2009) Changing drivers of deforestation and new opportunities for conservation. *Conserv Biol* 23(6):1396–1405
- Sasaki N, Putz FE (2009) Critical need for new definitions of “forest” and “forest degradation” in global climate change agreements. *Conserv Lett* 2(5):226–232
- Schowengerdt RA (2007) *Remote sensing: models and methods for image processing*. Academic Press, London
- State Bureau of Forestry Protection Division (2011) Hainan has developed 30 forestry nature reserves (in Chinese)
- The Central People’s Government of the People’s Republic of China (2012) Forestry development and people enrichment: the Sloping Land Conversion Program turns out to be effective (in Chinese)
- Umezaki M, Jiang H (2009) Changing adaptive strategies of two Li Ethnic Minority Villages in a mountainous region of Hainan Island, China (<Special Issue> Land Use Changes in the Uplands of Southeast Asia: Proximate and Distant Causes). *東南アジア研究* 47(3):348–362
- Viswanathan P (2008) Global market integration and China’s rubber industry: challenges and the way forward. *Asian J Soc Sci* 36(5):792–826
- Wang WZ, Jiao JY (1996) Quantitative evaluation on factors influencing soil erosion in China. *Bull Soil Water Conserv* 16(05):1–20 (in Chinese with English abstract)
- Webb CO (2000) Exploring the phylogenetic structure of ecological communities: an example for rain forest trees. *Am Nat* 56(2):145–155
- Xiao Y, Chen SB, Zhang L, Yue P, Ouyang ZY, Liu XC (2011) Designing nature reserve systems in Hainan Island based on ecosystem services. *Acta Ecologica Sinica* 24:7357–7369 (in Chinese with English abstract)
- Xu J (2011) China’s new forests aren’t as green as they seem. *Nature* 477(7365):371
- Xu JC, Lebel L, Sturgeon J (2009) Functional links between biodiversity, livelihoods, and culture in a Hani Swidden Landscape in Southwest China. *Ecol Soc* 14(2):20
- Xu J, Grumbine RE, Beckshafer P (2013) Landscape transformation through the use of ecological and socioeconomic indicators in Xishuangbanna, Southwest China, Mekong Region. *Ecol Indic* (0) (in press)
- Zhai D-L, Cannon CH, Slik JWF, Zhang C-P, Dai Z-C (2012) Rubber and pulp plantations represent a double threat to Hainan’s natural tropical forests. *J Environ Manag* 96(1):64–73
- Zhang YB, Ma KP (2008) Geographic distribution patterns and status assessment of threatened plants in China. *Biodivers Conserv* 17:1783–1798
- Zhang YQ, Uusivuori J, Kuuluvainen J (2000) Econometric analysis of the causes of forest land use changes in Hainan, China. *Can J For Res* 30(12):1913–1921
- Zhang Y, Mao X, Li Y (2007) Forest ecosystems in the long sweep of history: an economic perspective. *Sci Silvae Sinicae* 43(9):96–104
- Zhang MX, Fellowes JR, Jiang XL, Wang W, Chan BPL, Ren GP, Zhu JG (2010) Degradation of tropical forest in Hainan, China, 1991–2008: conservation implications for Hainan Gibbon (*Nomascus hainanus*). *Biol Conserv* 143(6):1397–1404

- Zhang L, Ouyang Z, Xiao Y, Xu W, Zheng H, Jiang B (2011) Priority areas for biodiversity conservation in Hainan Island: evaluation and systematic conservation planning. *J Appl Ecol* 22(8):2105–2112 (in Chinese with English abstract)
- Zheng Z, Cour P, Zhou H, Qin C (2002) Modern pollen rain in Hainan Island, southern China: altitudinal pollen distribution in the tropical rain forest. *Acta Palaeontol Sin* 41(4):487–496
- Zhou GY (1995) Influences of tropical forest changes on environmental quality in Hainan province, PR of China. *Ecol Eng* 4(3):223–229
- Zhu H, Zhou H-X (2002) A comparative study on the tropical rain forests in Xishuangbanna and Hainan. *Acta Bot Yunnanica* 24(1):1–13 (in Chinese with English abstract)