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Rubber and pulp plantations represent a double threat to Hainan's natural tropical forests

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A B S T R A C T

Hainan, the largest tropical island in China, belongs to the Indo-Burma biodiversity hotspot and harbors large areas of tropical forests, particularly in the uplands. The Changhua watershed is the cradle of Hainan's main river and a center of endemism for plants and birds. The watershed contains great habitat diversity and is an important conservation area. We analyzed the impact of rubber and pulp plantations on the distribution and area of tropical forest in the watershed, using remote sensing analysis of Landsat images from 1988, 1995 and 2005. From 1988 to 1995, natural forest increased in area (979–1040 sq km) but decreased rapidly (763 sq km) over the next decade. Rubber plantations increased steadily through the study period while pulp plantations appeared after 1995 but occupied 152 sq km by 2005. Rubber and pulp plantations displace different types of natural forest and do not replace one another. Because pulp is not as profitable as rubber and existing pulp processing capacity greatly exceeds local supply, considerable pressure exists on remaining upland forests. We recommend for future management that these plantation forests be reclassified as 'industrial', making a clear policy distinction between natural and industrial forestry. Additionally, the local government should work to enforce existing laws preventing forest conversion on marginal and protected areas.

1. Introduction

Tropical deforestation is an expanding global phenomenon (Skole and Tucker, 1993; Hansen et al., 2008; Sehgal, 2010). Deforestation can alter whole ecosystems, affect disease transmission (Taylor, 1997; Yasuoka and Levins, 2007), cause loss of biodiversity (Gardner et al., 2009), and change regional and global climate (Foley et al., 2005). The largest cause of tropical deforestation is the expansion of agricultural crops and plantations (Sala et al., 2000; Sodhi et al., 2004; Edwards et al., 2010; Laurance, 2007; Butler and Laurance, 2008; Gibbs et al., 2010; Wilcove and Koh, 2010). Previous research has indicated that small-scale swidden agriculture played a major role in deforestation and forest degradation in Hainan (Zhou, 1995) but recently, industrial enterprises have established large-scale plantations of exotic, fast-growing trees, linking deforestation to global markets (Rudel et al., 2009). The changing trends in the drivers of deforestation led Rudel et al. (2009) to predict that deforestation, particularly in Southeast Asia, will intensify in the lowlands as uplands become depopulated and go through a period of natural regrowth.

Hainan Island is the only major island in the Indo-Burma biodiversity hotspot, which ranks among the top eight hotspots in the world (Myers et al., 2000; Schowengerdt, 2007). Its flora and fauna possess a high level of overall diversity and endemism, particularly among mammal and bird species (Huang et al., 2004; Chan et al., 2005; Wang et al., 2006; Chen, 2008). Its biogeographic position in China is also unusual. Distribution patterns and genetic evidence in plants and animals indicate that the island shares a stronger historical and biotic connection with Southeast Asian countries, such as the Philippines and Malaysia, than with mainland China (Zhu and Roos, 2004; Su et al., 2007; Chen, 2009; Dong, 2009).

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In 1988, China designated Hainan Island as a Special Economic Zone and separate province. The island rapidly became a major center for importing and processing natural resources, such as coconut and pulp (Zhang et al., 2000), creating a quasi-colonial status for the island to meet the demand of the mainland for tropical crops (Xu et al., 2002). The island has a long history of plantation forestry, starting with rubber and, more recently, pulpwood trees including *Eucalyptus* spp. and *Acacia* spp. (Barr and Cossalter, 2004). Rubber was introduced more than fifty years ago to ensure a steady supply of raw rubber latex, especially for military purposes (Guo et al., 2006). Until 1979, rubber was strictly controlled by state farms (Lardy, 1983), but with the introduction of a household responsibility system, smallholders were able to plant rubber (Viswanathan, 2008). Most of the rubber plantations were originally planted by the state farm, typically in large areas, while the small holders were not greatly involved in rubber plantations until 1995 (Umezaki and Jiang, 2009) and only after 2000 (Xu, 2010) did they expand rubber planting. In 1982, the “2 million mu (1333 sq km) joint plantation of fast-growing and high yield tree species (*Eucalyptus* spp.)” project was officially launched (Zhang et al., 2000). In 1995, the Asia Pulp and Paper Co. Ltd. (APP) was established in Hainan and built its Hainan Yang Pu mill. In 1997, the State Council of the People’s Republic of China approved APP-Hainan Jinhai’s project to build a 600,000 ton pulp mill and to establish a 2330 sq km pulp plantation base to supply the mill.

The recent introduction of pulpwood plantations to the inland forests of Hainan Island allows us to examine the effects of these new plantation species on existing land-use patterns, particularly in relation to rubber (*Hevea brasiliensis*), a well-established and highly profitable plantation species. We can also test whether the hypothesis proposed by Rudel et al. (2009) that increased activities of industrial plantations, focusing their efforts on lowland areas, generally leads to reforestation in the uplands is true for Hainan. Remote sensing is an efficient and politically transparent technique for tropical forest monitoring and management, through the analysis of a time-series of satellite images, and it has become widely accepted by both policymakers and the general public (Baker and Williamson, 2006; Wulder and Franklin, 2007; Wiens et al., 2009). We use a remote sensing approach to address several questions about forest cover changes in a central watershed of Hainan island from 1988 to 2005: 1) where were the pulp plantations created, and what types of forest did they replace; 2) did pulp plantations have any impact on the distribution or expansion of rubber plantation; 3) were protected areas affected differently by rubber and pulp plantations from that of unprotected area; and 4) what major policies or factors might drive future change?.

2. Material and methods

2.1. Study area

Hainan Island (18°10′–20°10’N and 108°37′–111°03 ’E, Fig. 1) is the largest tropical island in China, with an area of 33,920 km^2 (Lopez et al., 2009) and 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). The island has a tropical monsoon climate,

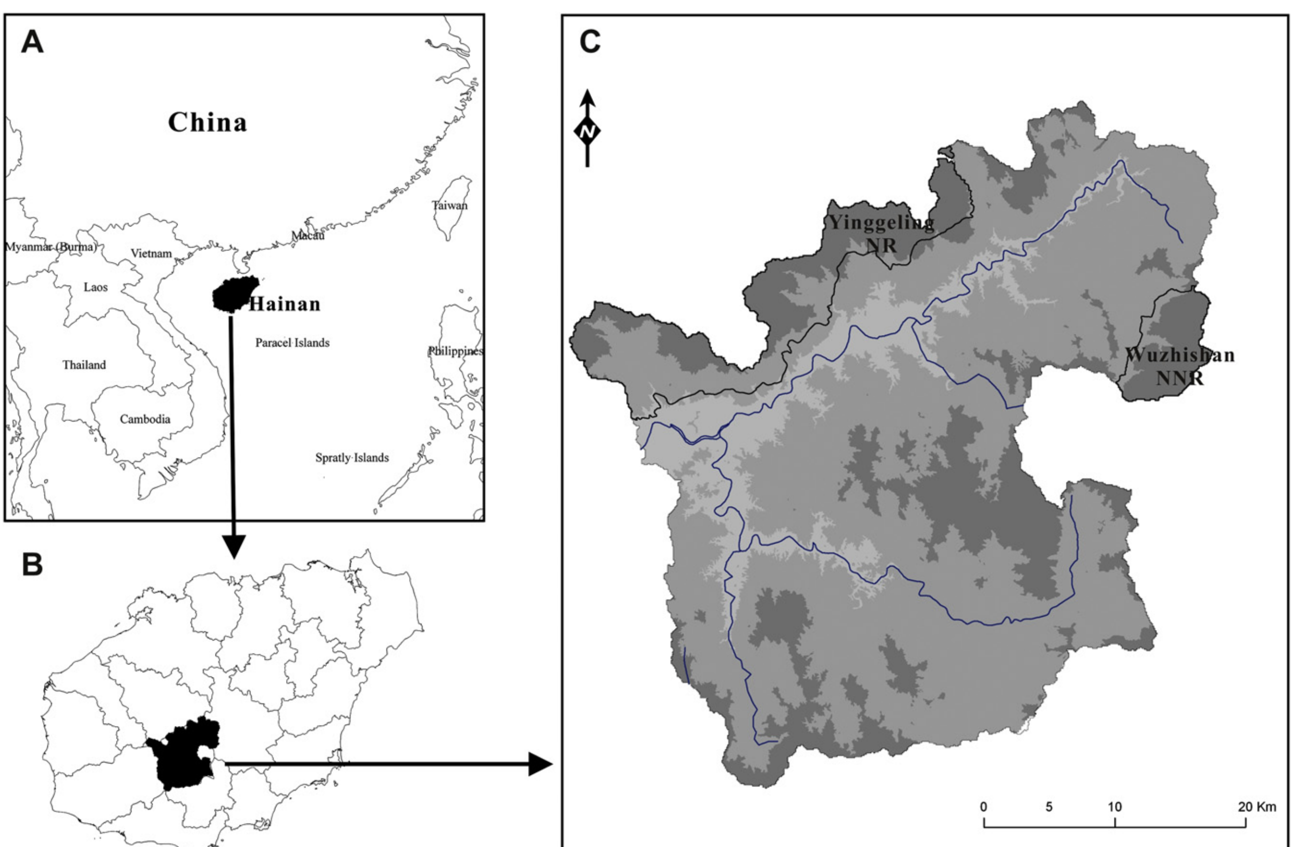

Fig. 1. The Changhua watershed on the island of Hainan, China: A) Image of China showing the position of Hainan Island; B) Hainan with the location of the study area indicated by black; C) the watershed with the nature reserves and elevation classes indicated by the gray shading: light gray indicates 70–300 m, medium gray 300–750 m, and black indicates 750–1860 m elevation.

Table 1
Land-use change in the Changhua watershed on Hainan island, China compared between protected and unprotected areas, represented by the total area, the relative area, the absolute amount of change, and the rate of change of each land class for each time period of the study. Land classes: NF-Natural Forest; NS&G-Natural Shrubs and Grasslands; TC-Tropical Crops; RP-Rubber Plantation; OA-Open Area; PP-Pulp Plantation.

	Area (ha)			Relative area (%)			Absolute amount (ha yr^{-1})			Change rate (% yr^{-1})		
	1988	1995	2005	'88	'95	'05	'88-'95	'95-'05	'88-'05	'88-'95	'95-'05	'88-'05
Protected area												
NF	548.2	584.2	562.2	86.3	92.2	88.8	5.16	−2.21	0.82	0.94	−0.38	0.15
NS&G	79.2	45.1	35.1	12.5	7.1	5.5	−4.87	−0.99	−2.59	−6.15	−2.2	−3.28
TC	0.4	0.9	3.1	0.1	0.1	0.5	0.07	0.22	0.16	17.28	22.88	−39.7
RP	2	1.8	15.9	0.3	0.3	2.5	−0.03	1.41	0.82	−1.31	79.04	40.88
OA	5.6	1.3	4.8	0.9	0.2	0.8	−0.61	0.35	−0.05	−10.97	26.71	0.84
PP	0.08	0	12.2	0.01	0	1.93	−0.01	1.22	0.71	−14.29	–	891.18
Unprotected area												
NF	97361	103438	75743	66.3	70.4	51.6	868.1	−2769.5	−1271.6	0.89	−2.68	−1.31
NS&G	18813	13300	6543	12.8	9.1	4.5	−787.6	−675.7	−721.8	−4.19	−5.08	−3.84
TC	3151	4034	9110	2.1	2.7	6.2	126.2	507.6	350.5	4.01	12.58	11.13
RP	8324	12924	26760	5.7	8.8	18.2	657.2	1383.6	1084.5	7.89	10.71	13.03
OA	19227	13176	13450	13.1	9	9.2	−864.5	27.4	−339.8	−4.5	0.21	−1.77
PP	2.3	22	15289	0.0	0	10.4	2.8	1526.7	899.2	121.42	6939.4	38825.7

Notes: Absolute Amount = $(A_{ye}-A_{yb})/T$, Change Rate = $(A_{ye}-A_{yb})/A_{yb} \times 1/T \times 100\%$, A_{yb} is the area of a land cover in the beginning year of a study period, A_{ye} is the area of a land cover in the end of a study period. T is the time length.

with a rainy season from May to October and a dry season from November to April (Luo, 1985). The study area is located in the upper Changhua Watershed, southern Hainan, which is one of eight plant conservation hotspots in China (Zhang and Ma, 2008). The watershed ranges from 169 to 1860 m in elevation above sea level. The interior uplands of the island are characterized by great habitat diversity and have been recognized as one of the eleven Critical Terrestrial Regions for Biodiversity (Compilation Group of China's Biodiversity, 1998) and one of 33 Terrestrial Priority Conservation Areas in China (Xie et al., 2009). The Changhua River is the cradle of Hainan's main river (Feng et al., 1999) and has been identified as a center of endemism for plants and birds (Wang et al., 2006; Chen, 2008).

2.2. 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 different years: 1988, 1995, and 2005 (see S1). The TM and SPOT images of 1995 and 2005, corrected for atmospheric and radiometric distortions, were bought from Beijing Spot Image Co. Ltd. The 1988 Landsat TM image was downloaded from Earth Explorer (http://edcsns17.cr.usgs.gov/EarthExplorer/). This 1988 image had already been preprocessed according to a standardized set of processing parameters and orthorectified using geodetic and elevation control data to correct for positional accuracy and relief displacement. The data were topographically corrected by coregistering them to a digital elevation model (DEM) (Ekstrand, 1996), derived from topographic maps (scale = 1:50,000) provided by the Chinese State Bureau of Surveying and Mapping. The TM images were then rectified to the Pulkovo 1942 Transverse Mercator projection system and then registered against a reference image from the year 2000 to ensure a root mean square error of less than one pixel. To enhance the resolution, the multispectral TM and the SPOT panchromatic band images were fused, using principal component analysis (PCA) on PCI software (Chavez and Kwarteng, 1989; Pohl and van Genderen, 1998; Antunes, 2000), to obtain a 10 m resolution multispectral composite image.

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" represented a transition between abandoned agricultural land and forest as an alternative climax community after the removal of natural forest. A data layer for this land-cover type was provided by Hainan Environmental Science Institute and used in the initial classification efforts. "Tropical crops" consisted of *Cocos nucifera, Areca catechu, Anacardium occidentale, Litchi chinensis* plantations and tea gardens. "Rubber plantations" were identified by the characteristic image texture, land form and landscape terracing. These areas were mainly confined to state farms. "Pulp plantations" were distinguished by their special image color and hue, in combination with a reference data layer provided by Jinhua Forestry Co. Ltd. "Open areas" included shifting cultivation, paddy rice, cultivated lands, rivers, pools, cities, villages and industrial lands.

Further land-cover classification was performed on the non-thermal channels of the composite images for each year, using the supervised maximum likelihood classification method (Jensen and Lulla, 1987) in ERDAS 9.0. The results were manually edited in ArcGIS (Version 9.3.1, ESRI) 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 the classification errors caused by differences in satellite image resolution, we continued to do transformation using clump and elimination so that all polygons <900 m^2, equivalent to 1 pixel, 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 (Richards and Jia, 2006; Li et al., 2007; Schowengerdt, 2007) were selected to reflect the variation due to topography and growing condition.

The classification accuracy was evaluated in terms of producer's accuracy, user's accuracy, and overall accuracy, which is commonly calculated by an error or confusion matrix (Congalton and Green, 1999; Foody, 2010). Six hundred points were sampled during field surveys in 2006 and 2007 for the accuracy assessment. The land-cover map for 2005 was generally reliable (the overall classification accuracy and Overall Kappa Statistics was 83.5% and 80.8% respectively, see S2), especially for the rubber plantation with 96% accuracy after manual interpretation, although rubber plantations were generally under-estimated, confused most frequently with natural forest and tropical crops. The classification accuracy assessment of 1995 was based on the assumption that images of the same resolution and spectral quality would achieve the same level of accuracy. No accuracy assessment of the 1988 image was performed because no appropriate images or ground truth data were available, but we are confident that the level of accuracy after supervised classification, using multiple sources of ancillary data as a reference, is equivalent to the 2005 image after careful visual interpretation.

The association of the different land-cover classes with both elevation and slope was examined for each year, using random permutation tests (Webb, 2000). For the elevation tests, we used three different classes to capture differences in conservation value and human activity (Fu and Feng, 1995; Yang et al., 1995; Lin and Zhang, 2001; Wang et al., 2001): Low (169–300 m above sea level); Mid. (301–750 m asl) and High (751–1860 m asl). For the slope tests, we considered soil erosion and existing laws to create four classes: 0–10; 11–25; 26–40; and >40° (Wang and Jiao, 1996; Hill and Peart, 1998; Zhang et al., 2004). To remove any possible effects of spatial auto-correlation in the association between land-cover and the two environmental factors, we performed the permutation tests on a 15% random subsample of the image. We performed 250 permutations to generate the 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.

3. Results

3.1. Pulp plantation mainly displaced natural forests in the uplands

Natural forests expanded slightly between 1988 and 1995 (Table 1, Fig. 2) and a small fraction of natural forest was converted to rubber plantation and tropical crops, while pulp plantations were basically absent. Natural forests regenerated mainly from the natural shrub-grasslands and open areas between 1988 and 1995 (Table 1, Fig. 2), while almost no plantation areas returned to natural forest. These trends changed dramatically in the following decade with conversion of 21,000 ha (or 22%) of natural forests into rubber and pulp plantations and tropical croplands (Table 1, Fig. 2). The rapid expansion of pulp plantations between 1995 and 2005 primarily occurred in natural forest areas (58%), predominantly at mid and high elevation areas with a bias against low elevation (Fig. 3). In a similar fashion, pulp plantations were primarily on mid-range slopes while being significantly under-represented on flat areas (Figs. 3 and 4). Meanwhile, natural shrubs and grasslands declined dramatically throughout the study period at mid-elevations and on mid-range slopes.

Only a small fraction of open area was converted to rubber or pulp plantations, while no conversion from rubber to pulp plantations took place (Fig. 2). Very little natural vegetation remains at lower elevations and on flat areas (Figs. 3 and 4), which were largely occupied by tropical crops and rubber plantations. Rubber plantations, open areas, and tropical crops were almost non-existent at high elevations (Fig. 3). The appearance of pulp plantations between 1995 and 2005 did not displace the rubber plantations in the lowlands but instead replaced upland natural forests.

3.2. Protected areas suffered similar trends but lower rates of conversion

This study area included portions of two nature reserves, WuZhiShan National Nature Reserve (WZS) and YingGeLing Nature

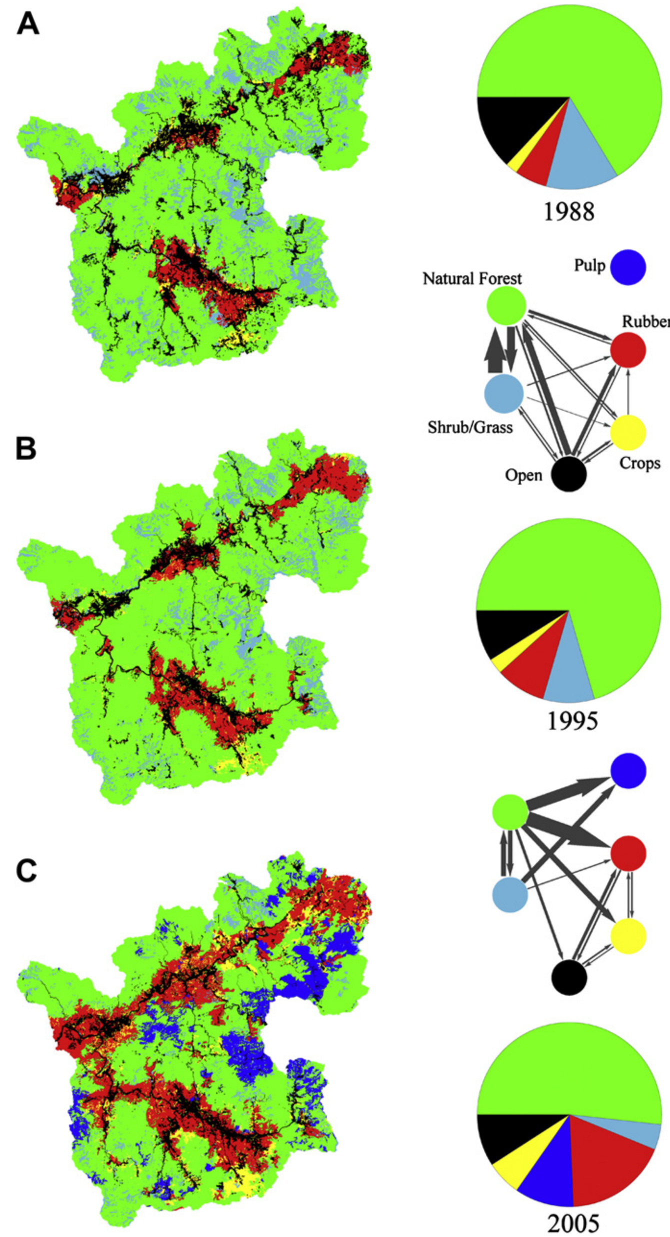

Fig. 2. Land-cover change in the Changhua watershed from 1988 to 2005. Maps shown in the left column illustrate the spatial distribution of land-use classes: A) 1988; B) 1995; and C) 2005. Pie-charts in right column indicate the relative proportion of each land-use class for each time period. Transition matrices separating each pie-chart indicate the change between land-use types, with the thickness of the arrows indicating the relative amount of change. Color-coding follows the labels on the first transition matrix. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Reserve (YGL). From 1988 to 1995, the proportion of protected natural forest increased from 86.3% to 92.2% while the natural shrubs and grasslands decreased from 12.5% to 7.1%. The rate of natural forest increase (0.94% y^{-1}) in the protected area was larger than in the unprotected area (0.89% y^{-1}), and the rate of natural shrubs and grasslands loss in the protected area (6.15% y^{-1}) was larger than in unprotected area (4.19% y^{-1}). The trends of natural forest and natural shrubs and grasslands in unprotected areas were similar to those of protected areas (Table 1). The annual loss rate of natural forest and natural shrubs and grasslands in the unprotected areas were much higher (a. 2.3%/yr and 2.8%/yr) than that of the

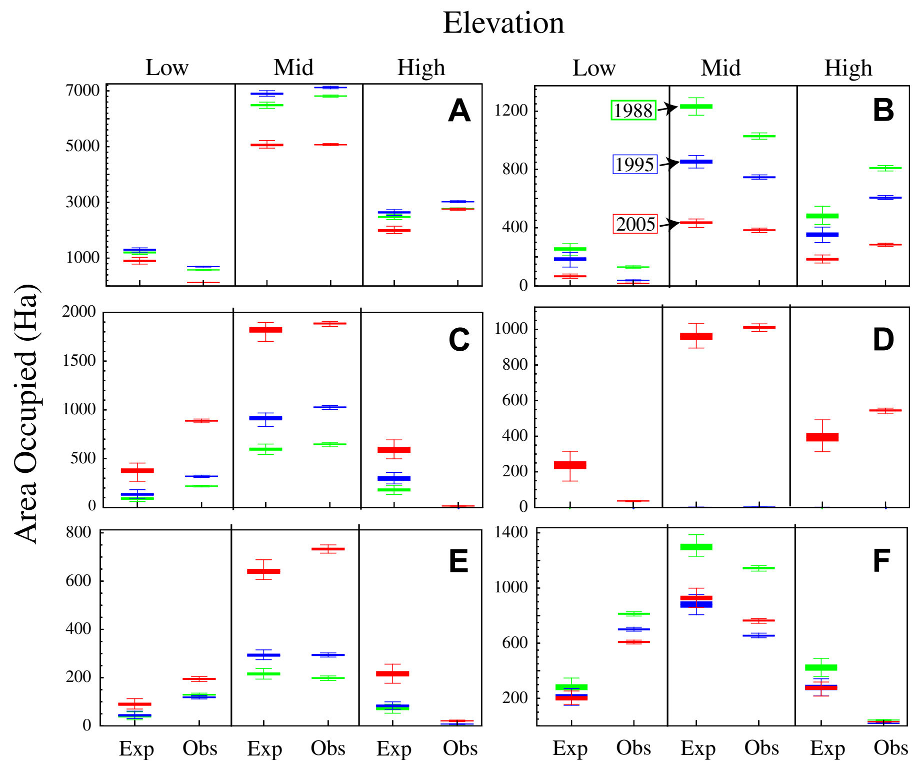

Fig. 3. Change in area for each land-use type according to elevation in the Changhua watershed. A) Natural Forest; B) Natural Shrubs and Grasslands; C) Rubber Plantations; D) Pulp Plantations; E) Tropical Crops; and F) Open Area. Observed (Obs) and Expected (Exp) values for each elevation class represent means, 1 standard deviation and 95% confidence limits. The distribution for the expected values was generated using 250 randomizations given a 15% sub-sampling rate. Values for each year are color-coded as labeled. The elevation was divided into three different classes: Low (169–300 m above sea level); Mid (301–750 m asl) and High (751–1860 m asl). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

protected area. A more dramatic expansion of rubber plantations occurred in protected than unprotected areas from 1995 to 2005 (Table 1), while pulp plantations expanded primarily in unprotected areas.

Comparing the two nature reserves, YGL nature reserve lost more natural forest types (806 ha) than the WZS nature reserve (96 ha) during the study period (see S3). The most dynamic zones concerning land-cover changes were the experimental zone in the YGL nature reserve and the buffer zone in the WZS nature reserve (Table 2). Additionally, natural forest types in the core zones of the YGL nature reserve experienced a slightly larger reduction in area than in the WZS nature reserve (from 1988 to 2005: forest cover changed from 99.85% to 97.99% vs. 99.69%–99.62%, respectively).

4. Discussion

4.1. Rubber and pulp plantations are separate threats to Hainan's natural forests

A slight recovery of natural forests between 1988 and 1995 followed the separation of Hainan Island from Guangdong Province and the creation of the Hainan Special Economic Zone (SEZ), agreeing with results from Lin and Zhang (2000) but over the next decade, plantation forests expanded dramatically, displacing natural forests and shrubs/grasslands primarily at low and mid-elevations. Rubber plantations were almost entirely concentrated in these two lower elevation classes (Fig. 3C) but pulp plantations were predominant in the mid and high elevations (Fig. 3D), indicating these two land-cover types only compete for land in the mid-zone. However, together they effectively displace natural forests across the entire landscape.

Rubber plantations, managed by centralized state farms in the past, were not displaced by pulp plantations, despite the strong demand of pulpwood from the large processing capacity on the island, for two reasons: 1) rubber plantations provide a continuous revenue stream over a long economic lifespan (~30 years) while pulp plantations are harvested one time, every five to seven years and 2) rubber is substantially more profitable, as rubber plantations produced 11,178 yuan/ha in 2003 (Huang, 2005), while the farmers could only get 450–490 yuan/ha (Greenpeace, 2004) to 1500 yuan/ha (Wang and Lin, 2000; Peng et al., 2006) by planting pulp. Compared with the recently introduced pulp plantations, rubber plantations have made a steady contribution to Hainan GDP and Hainan economic growth (Deng, 2006) and are a main source of farms' income in this region (Cadario et al., 1992; Huang, 2005; Deng, 2006).

But pulpwood plantations on Hainan have been strongly promoted by the Chinese government as one of the thirteen national high priority pulp and paper projects, with the aim to develop a domestic wood pulp industry and meet the growing domestic demand. The Chinese government provided substantial capital subsidies in the form of low interest rate on loans, discounted loans, and extended repayment periods for loans from state banks (Barr and Cossalter, 2004, 2005), thus stimulating the construction of pulp processing mills despite the lower overall profitability. Government policymakers must be careful not to create 'perverse' incentives, where inefficient and destructive activities are encouraged at the expense of conversion of high conservation and environmental value forests of the watershed. The substantial transition in land cover from natural forest to intensive plantations in our study area had been observed across the entire island but on a shorter time scale (Zhou, 1995).

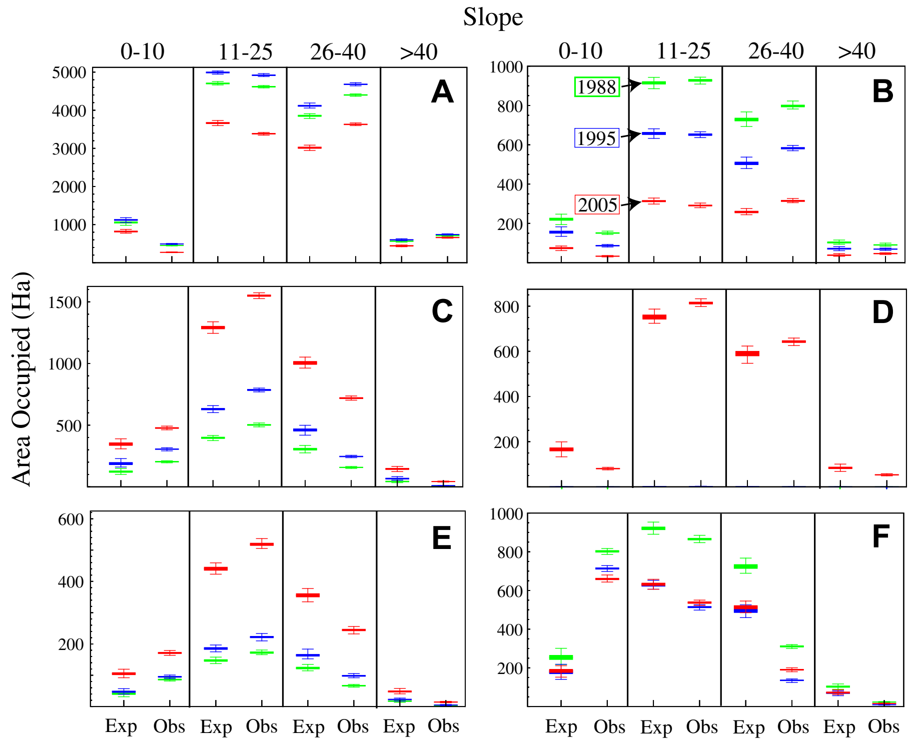

Fig. 4. Change in area for each land-use type according to slope in the Changhua watershed. A) Natural Forest; B) Natural Shrubs and Grasslands; C) Rubber Plantations; D) Pulp Plantations; E) Tropical Crops; and F) Open Area. Observed (Obs) and Expected (Exp) values for each slope class represent means, , 1 standard deviation and 95% confidence limits. The distribution for the expected values was generated using 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: 010; 11–25; 26–40; and >40°. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

4.2. Overcapacity of the pulpwood mill is a main factor in the deforestation of Hainan's forests

According to APP-Jinhai mill's announcement, the pulpwood mill initiated production in 2004, with an installed capacity of 1.1 million air-dried tons per year (Adt/yr) for bleached hardwood kraft pulp (BHKP). However, in the same year, only 375,000 m^3 of harvestable pulpwood existed, assuming an annual mean increment (MAI) of 12 m^3/ha/yr and based on a six year rotation cycle (Table 3) and the assumption that 4.15 m^3 of solid debarked roundwood is needed to produce 1.0 Adt of pulp (Barr and Cossalter, 2004). The installed capacity of 1.1 million Adt/yr for BHKP in 2004 will require at least 4,565,000 m^3 of pulpwood per year, leading to a major shortage of locally produced pulpwood. Nonetheless, the Hainan Jinhai mill continued to expand to 1.2Adt/yr in 2005, with further plans to reach a maximum capacity of 2.4 million Adt/yr of BHKP and 3.6 million tons of paper in the near future. In 2005, the amount of harvestable pulpwood plantations increased to 8809 ha (Table 3) which still equaled only 12% of the pulpwood mill capacity of 5.0 million m^3. The disparity is further exacerbated by the low quality of current pulp forests, of which only about 6,600 ha can be used due to improper management and the restriction of logging quotas (Greenpeace, 2004; Liu, 2007). The overcapacity and the raw material shortfall were balanced by wood imported from other parts of China and from abroad (Barr and Cossalter, 2004). However, the overcapacity of the pulp mills on Hainan Island threaten natural forests in other countries, particularly in the Mekong region or Indonesia (Barr, 2001; Lang, 2002; Greenpeace, 2004), given the increasing trends of globalized trade.

4.3. Impact of the expansion of rubber and pulp plantation on protected areas

From 1988 to 1995, the restoration of natural shrubs and grasslands into natural forest was linked to the introduction and implementation of new provincial forestry policies and strategies: 1) the conservation and rehabilitation of mountain areas in the 1980s (Zhang et al., 2000); and 2) a logging ban in natural forest, which was enacted in 1994 (Zhang et al., 2000; Xu et al., 2004). However, after 1995, the introduction of pulp plantation and the

Table 2
The proportion of change of natural forest, rubber plantation and pulp plantation in the corresponding functional zones in the YingGeLing and WuZhiShan nature reserves in 1988–1995(%) and 1995–2005(%). Functional zones: core = "core zone", buff = "buffer zone" and exp = "experimental zone".

	YingGeLing						WuZhiShan					
	1988–1995			1995–2005			1988–1995			1995–2005		
	Core	Buff	Exp	Core	Buff	Exp	Core	Buff	Exp	Core	Buff	Exp
NF	3.1	1.8	1.8	−0.1	−0.9	−2.3	1.8	0.8	0.2	−1.7	−2.2	−0.2
RP	0	0	0	0.2	0.4	2.1	0	0	0	0	0.2	0
PP	0	0	0	0.7	0.9	0.2	0	0	0	0.2	2.2	0

Table 3
The history of pulp plantation establishment by APP-Hainan Jinhua Forestry Co., including the areas of mature harvestable stock and projected wood volume output. The wood density (1.25 ton/m^3) used to calculate the projected output volume of wood is from http://www.featuretimbers.com.au/wooddata.html.

Year	Annual plantation establishment (ha)	Area ready for harvesting (ha)	Projected output volume of wood (m^3)	Notes
1997	5817	–	–	–
1999	8989	–	–	–
2000	29,683	–	–	–
2003	11,845	–	–	–
2004	5604	5244	375,000	Logging the area cultivated in 1997
2005	5912	8809	437,500	Logging the area cultivated in 1999
Sum	67,851	14,053	812,500	–

continued expansion of rubber plantations reversed this pattern with pulp plantation replacing the natural forests on mid and high elevations and steep slopes, and the rubber plantation replacing natural forests at lower elevation. The high rate of rubber plantation expansion in protected areas is especially troubling, especially given the significant changes in hydrological cycles and water storage caused by these plantations (Guardiola-Claramonte et al., 2008, 2010).

The two reserves, Yinggeling Nature Reserve (YGL_NR) and Wuzhishan National Nature Reserve (WZS_NNR), are actually threatened by different types of plantation, with rubber surrounding the former and pulp surrounding the latter (Fig. 2C). While protected areas were not generally converted as rapidly as unprotected areas, the separate and largely non-overlapping threats presented by both pulp and rubber plantations to the protected area indicate a need for comprehensive policies (Zhou and Edward Grumbine, 2011) and clear implementation and enforcement. The lack of clarity in China's current protected area administration system could be also responsible for the deforestation and expansion of plantations in protected areas (Zhou and Edward Grumbine, 2011). Finally, the joint venture of investment of APP-Hainan Jinhua Forestry Co. Ltd with the Hainan government in the development of high capacity pulp mills is a probable driver of plantation expansion into protected areas (State Forest Administration, 2002; Pirard and Irland, 2007). Additionally, both plantation types expanded on medium and steep slopes (Fig. 4C–E), particularly the pulp plantations, violating the policy banning clearing and cultivation on steep slopes of 25°–40°, indicating poor enforcement of existing policy.

The Provincial Forestry Department plans to create a 3500 km^2 forest and wildlife protection area by 2010 in Hainan, requiring an increase of 2.8 times the existing nature reserve system in 2000 (Wu, 2000; Zhang et al., 2010). Unfortunately, this plan defines both rubber and pulp plantations as "forest" (Li et al., 2007; Viswanathan, 2008). In China, "forest" is defined as both natural and planted forests with a canopy density greater than 0.3 before 1994 and larger than 0.2 after 1994 (Xiao, 2005). According to this definition, plantation forests have contributed greatly to forest coverage in China (Zhang, 2007). The problem of equating natural forest and plantation forest as definitions for land-cover systems goes far beyond China. For example, the UN Food and Agriculture Organization (FAO) and Clean Development Mechanisms (CDM) have the same problem (Putz and Redford, 2010).

The equivalence of plantations and natural forests in forest management policies has significant environmental consequences (Rudel et al., 2005). This undiscriminating definition of forests led to the legal and widespread conversion of natural forests into plantations in other Southeast Asian countries (Aziz et al., 2010). In China, the transition in the past decade from net forest loss to net forest expansion was confounded by the lack of distinction between plantations, reforestation and natural regeneration (Mather, 2007). The Southeast Asia region has experienced serious deforestation caused by agricultural expansion and other human activities, jeopardizing local forest biota and threatening remaining tropical rainforest (Brook et al., 2003; Koh and Wilcove, 2007, 2008, 2009; Sodhi et al., 2010). Although some have argued that plantations can contribute to the biodiversity conservation and forest species' restoration, the conversion of natural forests to plantations is deleterious for biodiversity (Bremer and Farley, 2010). The conversion of natural forests to rubber and pulp plantations also accelerates soil erosion (Zeng et al., 2009; Zheng et al., 2009), particularly on steeper slopes (Zeng et al., 2009). For the purpose of conservation and the value of natural forests, plantation forests should be redefined as "industrial forests".

Regional market trends in Southeast Asia will cause major conversion pressure on natural forests in Hainan (Rudel et al., 2009). Rubber plantations are likely to expand under the new regulations and as the demand for and consumption of rubber grows (Li et al., 2007; Manivong and Cramb, 2008). As smallholders become increasingly involved, rubber generates a new source of revenue for rural people, bringing about a great economic transformation with social, culture, and ecological consequences (Xu et al., 2005, 2009; Sturgeon and Menzies, 2006; Sturgeon, 2010). In Xishuangbanna, SW China, the demand, price, and government policies were the driving force behind the expansion of rubber plantations and decrease of natural forests (Li et al., 2007; Liang et al., 2010).

The high price of rubber and increasing demand for pulpwood in China has been affecting the natural forests of neighboring countries, leading to the launch of rubber plantation programs (Manivong and Cramb, 2008; Qiu, 2009; Mann, 2009) and stimulating international timber trade (Lang, 2002). Additionally, improved varieties of rubber trees that remain productive at higher elevations have been developed (Li et al., 2007, 2008), implying more pressure on upland forests and potentially pushing pulp plantations onto even higher and more marginal areas. With the ongoing reform in forest policy in China and with property rights being transferred to smallholders who will have much greater freedom in the management choices (Zhang et al., 2000). From 2000 to 2005, two thirds of the rubber was controlled by state farm, and the remaining one third was controlled by small holders (Yi and Fu, 2007; Xu, 2010).

In 2008, Hainan's state farm tenure policy was reformed, in a program called 'mature rubber garden staff-household long-term contract system' with a principle of 'delivering part of the latex to the state with the remaining latex owned by the contractors with a uniform latex purchase authority that pays the market price'. For the impact of this reform on rubber planting, we don't have any empirical evidence but according to the published Chinese material they raised the employees' income (Tan and Cai, 2010). If this is true, then one would expect rubber planting by smallholders to greatly expand because of its great profitability. No previous research has examined the disadvantages of the tenure reform and expansion of rubber plantations, so further research is required. Finally, we did not find any major impact by swidden agriculture, contrary to previous results (Zhou, 1995). Instead, the intensification of plantation forestry was the main cause for deforestation.

4.4. Conclusion

Rubber and pulp plantations are rapidly expanding in a major watershed in central Hainan Island, and the two types of plantation forestry displace different types of natural forests and are encroaching on protected areas. The weak enforcement of existing policy to protect forests and ban conversion of inappropriate areas is a major problem in local conservation. The clear definition of rubber and pulp plantation as separate management systems and separate from natural forest should be a priority for future forest conservation. Additionally, forest tenure reform in China since 2008 has focused on the privatization of collective forests. Historically, in other areas, this process of privatization has promoted natural forest conversion because the shift towards smallholder management systems creates strong incentives for short-term revenue generation through plantation expansion (Zhang et al., 2000). Simply more land might be available for conversion as well since most current plantations occur on collectively owned lands (Barr and Cossalter, 2006). Moreover, the increased productivity and installed capacity of 2.4 million Adt/yr of BHKP and 3.6 million tons of paper in the future will drive new land to expand plantations, but the land available for plantations is limited (Cossalter et al., 2006).

While similar changes in the driving factors for forest conversion have occurred in the Changhua watershed of central Hainan as those reported from elsewhere in the tropics (Rudel et al., 2009), the combined effects of rubber and pulp plantations and the inequity in their profitability and policy initiatives creates a situation where deforestation will probably continue on both lowland and upland sites. The current shortfall of raw material for pulp mills will drive APP's expansion of annual planting programs in the uplands, while the high price and demand for rubber will stimulate expansion of rubber plantations in the lowlands. Therefore, conservation strategies should be developed that can improve the conservation of forests without sacrificing economic development. The protected areas should be strictly enforced and forest conversion in the buffer zones around the two nature reserves, YGL_NR (rubber) and WZS_NNR (pulp), should be halted and replaced by environmentally friendly corridors to maintain ecosystem connectivity. Future expansion of rubber in the highly threatened lowlands and pulp plantations on slopes greater than 25° should be stopped. Improving current planting plantations' productivity can be an effective way to protect the remaining natural forests. Government agencies at both national and provincial levels should monitor and investigate the companies' capacity to ensure a balance between processing capacity and raw materials needed. Additionally, regular monitoring of forest cover and type, using well-established remote sensing techniques, should be implemented. Finally, rubber and pulp plantations should be defined as 'industrial forests', to clarify future priorities for the natural forest conservation and management. Future's forest assessment should distinguish between natural forests and these industrial plantations to create proper accounting of forest change. There is a critical need for improving governments' role on the monitoring, planning and regulation with large-scale environmental associated projects, as well as the conservation of natural forests.

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Appendix. Supplementary material

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