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Effectiveness of Nature Reserves for Natural Forests Protection in Tropical Hainan: a 20 Year Analysis

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Abstract: The establishment of nature reserves is a key approach for biodiversity conservation worldwide. However, there is a lack of unified methodology to evaluate the effectiveness of nature reserves, particularly in China, the world′s most populous nation supporting some of the most valuable biodiversity hotspots in the world. In this study, we conducted a long-term and large-scale analysis of the effectiveness of 20 of the earliest nature reserves established in Hainan Province, an island home to among the highest concentration of plants and animals in China. Remote sensing imagery from 1988, 1998, and 2008 were analyzed to investigate the temporal and spatial changes of natural forests in these nature reserves and surrounding areas. We also conducted transition matrix analysis and principle component analysis to identify the driving factors that affect the protection effectiveness of nature reserves. The results were as follows: 1) During the 20-year period from 1988 to 2008, natural forests coverage of the 20 studied nature reserves dropped 2.34 percentage points, whereas the natural forests coverage dropped 11.31 percentage points in a 0–5 km outside reserve buffer and 9.36 percentage points in a 5–10 km outside reserve buffer, indicating a significant inhibitory effect of the nature reserves on the loss of natural forests. 2) Natural forests coverage dropped in 60% of the studied nature reserves during the 20-year period, suggesting a poor protection effectiveness of these reserves, while the coverage proportion showed some increase (0%/yr–5%/yr) in other reserves. 3) Expansion of rubber and pulp forests as part of a booming economy were the main factors affecting the effectiveness of the nature reserves for conserving natural forests in Hainan Province. The results of this study provide an important empirical basis for the protection of natural forests in Hainan Province, which can be used as a blueprint for nature reserve evaluation in other places in China.

Keywords: nature reserve; natural forests; reserve effectiveness; Hainan Province, China

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1 Introduction

Biodiversity loss due to human activities has become a major environmental problem worldwide (IUCN *et al*., 1991; Wilson, 1992; Chapin *et al*., 2000). Establishing nature reserves to protect species and their habitats has historically been the cornerstone of biodiversity conservation (Butsic *et al*., 2012). Currently, there are over 100 000 nature reserves around the world, covering approximately 11.5% of the world′s land area (Boitani *et al*., 2008). Nature reserves are a part of conservation efforts taking place in China, the country with the fastest growing economy in the world and containing 2 of 25 biodiversity hotspots (Myers *et al*., 2000). In the past three decades, the number of nature reserves in China has rapidly increased (Quan *et al*., 2011). By the end of 2014, 2692 nature reserves varying in type and protection levels had been established in China, including 428 national nature reserves with a total area of 95 million ha, accounting for 65% of China′s total natural reserve

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area and nearly 10% of China′s total territorial area (Hong Kong, Macau and Taiwan regions are not included). However, there have been ongoing debates in the literature on the efficacy of nature reserves for achieving their stated goals (Stoner *et al*., 2007; Andam *et al*., 2008; Joppa *et al*., 2008; Beresford *et al*., 2011; Taylor *et al*., 2011), given challenges such as funding constraints and logistics of monitoring and enforcement of human activities (Oliveira *et al*., 2007; Craigie *et al*., 2010; Mwangi *et al*., 2010; Joppa and Pfaff, 2011; Butchart *et al*., 2012). More rigorous analyses on nature reserve effectiveness are thus urgently needed. The number of nature reserves should not be the only focus; once the number reaches a certain level, the protection effectiveness of nature reserves depends more on the improvement of the quality of management within the reserves (Ma, 2011).

Currently, there is an urgent need for reserve development to enter a new phase that focuses more on improving protection effectiveness. Past studies of the effectiveness of nature reserves have been focused on wild animal and plant species, population dynamics and distribution (Fellowes *et al*., 2008). However, long-term monitoring data on ecosystems, animals, and plants are scarce and the protection effectiveness varies greatly with protection targets, regions and evaluation scales (Bruner *et al*., 2001; Liu *et al*., 2001; Curran *et al*., 2004; DeFries *et al*., 2005). Hence, even though so many nature reserves have been established, evaluations of their protection effectiveness are mostly experience-based judgments or estimates.

Hainan Island has a rich biodiversity and preserves the largest rainforests in China (Deng *et al*., 2008; Zhang and Ma, 2008). However, with the rapid socioeconomic development occurring in recent decades, large areas of rainforests have been destroyed (Hu and Gao, 2008). Establishment of nature reserves is one of the main strategies implemented to protect natural forests in Hainan, but the effectiveness of this measure is still unclear (Wang *et al*., 2013). Therefore, in this paper, we used remote sensing analysis to investigate the effectiveness of nature reserves on Hainan Island for protecting natural forests over a period of 20 years (1988–2008). This study aims to adopt a long-term and large-scale approach to contribute to the ongoing debate on the efficacy of nature reserves and provide recommendations for improved reserve planning in the future.

2 Methods

2.1 Study area

Hainan Province (03°58'–20°10'N, 108°37'–117°40'E) is located in the southern part of China, and is China's second largest island, with a total area of 3.39×10^4 km^2. The terrain is low and flat in the marginal areas, and mountainous in the center (Xiao *et al*., 2012). It has a maritime tropical monsoon climate that is warm and humid throughout the year. The natural forests coverage of this island is 20.3% (Wang *et al*., 2012). Natural forests are mainly distributed in the central mountain areas, including rainforests, tropical monsoon forests, and evergreen broadleaf forests. Planted forests are mainly distributed in lowlands sounding the mountain areas, and include eucalyptus, rubber tree, and casuarina. Crops are mainly distributed in the plains, including rice, sugar cane, and sweet potatoes (Wang *et al*., 2012).

The Hainan Island was among the richest biodiversity in all of China and the world (Myers *et al*., 2000). The fauna and flora are mainly tropical. At least 5200 vascular plant species (over 600 endemic species) have been discovered, accounting for 15% of all vascular plant species of China, including 48 level 1 or level 2 national protected plant species. There have been 648 terrestrial vertebrates (21 endemic species) discovered on the island, accounting for 31% of all vertebrate species of China (Huang *et al*., 2012). A total of 8761 invertebrates (865 endemic species) were discovered, including 79 level 1 or level 2 national protected animal species (Huang, 2002).

By the end of 2012, Hainan had 50 nature reserves varying in type and level, which formed a natural reserve network system to protect the ecosystems, wildlife species, natural monuments, and shoreline. This system has a total area of 2.7×10^6 ha, accounting for nearly 7% of Hainan's land area, mainly distributed in the central mountain areas and coastal areas. However, management of nature reserves in Hainan is challenged by an ongoing conflict between biodiversity conservation and economic development. A major example of this is the fact that massive cultivation of rubber forests and pulp forests has caused reduction of natural forests.

2.2 Data analysis

Changes in the area of natural forests inside and outside nature reserves within Hainan since its establishment in

1988 until 2008 were analyzed as indicators to evaluate effectiveness of nature reserves.

2.2.1 Remote sensing interpretation

We first analyzed changes in natural forests over time. Based on land surface features and the existing spatial distribution information of pulp forests and rubber forests, an object-oriented decision tree information-extracting method was applied in satellite image interpretation of Landsat TM remote sensing images from 1988, 1998, and 2008. A total of 11 land cover types were classified, including natural forests, pulp forests, rubber forests, tropical crop land, grassland, shrub, paddy fields, dry land, urban area, wetland and sand land. The detailed classification process can be found in related literature (Wang *et al.*, 2012).

We compared natural forests change inside and outside of nature reserves. All reserves established in or before 1988 were included as study objects. The exception was island reserves and marine and seashore reserves because they do not contain natural forests. Based on the above-mentioned inclusion criteria, 20 nature reserves were included for analysis, which covers a total area of 152 628 ha that represents 4.5% of Hainan Island's land area or 56% of the total reserve area. The average size of these reserves is 7631 ha. Among the 20 reserves, 7 are national reserves with an average size of 13 003 ha and 13 are provincial reserves with an average size of 4738 ha.

2.2.2 Evaluation of reserve effectiveness

For evaluation of reserve effectiveness, we compared natural forests area changes occurring inside the reserve to changes in forests to areas outside found in a) a 0–5 km reserve buffer; b) a 5–10 km reserve buffer; and c) the entire province. Indices we evaluated included natural forests cover area, proportion of area, magnitude of change, and rate of change. Statistical analysis of significant differences in these indices over the three time points was conducted using a two-sample paired t test if Shapiro-Wilk test revealed a normal distribution or Wilcoxon signed-rank (non-parametric) test if the Shapiro-Wilk test revealed a non-normal distribution. We also calculated an annual rate of change of natural forests area by dividing the number of years between each of the three time points. Analyses were carried out using R 3.1.2 (R Development Core Team) software.

2.2.3 Evaluation of factors contributing to reserve effectiveness

We constructed a transition matrix analysis of land coverage in ArcGIS 10.0 to reflect the conversions between different land cover types over time (Liu and Buheaosier, 2000). To identify the driving forces of natural forests loss, we calculated the conversion of natural forests inside and outside the entire reserve network in different time periods, such as the amount, ratio and type of conversion. In addition, we analyzed social and economic factors that may contribute to nature reserve effectiveness, including natural reserve level (e.g., national and provincial level), reserve establishment date and area, and a number of county level variables including overall and per capita gross domestic product (GDP), primary and secondary industrial output, human population employment in primary industries, and cultivated land area. Principle component analysis was carried out in R with natural forests area as the response variable and the aforementioned factors as explanatory variables to determine driving forces behind reserve effectiveness. A multiple linear regression model was also conducted to determine the relative importance of each of the aforementioned factors in explaining proportion of forest loss in nature reserves. Variable screening was performed using a multicollinearity test and stepwise regression. Significance tests were then performed for overall regression and partial regression coefficients.

3 Results

3.1 Change in natural forests area

3.1.1 Comparison between inside and outside reserves

Land cover inside nature reserves was mainly natural forests (Fig. 1). The average proportion of natural forests cover of the overall reserve network in the three time points was 82.26% inside reserves, 36.02% in the 0–5 km outside buffer, and 26.30% in the 5–10 km outside buffer from 1988 to 2008. Proportion of natural forests cover of 20 individual nature reserves significantly differed across these three areas in all three periods. The proportion of natural forests inside reserves was significantly higher than that in the 0–5 km outside buffer (1988: $t = 5.297$, $P < 0.001$; 1998: $t = 5.042$, $P < 0.001$; 2008: $t = 9.111$, $P < 0.001$) and 5–10 km outside buffer (1988: $t = 4.235$, $P < 0.001$; 1998: $W = 193$, $P < 0.001$; 2008: $t = 9.964$, $P < 0.001$). The natural forests coverage proportion of the 0–5 km outside buffer was also significantly higher than that of the 5–10 km outside buffer (1988: $W = 160$, $P = 0.019$; 1998: $t = 2.215$, $P = 0.020$; 2008: $t = 2.546$, $P = 0.010$).

Fig. 1 Percent cover of natural forests inside and outside nature reserves in Hainan, China

Over the 20 year period from 1988 to 2008, the total area of natural forests inside reserves decreased from 1.48×10^5, to 1.45×10^5, to 1.41×10^5 ha, resulting in a net decrease of 6737 ha (2.34 coverage percentage points reduction) (Table 1). Coverage of natural forests decreased by 7.07 percentage points in the entire province during the corresponding period, and fell by 11.31 and 9.36 percentage points in the 0–5 km and 5–10 km buffers, respectively. Natural forests area inside reserves did not change significantly during the 20 years (t = 1.709, P = 0.052). However, the area of natural forest in the 0–5 km outside buffer and 5–10 km outside buffer decreased significantly (W = 174, P = 0.001; W = 207, P < 0.001).

Natural forests change differed during the periods of 1988–1998 and 1998–2008 (Table 1). In the first 10 years, the area of natural forests inside reserves did not change significantly (loss of 0.04%/yr, t = 1.268, P = 0.110), whereas the areas of natural forests in the 0–5 km outside buffer and 5–10 km outside buffer decreased significantly (loss of 2.44%/yr, W = 203, P < 0.001; loss of 2.99%/yr, W = 208, P < 0.001). On the contrary, in the second 10 years, the area of natural forests inside the reserve decreased significantly (loss of 0.24%/yr, W = 155, P = 0.032), whereas the areas of natural forests in the 0–5 km outside buffer and 5–10 km outside buffer did not change significantly (loss of 0.23%/yr, W = 93, P < 0.676; increase of 0.18%/yr, t = 0.68, P < 0.252).

3.1.2 Comparison among reserves

Proportion of natural forest cover was increased or unchanged in eight (40%) of the 20 nature reserves over the 20 year period evaluated (Fig. 2). However, 12 reserves (60%) experienced a decrease in natural forest. Among them, 4 lost more than 0.5% yearly. The reserve Liulianling had the greatest natural forest cover loss with yearly ratio of 1.5%.

Reserve effectiveness also varied over time. Eleven of the 20 reserves experienced an increase or no change in forest cover in the first 10 years (1988–1998). But only seven avoided a decrease in forest cover during the second 10 years (1998–2008). The number of reserves experiencing an annual loss above 0.5% increased from 6 to 8 reserves from the first to the second period.

3.2 Evaluation of factors contributing to reserve effectiveness

Pulp forests, rubber forests, and tropical crops were the main land cover types that replaced natural forests in

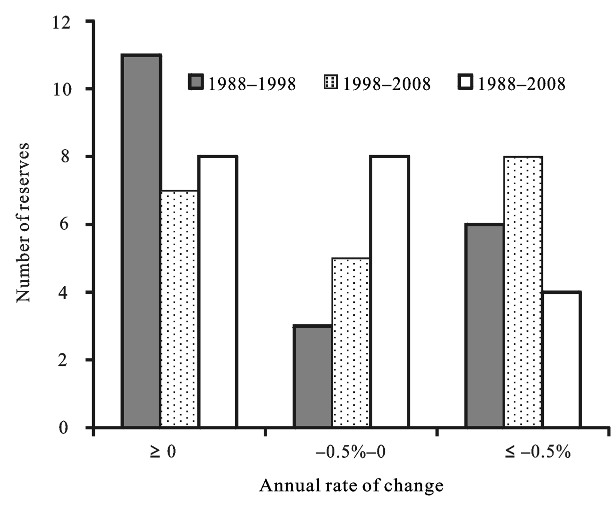

Fig. 2 Number of nature reserves with different proportions of loss of forest cover between 1988 and 2008

Table 1 Changes in natural forests cover inside and outside nature reserves in Hainan, China

Natural forest	1988–1998		1998–2008		1988–2008	
	Total area of change (ha)	Annual rate of change (%)	Total area of change (ha)	Annual rate of change (%)	Total area of change (ha)	Annual rate of change (%)
Inside reserve	–3454	–0.04	–3283	–0.24	–6737	–0.14
0–5 km buffer	–54425	–2.44	–4010	–0.23	–58435	–1.31
5–10 km buffer	–48152	–2.99	1953	0.18	–46199	–1.43

Hainan from 1988 to 2008 (Fig. 3). For instance, inside the reserves, 36% of natural forests change within the deforested areas was converted to pulp forests, 33% was converted to rubber forests, and 16% converted to tropical crops from 1988 to 2008. Similar patterns were found in the 0–5 km outside buffer areas and 5–10 km outside buffer areas.

Natural forests gains also occurred. Shrubs, grassland, dry land, and tropical crops were the main types that converted to natural forests (Fig. 3). Among the recovered forests, 36% were converted from grassland, 20% from tropical crops, and 18% from shrubs. Similar patterns were found in the 0–5 km outside buffer areas and 5–10 km outside buffer areas.

According to principle component analysis, three principle components with eigenvalues greater than 1 were retained based on the Kaiser-Harris criterion. The accumulative contribution rate was approximately 85%, meeting the requirement of analysis. In addition, the principle component matrix after rotation was also obtained (Table 2). The first principle component explained 56% of the variance. The influencing weight of GDP on natural forest was as high as 0.988, and other components such as primary industrial output, second industrial output, and population in counties also showed influencing weights greater than 0.9. Variance contributions of the second and third principle components were 17% and 12%, respectively. The components having relatively higher influencing weights were natural reserve level (0.888), natural reserve area (0.855) and date of establishment (0.918).

The regression analysis produced a significant model explaining loss of forest cover in reserves ($R^2 = 0.93$, $P < 0.01$), while the partial regression coefficient tests showed that date of establishment and per capita GDP had significant positive correlations with the natural forest area change and the natural reserve area had a significantly negative correlation with natural forests area change ($P < 0.05$).

4 Discussion

Our study is the comprehensive evaluation of nature reserve effectiveness in Hainan, a province in China that has considerable importance for biodiversity conservation. We found that protect considering the fact that a higher proportion of natural forests was conserved inside reserves than outside, and there was a rate of loss compared to outside. But the effectiveness varied across reserves. In the reserves studied, 60% of the reserves show natural forests loss between 1988 and 2008, and decreasing protection effectiveness of reserves through years, indicating a serious situation of protection effectiveness of reserves in Hainan.

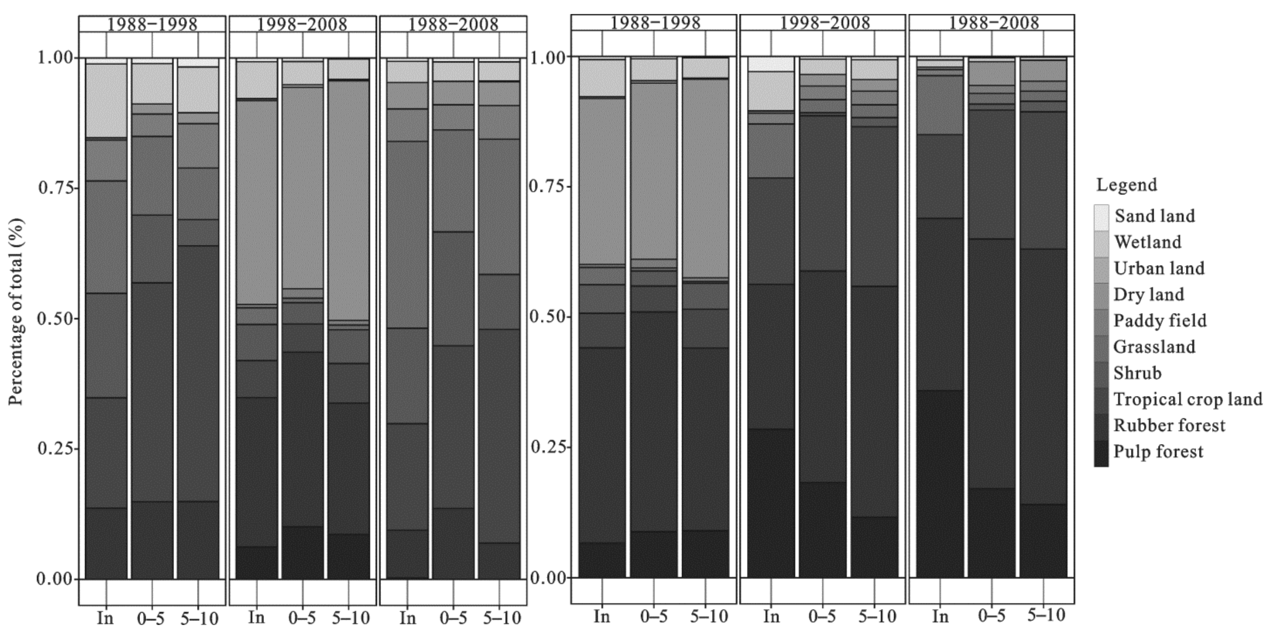

Fig. 3 Gain (right) and loss (left) transformation analysis of natural forests inside (in) and outside (0–5 km buffer, 5–10 km buffer) of nature reserves in Hainan, China

Table 2 Rotated principle component loadings matrix and the total variance explained for a model explaining natural forest cover loss inside nature reserves in Hainan, China

Indice	Component 1	Component 2	Component 3
Reserve level			
Nature reserve level	0.23	0.86	0.01
Date of reserve establishment	0.02	–0.10	0.92
Nature reserve area	–0.21	0.89	–0.10
County level			
Gross domestic product (GDP)	0.99	–0.03	–0.10
Primary industrial output	0.96	0.09	0.04
Second industrial output	0.96	0.03	–0.09
Per capita GDP	0.77	–0.14	–0.39
Population	0.97	0.05	0.07
Employment in primary industry	0.72	–0.32	0.19
Cultivated land area	0.81	0.26	0.31
Summary			
Eigenvalues	5.63	1.73	1.17
Contribution rate (%)	56.26	17.33	11.65
Accumulative contribution rate (%)	56.26	73.59	85.24

It is important to note that evaluation of area of forest alone is not enough to reflect the overall protection effectiveness of the reserves (Terborgh *et al.*, 2001). However, the area of forests that species rely on is so fundamental to the reserve functioning that if it cannot be effectively maintained, it is very likely that reserves will be ineffective (Barber *et al.*, 2012). In addition, change of forest coverage can reflect changes in the structure and function of ecosystem (Ervin, 2003). Considering that long-term monitoring data on ecosystems and species in large scale were not available, the area-based approach using remote sensing that we used here is a good starting point for evaluating effectiveness.

Our finding that nature reserve effectiveness was influenced by a multitude of factors reflects the complexity of human-nature interactions occurring in Hainan in recent years. There has been considerable growth in the industries of rubber, pulp, and tropical crops, which has resulted in reduction of natural forests area. Increasing population growth also places great pressure on effectiveness, with the total population of 6.27×10^6 in 1988 to 8.60×10^6 in 2008 (Wang *et al.*, 2012). Conservation policies such as the Grain to Green, Natural Forest Conservation also influenced the protection effectiveness. These policies contributed the natural forests conservation on one side, but on another side also caused the increase of rubber, pulp since they were also in the definition of 'forest' (Zhai *et al.*, 2014). Finally, other factors such as the joint venture of investment of Asia Pulp & Paper (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 (Zhai *et al.*, 2014).

Establishment of nature reserves is an important means for the conservation of biodiversity and ecosystem services. Understanding and improving effectiveness is a key step for better conservation. Currently, although a total amount of 2692 nature reserves have been established in China, the effectiveness of reserves at the national scale is still unclear. Therefore, considering the rapid pace of economic development in China, a nationwide evaluation on nature reserves is urgently needed. Our study provides a blueprint that can be used to replicate such an analysis at the scale of the entire country. Such an evaluation would contribute to efficiency of nature reserve networks that enhance biodiversity conservation in the entire country of China.

5 Conclusions

This paper describes the temporal and spatial change of natural forests inside and outside nature reserves in Hainan Island, and explores main factors that affect these changes based on GIS and high resolution remote sensing images from 1988, 1998, and 2008. Through above analyses, we found that natural forests inside and outside buffer zones of nature reserves have experienced obviously changes in the study period (1988–2008). From 1988 to 2008, natural forests coverage inside the overall nature reserve network decreased 2.34 percentage points, whereas decreased 11.31 and 9.36 percentage points outside 0–5 km and 5–10 km nature reserves, respectively, indicating nature reserves had important inhibitory effect on the loss of natural forests.

However, in the 20 years, natural forests inside nature reserves reduced in 60% of studied reserves. Furthermore, natural forests loss was more severe in the second ten years (1998–2008) than in the first ten years (1988–1998). The conservation effectiveness should be further improved.

The main factors of affecting conservation effectiveness of nature reserves in Hainan were the expansion of rubber and pulp forests, the status of themselves and social-economic development. We suggest that the government should continue to protect natural forest strictly, and improve policies on their protection. Furthermore, it is important to improve management level of nature reserves and intensify their dynamic monitoring and evaluating on natural forests.

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