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South China Tropical Forest Changes in Response to Economic Development and Protection Policies

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Abstract

The destruction of tropical forests continues to attract attention from the international community. China's National Forest Administration has adopted protective measures for tropical forests, and efforts have been developed to balance forest protection and economic development in Hainan Island, China. However, the response of natural tropical forest to local economic development and the effectiveness of forest management and protection policies remain unclear because of complexity of tropical evergreen ecosystems. After comprehensive analysis of spectral characteristics, spatial distribution, patch shape, and other characteristics of main forests, we developed an information extraction method based on the decision tree method, combining digital elevation model (DEM) and forest planning maps, and established flowcharts and processes for sophisticated object-based information extraction. The accuracy of our method was 92%, and the method proved to be applicable and effective in the classification of complex surface features in a tropical evergreen ecosystem. Forces resulting in the change of these forests were explored by analyzing the relationships between economic development, protection policies, as well as environmental factors.

Keywords: tropical forest, economic forest, forest management, Hainan Island, remote sensing, GIS, development and protection policies

1. Introduction

Deforestation, especially of natural tropical forests, has attracted international attention as these tropical forests have very high levels of biodiversity [1–4]. Tropical forests mainly occur in developing countries. However, large areas of natural forests have disappeared as a result of continuous human population growth and their economic development. Some protective

measures have been adopted, but it is still difficult to prevent the loss of natural tropical forests due to conflicts between economic development and forest protection.

In China, the total area of tropical forest is currently increasing because of national reforestation policies, but the proportion of natural tropical forest to economic forest has changed in recent years [5]. As a result, changes have occurred affecting the maintenance of biodiversity, ecological functioning, and stability of forest ecosystem [6–8]. The Hainan Island of China has a large area of tropical forest, which serves as a natural treasure of biodiversity [2]. In recent years, the island has seen rapid economic development. Natural tropical forest is being constantly replaced by economic forest because of increasing demand for rubber, timber, and other forest products since 1988. To develop the economy in a sustainable and ecologically sensitive manner, the local government has proposed various ecological protection measures since 1998. In fact, the tropical forest in Hainan Island has greatly changed because of economic development and protection policies after 1998. Tropical forests are known to be impacted by population growth, economic development, national policies, and natural factors (such as terrain, climate, etc.) [5]. However, the key factors causing the changes of tropical forest remain unclear.

Because the proportion of natural tropical forest to economic forest has changed, two key challenges arise: (1) understanding how and why natural tropical forests are changing, and which factors have led to the changes; (2) understanding the fate and implications of the succession of different forest types. Thus, monitoring the dynamics of those changes occurring in natural tropical forest and economic forest becomes necessary, together with the identification of the main factors leading to those changes over broad spatial and temporal scales.

Brandt et al. recognized that mapping forest distribution and succession are an essential component of forest biodiversity assessment [2]. Remote sensing provides an efficient technique for the monitoring and managing of tropical forests [9]. In addition, a combination of remote sensing and GIS techniques could help scientists discover the intrinsic forces driving the dynamics of forests.

However, some challenges remain in using remote sensing image classification. For example, for vegetation classification, there is a problem with mixed pixels resulting from same objects exhibiting different reflectance at varying wavelengths [10]. Also, it is difficult to improve the precision of the process of extraction without the support of a prior knowledge, such as the spatial distribution of various forests or patch shapes.

In addition, the use of pixel-based methods is tiring and labor-intensive work, and misclassification of pixels is likely to occur because of errors during spectrum analysis [11]. For example, some natural forests lying within shaded areas of mountains tend to be regarded as other land use types. An object-oriented method could segment remote sensing images into different patch sizes based on integrated features of the spectrum, texture, shape of patch, and so forth [12]. In addition, the decision tree method could gradually extract individual land use types, using remote sensing extraction models and relevant auxiliary data, such as the distribution of various forest types.

In fact, much auxiliary information could be used. For example, when compared with rubber and pulp plantations, the remotely sensed spectra of natural forest exhibit more differences from December to the following January than it does during other seasons [13]. In addition, remotely sensed images of natural forest, and rubber and pulp plantations each have obvious characteristics related to their distribution, patch shape, and texture. For example, pulp and rubber plantations usually occur in areas where the slope is less than 25° , and rubber plantations often lie at comparatively lower elevations.

To overcome the abovementioned challenges, we used an object-oriented, decision tree method to deal with the complex change processes of natural forest, and rubber and pulp plantations for the first time. The overlay technique of GIS was also used to map natural forest, and rubber and pulp plantations during 1988–2008, and to analyze the main factors driving forest change and the relationships between the three forest types. Our objectives were to:

1. Map the spatial extent of natural forest, and rubber and pulp plantations, and to analyze temporal and spatial succession occurring during 1988 and 2008.
2. Assess the relationships between the spatial patterns of multiple forests; identify the main factors driving changes.

2. Materials and methods

2.1. Study area

The study area covers 14,000 km² in the central part of Hainan Island (**Figure 1**). The study area has a warm and humid tropical monsoon climate with annual average temperatures ranging from 22 to 26°C. Mountainous areas surround Five Finger Mountain and Yinggeling in Hainan Island. The island's natural tropical forest mainly includes tropical monsoon forest, tropical rain forest, evergreen broad-leaved forest, and coniferous forest. Economic forest mainly includes rubber plantations and orchards, which usually occur in the flatlands at the

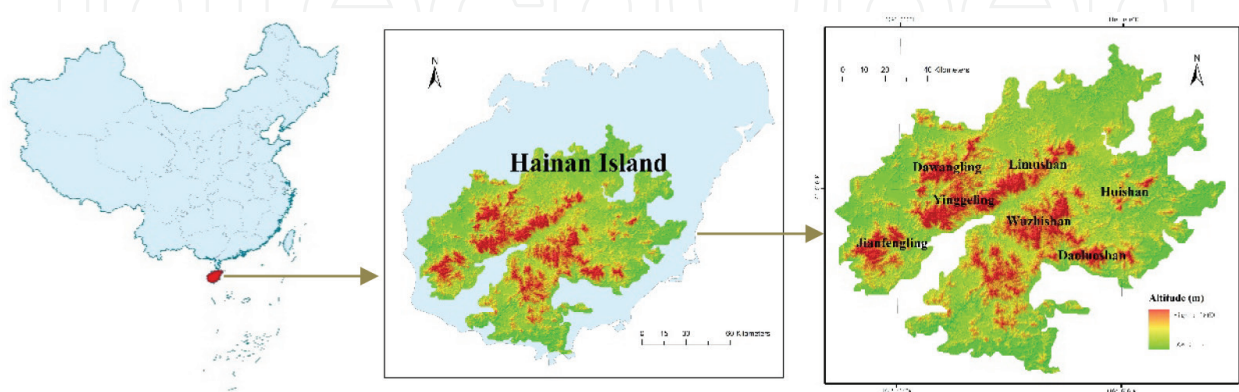


Figure 1. The location of the study area (the central Hainan Island in China).

foot of the mountains. Some national and provincial reserves have been established since the 1970s to protect the biodiversity of these tropical forests.

The natural vegetation of Hainan Island is tropical monsoon forest, tropical rain forest, evergreen broad-leaved forest, mangroves, coniferous forests, shrubs, and grassland types. The main species of artificial vegetation are *casuarina equisetifolia*, eucalyptus, rubber, lemon-grass, pepper, mango, and banana. The crops mainly include rice, sugarcane, sweet potato, cassava, and vegetables.

2.2. Data sources

Landsat TM images (path/row 124/47) cover the study area. We used six images captured from December to the following February in 1988, 1998, and 2008; these images were obtained from the University of Maryland website (<http://glcfapp.glcf.umd.edu:8080/esdi/index.jsp>) and satellite ground stations in China. The images were georeferenced with a precision better than 0.4 pixels. Finally, the digital data of these images were calibrated to surface reflectance values using the Fast Line-of-Sight Atmospheric correction of Spectral Hypercubes (FLAASH) Module in ENVI v.4.6. Other sources of information included a digital elevation model (DEM), and social, economic, and field survey data. DEM data were obtained from Aster satellite data (<https://wist.echo.nasa.gov/~wist/api/imswelcome/>). Slope and elevation data were derived from the DEM using the ARCGIS9.3 software. Some basic data (transportation corridors, population, national and provincial reserves, meteorological, social and economic data) were obtained from the Hainan Provincial Academy of Environmental Sciences. Field surveys were also conducted to collect information on the distribution of forests.

2.3. Methods

2.3.1. Extraction of multiple forest information datasets

We compared the spectral differences of Landsat TM images captured in 1988, 1998, and 2008 of multiple forests in different seasons within a year, and selected images taken between December and the following January (e.g., December 1988 to January 1989) (**Figure 2**). Then we established flowcharts and processes for use with a sophisticated object-oriented decision tree method. First, these images were divided into multiscale segmentations based on the texture, spectrum, patch shape, and distribution of land use types using the Cognition 7.5 software. There are also other parameters need to be set, such as scale, shape, and compactness, which are obtained from the ground comparative research. Second, a set of indices extracting remote sensing information were calculated (**Figure 3**), including MNDWI = $(\text{Green} - \text{MIR}) / (\text{Green} + \text{SWIR})$ [14], the Universal Pattern Decomposition Method (VIUPD), RVI = NIR / Red and the Grass and Shrub Differing Index GSI = $(\text{MIR} - \text{NIR}) / (\text{MIR} + \text{NIR})$. The wave bands of Green, Red, MIR, SWIR, and NIR were used in these models, since they contribute to identify different objects. It is concluded that the MNDVI, VIUPD, RVI, and GSI performed well in the information extraction of complex features. MNDWI is a modified normalized difference

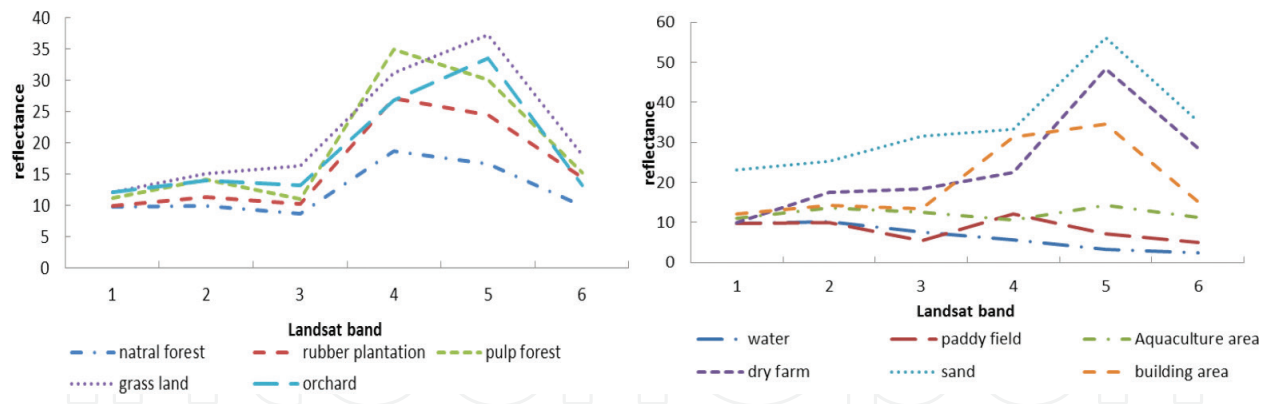


Figure 2. Examples of how phenology was used to discriminate the different forest classes. Representative pixels from three forest and other land use classes look similar under visual inspection on Landsat images from December to the following February.

water index, which is a simple graphical indicator that can be used to analyze whether the target being observed is water or not. The vegetation index RVI is very sensitive to vegetation canopy chlorophyll content [15]. VIUPD is a vegetation index and sensitively reflects the amount of vegetation and the degree of vegetation vigor. GSI is grass and shrub differing index and can be used to identify bushes and grass from other kinds of trees [5, 15]. Then, the object-oriented forests information was extracted based on decision tree. The extraction results are shown in **Figures 4–7**. Multisource data (including slope from the DEM, pulp plantation planning maps, and other auxiliary data) were used to extract different land use types. According to the stage order, we first separated water-related ground objects (water bodies, paddy fields, and aquaculture areas) from images using the MNDWI model and

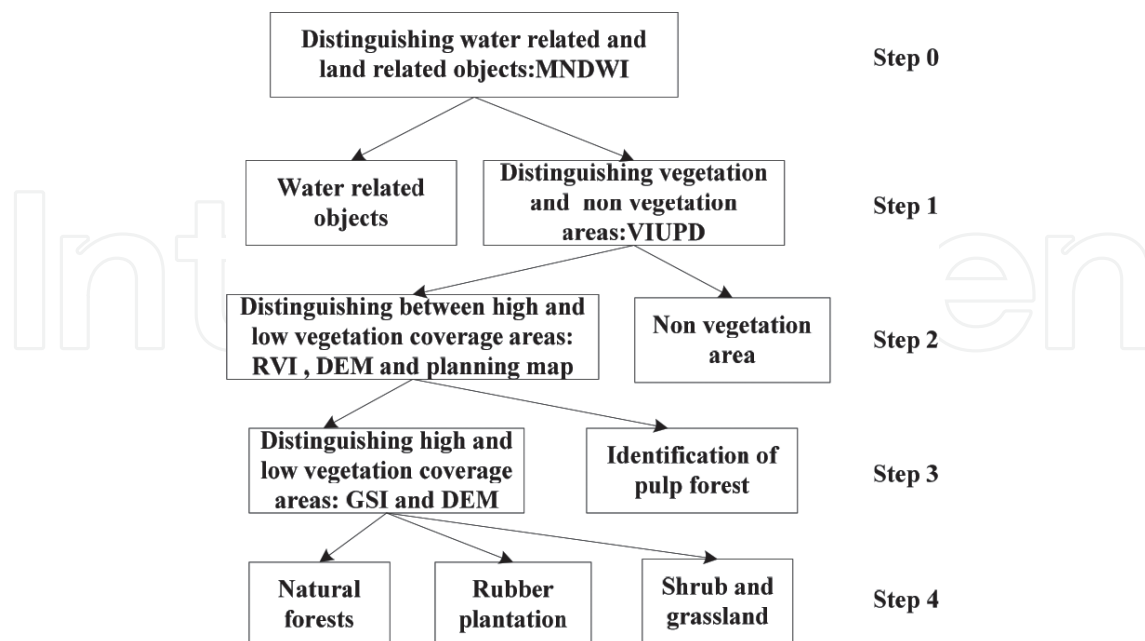


Figure 3. The steps to extract object-oriented information of forests based on decision tree.

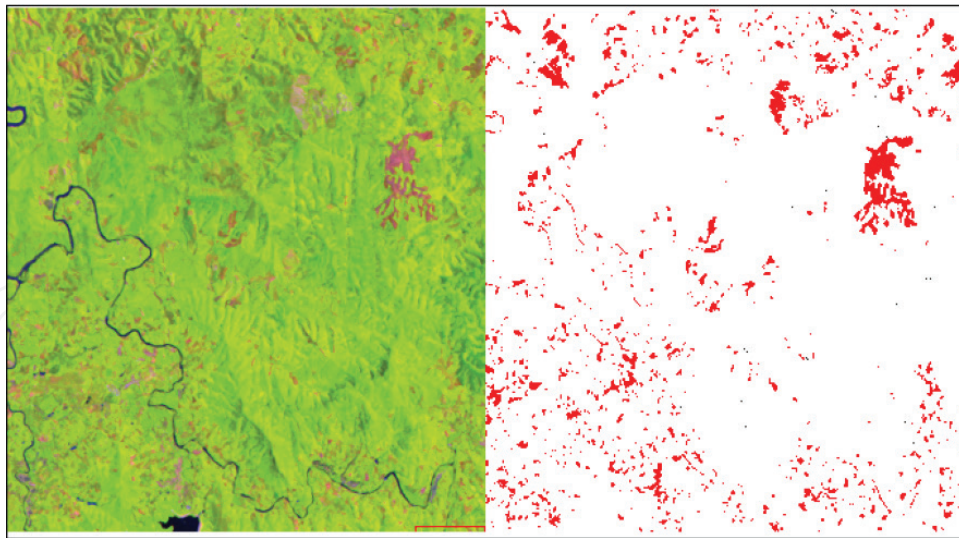


Figure 4. Extraction of orchard information based on GSI and R5-R6 method.

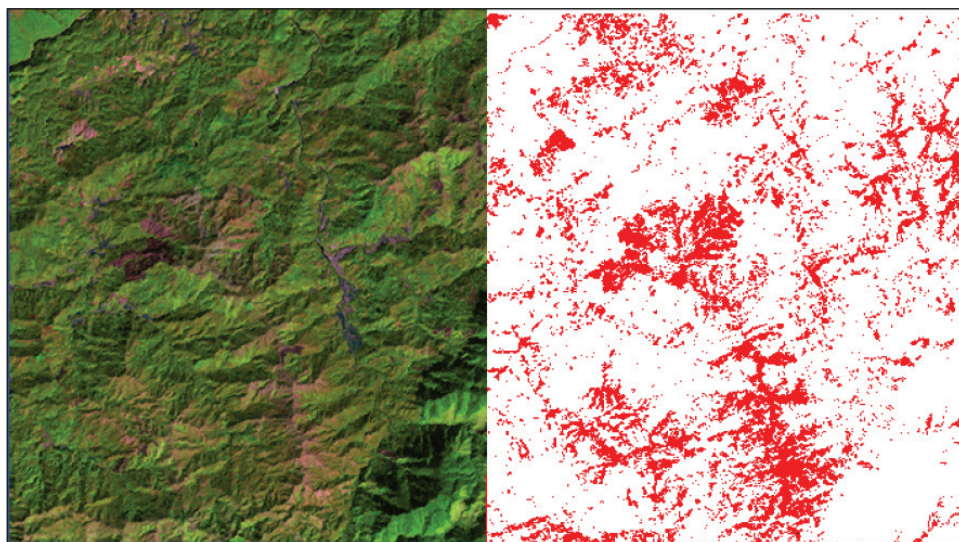


Figure 5. Shrub information extraction based on GSI method.

then identified areas without vegetation coverage, such as urbanized areas, using the VIUPD method. Next, the RVI model, slope from DEM, and economic forest planning map were used to extract and delineate pulp plantation areas from other land use types. Finally, we separated natural forest and rubber plantation areas from grassland and orchards using the Grass and Shrub Differing Index (GSI) model and slope data from DEM. To correct some mistakes, we did some field investigation. For example, we initially were not sure whether some patches were rubber plantation or not in Landsat TM image, but we found through field investigation that these patches indeed were rubber plantation if they were near river and residential area, so we might correct these mistakes through water system distribution map.

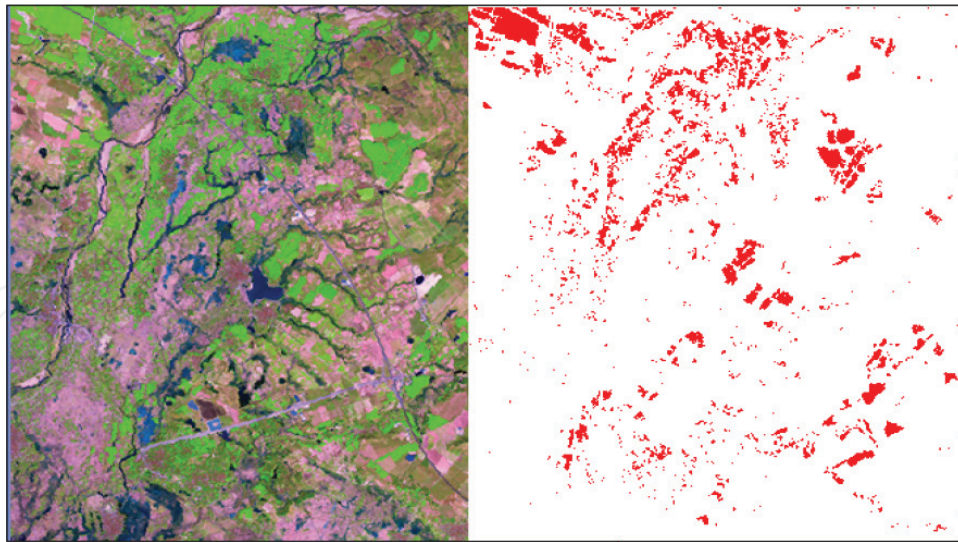


Figure 6. Extraction of pulp plantations information based on RVI method.

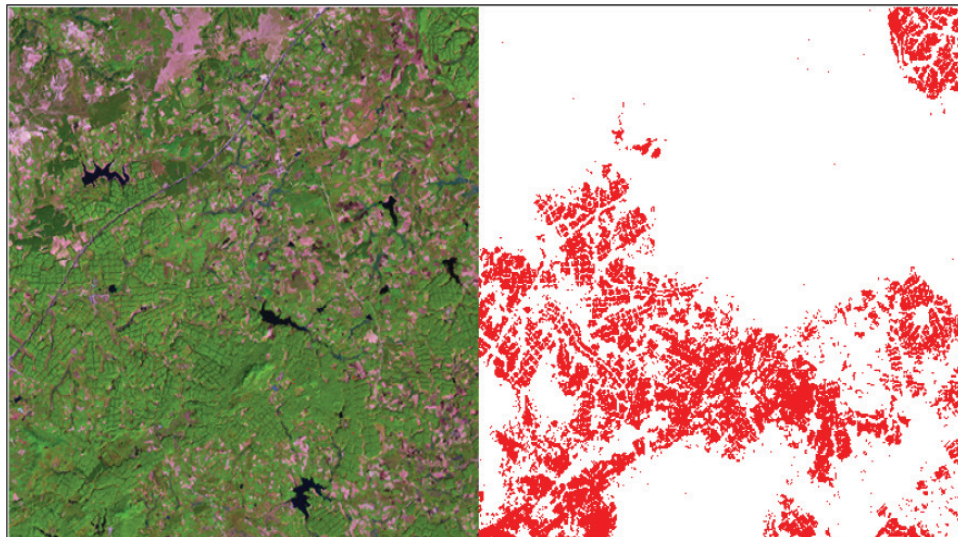


Figure 7. Rubber information extraction based on RVI and texture information method.

2.3.2. Change detection and key driving factor identification

Three forest types and other land use types in the study area were extracted: natural forest, rubber plantation, pulp plantation, and other land use types (e.g., paddy fields, dry lands, orchards, sand, and urbanized areas). Map overlays of forest type for 1988, 1998, and 2008 were created using the GIS software to quantify the dynamic transformation between different forest types. Economic activities and protection measures were considered, and a comparative analysis method was used to compare natural rubber demand and price changes, the area of natural forests and the area of economic forests before and after the implementation of protection measures.

To reveal the intrinsic driving factors from 1988 to 2008, in addition to considering economic and policy factors, the following factors were also considered: nature protection areas, farms,

transportation corridors, and the elevation and slope of each site. The data of nature protection areas were derived from the map of national nature protection area; the data of farms and transportation were extracted from Landsat TM images; the data of elevation and slope were extracted from DEM. The study area was divided into grid cells, and the information for each grid cell was extracted by the spatial analysis model of the GIS software. By using random permutation tests [16] to choose grid cells in each year, the association of different forest types with the abovementioned factors was examined. We used the average Euclidean distance between the multiple forest patches and these driving factors to capture differences in conservation value and human activity. For multiple forest conversions, the following method was used to identify the key factors: the patch of the different forest area serves as the basic unit; then, adjacent patches with the same change trends were classified into a uniform block. The average value of a factor in each block with the same trend was used to serve as a sample, and the value of the factor served as a collective value. The ratio of the area covered by a particular land use type in 2008 was compared with the corresponding blocks of the two previous periods (1988 and 1998) to detect changes using the overlay. Then, we took the altitude, slope, and the minimum distance from the farmland and road to the area where transformation occurred as variable and took the transformation of forest types as dependent variable. General regression analyses between them were conducted by collectively analyzing the blocks with the same trends.

3. Results and Discussion

3.1. Detection of changes in natural forest, and rubber and pulp plantations

3.1.1. Spatial distribution of natural forest, and rubber and pulp plantations

Combining DEM with remote sensing monitoring results in 1988, 1998, and 2008 (**Figure 8(1)–(3)**), the natural forests are mainly distributed in Wuzhishan mountain, Jianfengling mountain, Bawangling mountain, Diaoluoshan mountain, Limushan mountain of central Hainan Island areas above 600 m above sea level, while the central mountain valleys are invaded by other ecosystem types. There is relatively little natural forest distribution between 100 and 600 m above sea level, and below 100 m above sea level are mostly sparse grasslands.

As can be seen from **Figure 9(1)** and **(2)**, the planting scale of pulp plantation was relatively small in 1998, mainly scattered distribution in Qiongzong Li and Miao Autonomous County, Tunchang County, Baisha Li Autonomous County, Danzhou city, and Lingao County. From **Figure 9(2)**, the pulp plantation planting area of 2008 has significantly increased compared with 1998. The spatial distribution of 2008 is relatively wide and evenness. The eastern of the northwest, Changjiang Li Autonomous County, Danzhou city, Lingao County offshore area and northern Chengmai County, Anding County formed strip-shaped shelterbelts, accounting for 29% of the total area of pulp plantations (194,000 hectares). These shelterbelts are responsible for windbreak, sand retention, and storm surge prevention. There is a sparse distribution of in the northern, southern, and southeastern coastal areas of Haikou. From the terrain view, there is wide distribution of pulp plantations between the coastal plains to the platform below 25 degrees slope. Part of the pulp forest distribution in the mountains above 25 degrees occupied the central mountainous areas of natural forests and even nature reserves. The spatial distribution of rubber plantation in Hainan Island showed in (**Figure 10**).

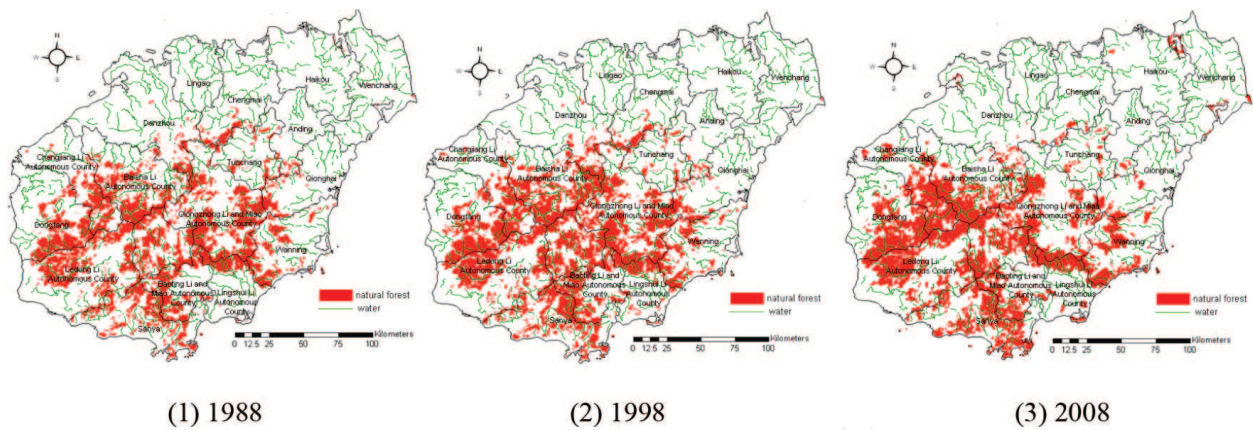


Figure 8. Spatial distribution of natural forest in Hainan Island. (1) 1988; (2) 1998; (3) 2008.

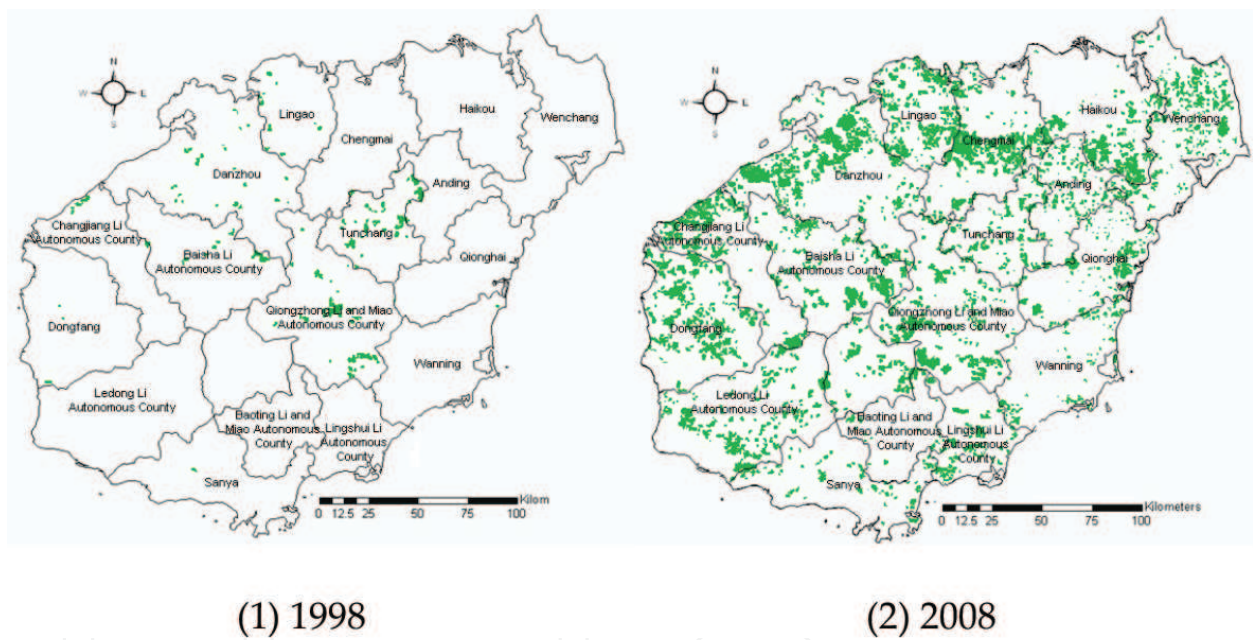


Figure 9. Spatial distribution of pulp plantation in Hainan Island. (1) 1998; (2) 2008.

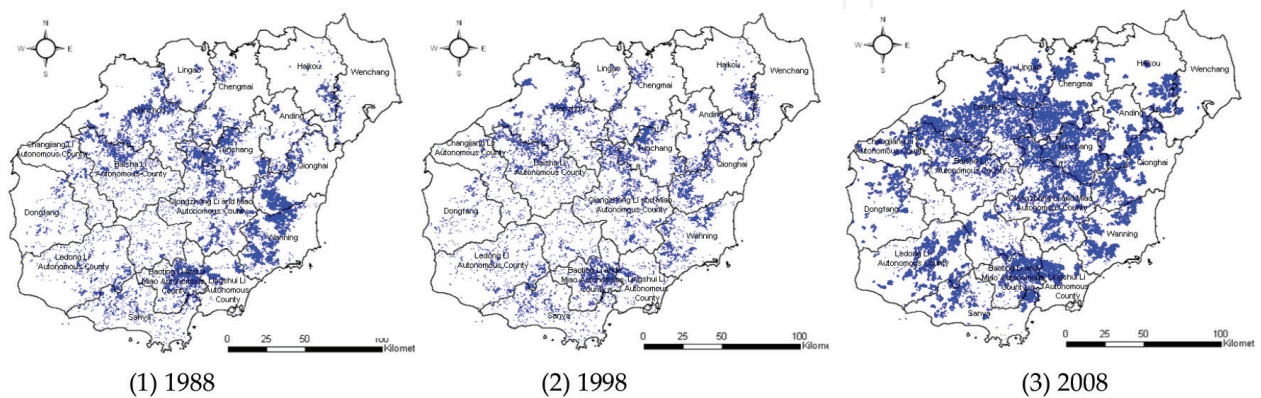


Figure 10. Spatial distribution of rubber plantation in Hainan Island. (1) 1988; (2) 1998; (3) 2008.

3.1.2. Change analysis of natural forest, rubber and pulp plantations

3.1.2.1. Newly increased natural forest distribution pattern analysis in 1988–2008

1. Newly increased natural forest distribution pattern.

The differences in the spatial distribution of natural forests in 1988, 1998, and 2008 (**Figure 11(1)–(3)**) are mainly concentrated on three large areas, namely Danzhou, Qiongzong, and Baisha, which showed the change in characteristics, for example, increasing-decreasing-increasing, and the same applied for Changjiang Li Autonomous County and Dongfang County. The boundaries of Qionghai and Wanning counties (cities) are increasing continuously, while others such as Sanya City show continuously reducing state.

2. Rubber plantations-natural forest pattern changes.

As a whole, the rubber plantation converted into natural forests from 1988 to 2008 showed fragmentation character, except parts of Qionghai, Wanning, and Qiongzong that have block area from 1988 to 1998 and from 1998 to 2008 (**Figure 12(1)–(3)**). Most of the changes are located in the central mountainous area and its surrounding areas, but the spatial distribution is uneven, such as Qiongzong and Ledong County. To analysis the total changed area, the area changes of 1988–2008 (29,200 hectares) are more significant than the changes of 1988–1998 (28,000 hectares) and 1998–2008 (12,000 hectares).

3. Distribution pattern of other forest converted into natural forest.

The total area of other forest (mainly farmland, grassland, etc.) converted into natural forests is small and shows sporadic distribution (**Figures 13 and 14**).

3.1.2.2. Spatial pattern of newly increased pulp plantation in 1988–2008

1. Spatial pattern of newly increased pulp plantation.

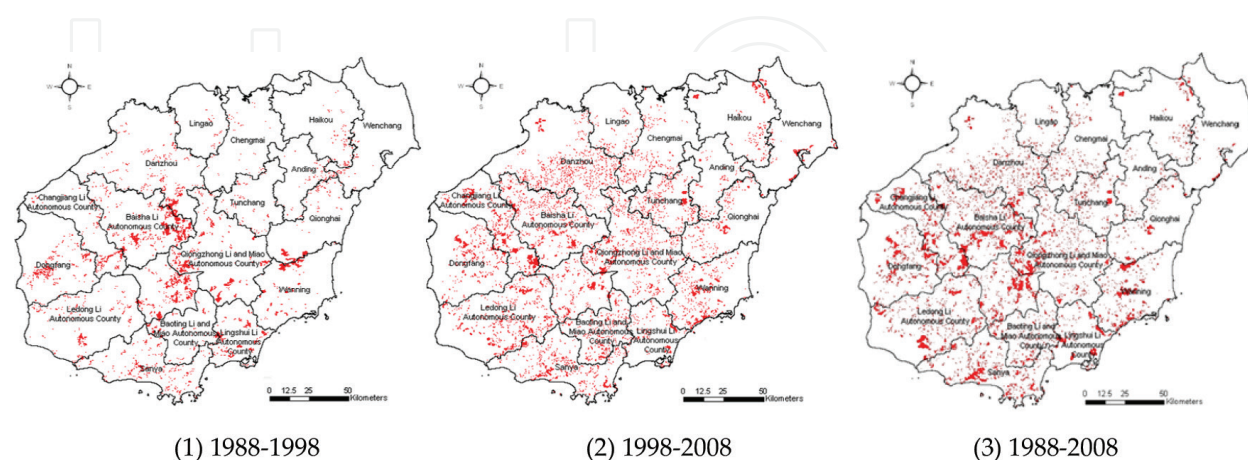


Figure 11. Newly increased natural forest distribution pattern: (1) 1988–1998; (2) 1998–2008; (3) 1988–2008.



Figure 12. Spatial distribution of rubber plantation converted into natural forest: (1) 1988–1998; (2) 1998–2008; (3) 1988–2008.

As can be seen from **Figure 15**, the area of newly increased pulp plantation was relatively small (11,400 hectares) during 1988–1998, which mainly distributed at Danzhou, Qiongzong, Baisha, Tunchang Counties. The area increased greatly to 193,800 hectares during 1998–2008. The most obvious is the formation of zonal areas along the northern coastal plains of the east, Changjiang, Danzhou, Lingao, Chengmai, the south of Haikou, and Wenchang. It contains 43.7% of the increased area. The strip-shaped forest zone also plays a role in the windbreak and sand fixation. The distribution of pulp plantation in other areas mainly showed small patches, mostly distributed in the central mountainous area and its surrounding area, with a small amount of distribution along the eastern coast.

2. Spatial pattern of natural forest converted into pulp plantation.

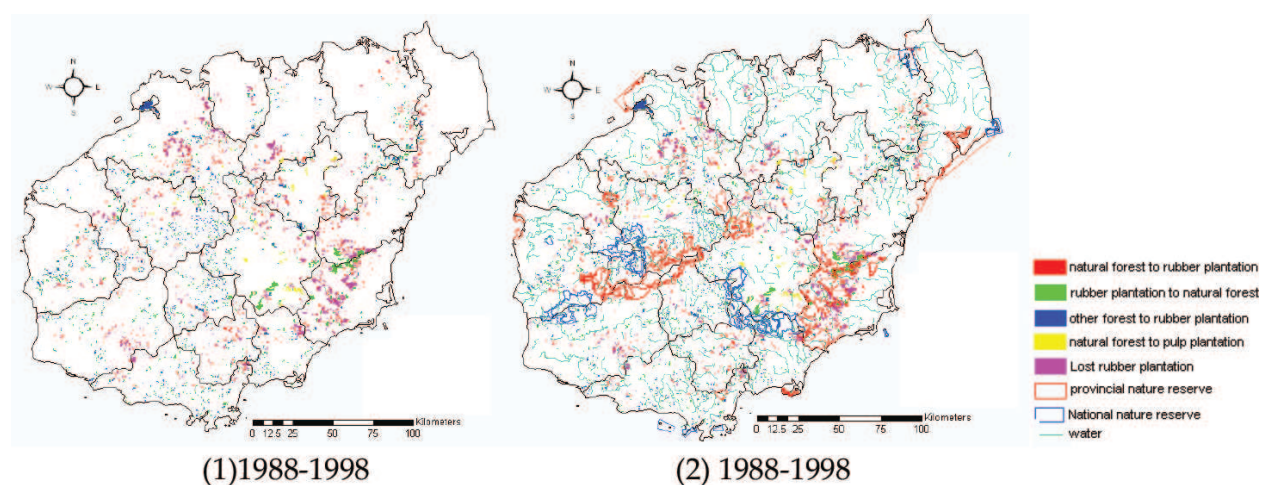


Figure 13. Distribution pattern of other forest converted into natural forest: (1)1988–1998; (2) 1988–1998.

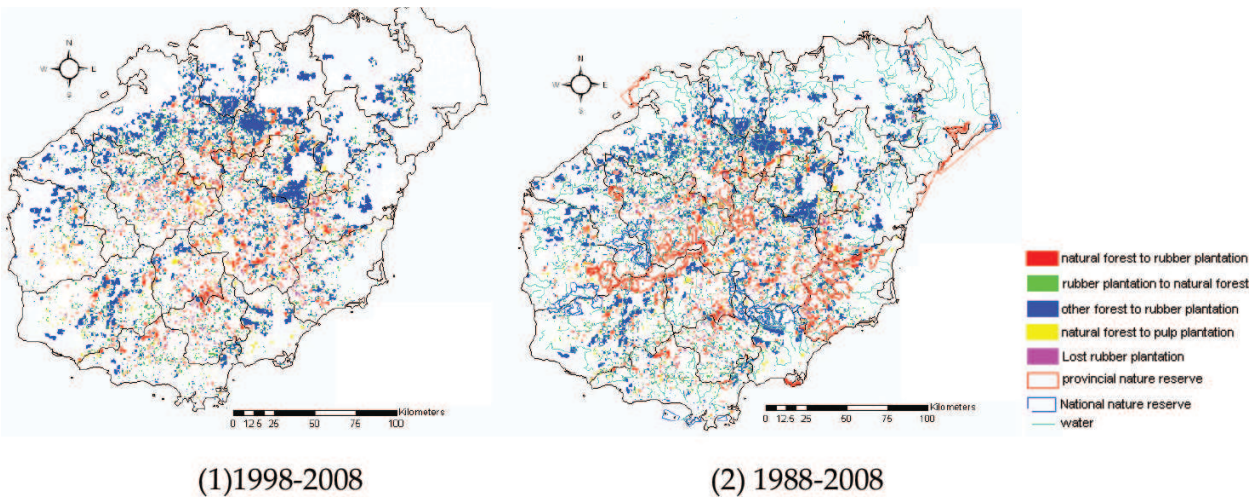


Figure 14. Mutual transformation of natural forest and rubber pulp plantation: (1)1998–2008; (2) 1988–2008.

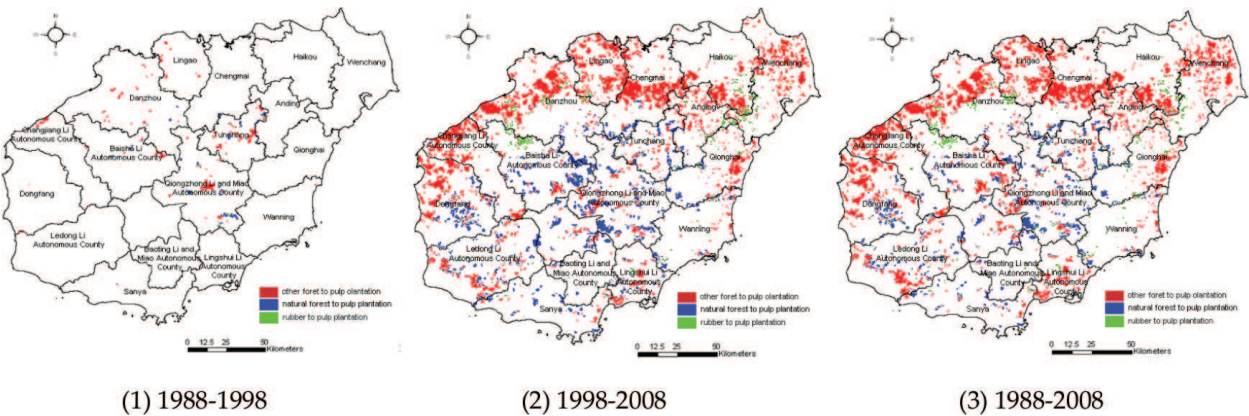


Figure 15. Spatial distribution pattern of newly increasing pulp plantation. (1) 1988–1998; (2) 1998–2008; and (3) 1988–2008.

From 1988 to 1998, the conversion of natural forests into pulp plantation was mainly distributed in Qiongzhang, Danzhou, and Tunchang counties in the northern part of Zhongshan District, with a relatively small area (0.29 million hectares). From 1998 to 2008, the total area (50–200 hectares) increased obviously, which mainly distributed in the central mountainous regions. The center of the change obviously migrated to the south. Apart from the obvious increase in three counties and cities mentioned above, they were also distributed in the Dongfang, Ledong and Sanya counties, and their area diffusions were significant.

3. Spatial pattern of rubber plantation converted into pulp plantation.

The change from rubber plantation to pulp plantation was very small (0.02 million hectares) in 1988–1998, mainly in Tunchang County in the northern area of central mountainous. The area (90,000 hectares) increased significantly from 1998 to 2008 mainly in the junction area of northwest Danzhou and northeastern Wenchang – Haikou (city).

4. Spatial pattern of other ecosystem types converted into rubber plantation.

The spatial distribution of other ecosystem types (farmland, tea garden, grassland, etc.) varied from 1988 to 1998, mainly in small blocks distributed in Danzhou, Qiongzong, Baisha, Tunchang counties and cities. It increased significantly during 1998–2008, accounting for 67.5% of the total increase area (193,800 hectares), forming strip-shaped areas along the northern coastal plain of the east, Changjiang, Danzhou, Lingao, Chengmai, south of Haikou, and Wenchang County (city). Others are distributed in the central mountainous areas and the coastal plains.

3.1.2.3. The pattern changes of newly increased rubber plantation

1. The pattern of newly increased rubber plantation.

The newly increased rubber plantation mainly evenly distributed in the central mountainous area and its surrounding area during 1988–1998. The total area (51,400 hectares) is small. From 1998 to 2008, the area (467,300 hectares) has a great increase in the central mountainous area and its surrounding area. It extends inward and outward along the central mountainous area, especially in the northeast of Tunchang, Chengmai, Lingao, Haikou, and other counties even into sheet shape. The area during 1988–2008 changes is not obvious compared with 1998–2008 (**Figure 16**).

2. The pattern changes of natural forest to rubber plantation.

The area of newly increased natural forests converted into rubber plantations (0.37 million hectares) is small and spatially dispersed during 1988–1998, as can be seen from **Figure 17(1)**. It is mainly around the central mountainous area. From 1998 to 2008, the area of natural forest into rubber plantation changed significantly (110,900 hectares), and the increase mainly concentrated in the central mountainous area and the surrounding areas, showing the Qiongzong, Tongshi, Baisha County as the center, the pattern of radiation to Sanya, Baoting, Ledong, Danzhou, and other counties (cities). From 1988 to 2008, the change of the total area (96,800 hectares) was not as obvious as that of 1998–2008 except for the changes in Qiongzong, Tongshish, Baisha County (city) as the center of the region, the distribution of Sanya and Ledong (city) changes is also obvious.

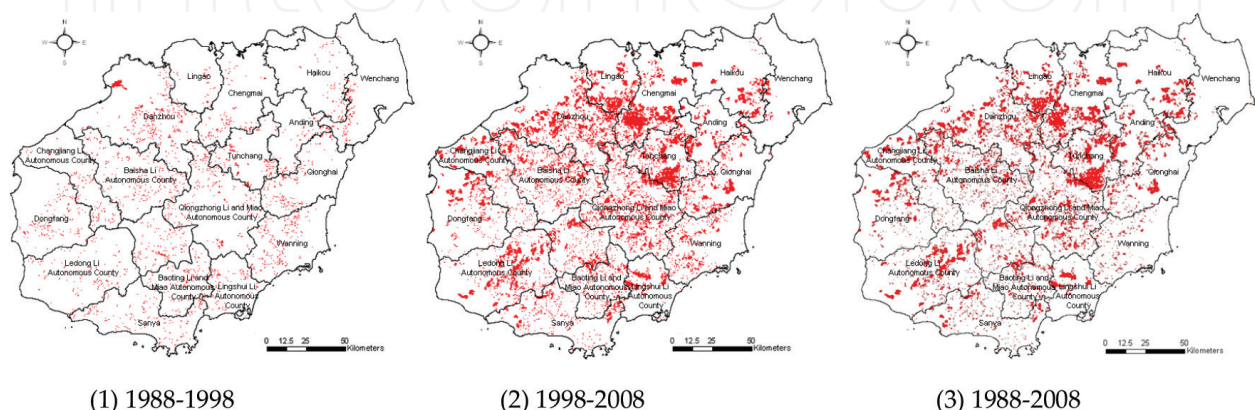


Figure 16. The spatial pattern of newly increased rubber plantation. (1) 1988–1998; (2) 1998–2008; and (3) 1988–2008.

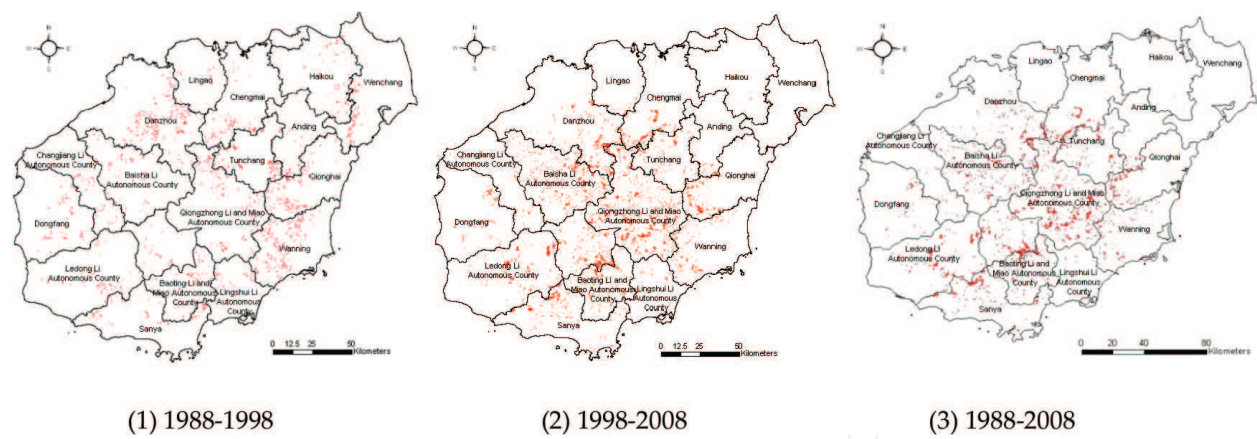


Figure 17. The spatial pattern of natural forest to rubber plantation. (1) 1988–1998; (2) 1998–2008; and (3) 1988–2008.

3.1.2.4. *Spatial pattern of newly increased other types of ecosystems*

The increased pattern changes of other types, such as orchards, farmland, grassland, and so forth, are mainly concentrated on the central region of Qiongzhang, Baisha Counties (**Figure 18**).

The major ecosystems in Hainan Island (natural forests, rubber plantation, pulp plantation, farmland, etc.) have been significantly changed in space from 1988 to 2008. Natural forests increased significantly from 1988 to 1998 and the spatial distribution expanded outward from the central mountainous areas, that is, infiltration and expansion from the central mountainous area to the surrounding land. The changes in the central mountainous area were obvious.

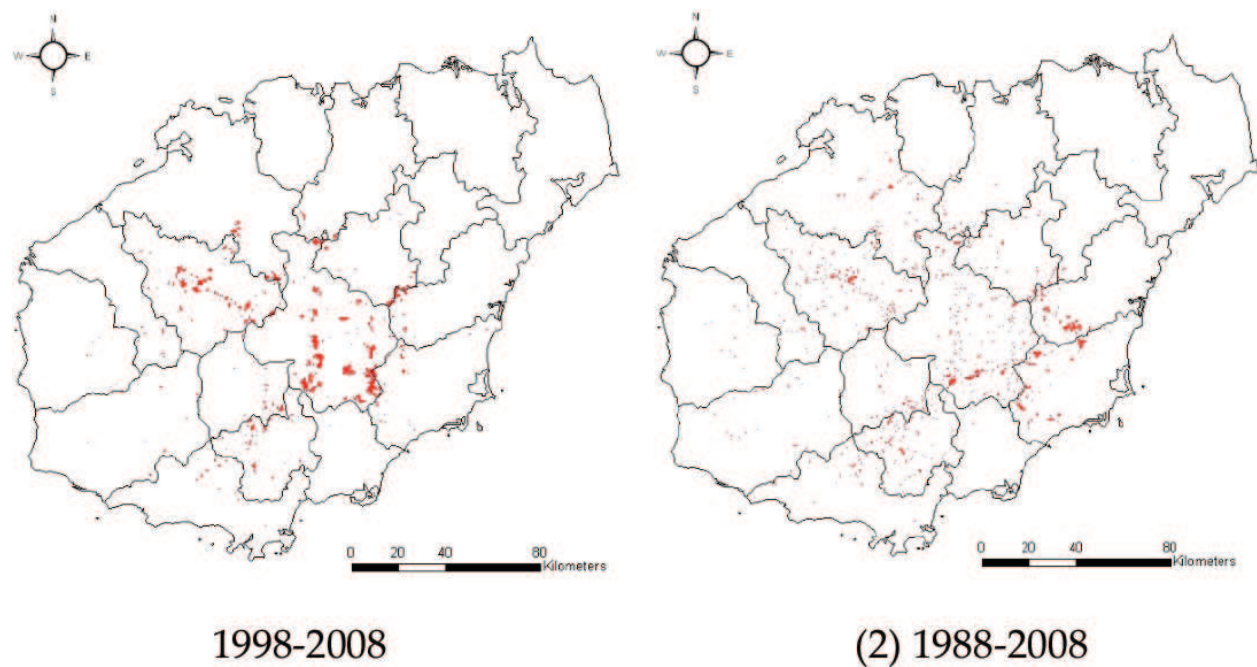


Figure 18. Spatial pattern of newly increased other types ecosystems: (1) 1998–2008 and (2) 1988–2008.

The rubber plantation was partly replaced by pulp plantation. The rubber plantation was mainly distributed around the platform around the central mountainous area. The rubber and pulp plantations invaded the natural forest in central mountainous area. During 1998–2008, the natural forest decreased significantly, and the main performance was from the terrain around the hills to the central mountain, which sharply declines. The rubber plantations are mainly distributed in the vicinity of water, extending to four directions from southeast to northwest, of which northeast is the most obvious. The pulp plantation area increased greatly, forming a banded area (acting as a shelterbelt) from the northwest to the north. The pulp plantation also expanding obviously in other areas, infiltrating in nature reserves, farms, the southern Sanya area, and so forth. The north and west of pulp plantation distribution was larger than the south and east in general. Large area of natural forest was replaced by pulp and rubber plantation.

3.2. The change of different forests during 1988–2008

The total area of tropical forest in the study area increased during 1988–2008. The area of tropical forest covered about 68.57% of the study area in 1988, and then covered about 71.89% of the study area in 2008, with the increase approximately 8% during 1988–2008.

Natural tropical forest always covered the largest area of land use type within the study area, increasing slightly (6.65%) in the first decade (1988–1998), and then decreasing sharply (13.69%) in the second decade (1998–2008). Generally, the area of natural tropical forest tended to decrease, despite obvious fluctuations during the study period.

The area of economic forest obviously expanded from 1988 to 2008. Of the economic forest, rubber plantations covered the largest area, but decreased slightly (3.79%) during the economic recession of 1988–1998; then, it experienced a rapid increase in conjunction with the renascent market economy during 1998–2008. A few scattered pulp plantations existed before 1988. Pulp wood was planted widely after 1988, eventually covering about 0.7×10^4 hectares by 1998 and about 7.09×10^4 hectares by 2008 (Table 1).

Landscape-scale transformation of various forest types obviously occurred. From 1988 to 1998, natural forest in the piedmont was converted into scattered rubber plantation, ultimately covering 9.57×10^4 hectares by 1998. During the next decade (1998–2008), an additional 9.72×10^4 hectares natural forest was converted into economic forest (rubber and pulp

Year	Natural forest (10^4 hectares)	Rubber plantation (10^4 hectares)	Pulp wood areas (10^4 hectares)	Total forest area (10^4 hectares)
1988	73.48	22.57	*	95.91
1998	82.66	17.28	0.70	100.64
2008	63.29	35.91	7.09	107.29

*Hainan Island had sporadic eucalyptus in 1988, but eucalyptus was grown for timber, not for pulp.

Table 1. Area of natural forest and economic forest during 1988–2008.

wood plantations), which led directly to a corresponding decrease in the extent of natural tropical forest. At the same time, up to 6.26% of natural forest and up to 3.09% of economic forests were converted to other land uses.

The spatial conversion of forest was also seen because of the transformation of different forest types. The remaining natural tropical forests tended to occur only at higher elevations and on steeper mountain tops, that is, the average distances to farms and transportation corridors increased. This occurred because some natural tropical forests at lower elevations, and with less steep slopes that were previously closer to farms and transportation corridors, were transformed into economic forests during 1988–2008. The increasing extent of economic forests might result in a loss in the value of ecosystem services [17]. Generally, forest transition theory assumes that increasing forest cover indicates that environmental conditions are improving [18], but the increasing forest cover in our study area does not necessarily mean that biodiversity and natural ecosystems are recovering (**Figure 19**).

3.3. The response of forest transformation to economic development and protection policies

Regional market trends contribute to the conversion from natural forests to economic forests (rubber, pulp forests, etc.). Rubber and pulp plantations expanded because of new regulations and increased demand from consumers. For example, the demand for rubber kept increasing slowly, and this led to low prices between 1988 and 1998. In addition, most rubber plantations were planted on government-operated farms, typically covering large areas, whereas small landholders were not involved significantly in rubber plantations until 1995. Thus, the conversion of natural tropical forests into rubber plantations in the piedmont had been only sporadic during 1988–1998. However, the market demand for rubber increased sharply after 1999, leading to higher prices, which encouraged smaller landholders to become deeply involved in rubber plantations after 1999. Therefore, the demand for rubber in the open market might be an important factor in driving the change of different forest types during 1988–1998 (**Figure 20**).

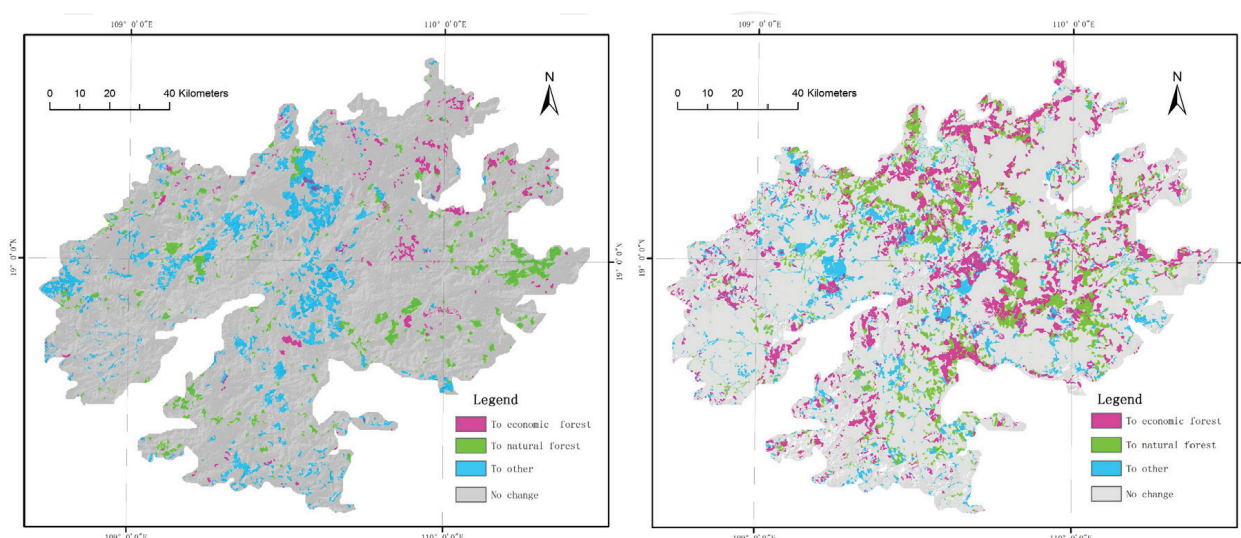


Figure 19. The transformation of different forest types in 1988–1998 (left) and 1998–2008 (right).



Figure 20. Chinese natural rubber demand and price changes.

The Chinese Government has strongly encouraged the planting of pulp plantations with the goal of developing a domestic wood pulp industry that could meet growing domestic demand. The government provided substantial capital subsidies in the form of low interest rate loans, discounted loans, and extended repayment periods for loans from state banks [19].

Thus, new plantations of economic forests greatly reduced the available space for natural tropical forests; therefore, the area of natural tropical forest decreased by 2008. Protection policies and the establishment of reserves delayed the transformation of some forests. In the early 1950s, policies encouraged the establishment of rubber plantations. Several nature reserves were established in Hainan Island starting in 1976. Currently, nine national nature reserves cover 11.20×10^4 hectares, while provincial nature reserves cover 13.84×10^4 hectares. Generally, both national nature reserves and provincial nature reserves limited the expansion of rubber plantations. The transformation of rainforests to plantation forests was suppressed by these protection policies, and especially by the existence of natural reserves during 1988–1998 (Table 2).

Different types of reserves provide different levels of protection. The national nature reserves play important roles in protecting natural forest. During 1988–2008, in the national reserves, the area of natural forest increased steadily while the area of economic forest decreased slightly. However, provincial natural reserves play an ineffective role in protecting natural forest because local and provincial government agencies support economic growth over the conservation of natural resources. Therefore, some natural forests in provincial reserves were replaced by economic forests during the same period (Table 2).

Reserves type	1988	1998	2008
National reserves	16.31%	10.96%	7.22%
Provincial reserves	14.24%	8.80%	16.77%

Table 2. The percentage of plantation forests in different natural reserves in 1988–2008.

Generally, the main forces driving the transformation of forest types seem to be protection policies and economic development. Some natural forests were protected by the established nature reserves, and protection policies suppressed the transformation process. Furthermore, the development of economic forests, such as rubber and pulp plantations, propelled the transformation between different forest types, even in provincial reserves formally under the protection policies during 1998–2008. Generally, the spatial extent of natural forests decreased significantly from 1998 to 2008. Although some protection efforts have been attempted, such as the “Natural Forest Protection Project,” the establishment of nature reserves, and the closing of hillsides to facilitate afforestation, our results suggest that some of these protection measures were poorly implemented. From another viewpoint, economic development exerted an enormous influence on the tropical forests of Hainan Island and reduced the effects of these protection efforts. Extensive areas of natural tropical forest in Hainan Island have been converted into economic forest. Local politicians are evaluated strongly on their support of economic development. This encourages them to support economic development at the expense of environmental protection. Changing policies related to local government officials could increase protection for natural landscapes.

To resolve the conflict between development and protection, a balance between economic development and forest protection needs to be found based on monitoring data [20]. The establishment of ecological compensation mechanisms might contribute to providing local communities with some economic benefits in exchange for forest protection [21].

3.4. Response of forest transformation to environmental factors

The dynamics of major ecosystems are the result of the combination of economic drivers and state-related policies. The following sections will be comprehensive analysis of the relationship between the spatial patterns of main ecosystem in Hainan Island with terrain, traffic, water sources, settlements, and nature reserves.

3.4.1. Relationship between distribution pattern of natural forest and topography

The process of natural forest change in Hainan Island is a process of human disturbance. It is a process of gradually approaching to the southern of the central mountains, that is, the natural forest follows the process of approaching from plains, terraces, and hills to mountains successively. Its altitude also follows the change from low to high. With the increase of the terrain, the average patch area tends to increase. The following is an example of the relationship between natural forest distribution and topography in 1998 (**Table 3**).

From **Table 3**, natural forests were mainly distributed in the central mountainous area, closely related with the terrain. The next distribution area was the terrace, and the coastal plain was sparsely distributed. This shows that natural forests are closely related to the terrain. One thing to note is that mangroves and other natural forests distributed in coastal areas need to increase protection.

3.4.2. Relationship between natural forest distribution pattern and water system

Under the analysis of water system (**Figure 21**), the natural forest near the hilly area or in relatively low altitude, where water system developed, is gradually replaced by other types of vegetation. The relationship between the natural forest distribution in the central mountainous

Region	Natural forest area(km ²)	Core area	patch numbers	Mean patch area(km ²)	Spatial pattern and terrain
Haikou City	1.634		5	0.32671	Coastal plains, low topography
Lingao County	1.535		2	0.76742	Coastal plains, low topography
Chengmai County	151.905		19	7.99502	Coastal plains, low topography
Wenchang City	5.021		6	0.83677	Coastal plains, low topography
Anding County	61.784		15	4.11895	Northeast terraces, plains, the terrain is relatively low
Pizhou City	273.933		49	5.59048	Coastal plains and terraces
Tunchang County	173.980		37	4.70216	North Central Plains, hills
Baisha Li Autonomous County	1078.765		54	19.97714	Central mountains, terraced hills
Qiongzong Li and Miao Autonomous County	1403.166		56	25.05654	Central mountainous area
Changjiang Li Autonomous County	487.069		50	9.74138	Terrace and coastal plains
Qionghai City	190.571		22	8.66231	Terrace and coastal plains
Wanning City	532.908		46	11.58496	Coastal plains
Wuzhishan City	809.595		17	47.62325	Central mountainous area
Dongfang City	794.933		25	31.79732	Central mountains, terraced hills, coastal plains
Ledong Li Autonomous County	1121.411		50	22.42821	Central mountains, terraced hills, coastal plains
Baoting Li and Miao Autonomous County	549.121	431.76	12	45.76008	Central mountainous area
Lingshui Li Autonomous County	358.404	257.45	26	13.78476	Terraced hills
Sanya City	910.537	591.3	54	16.86180	Terrace - coastal plains

Table 3. Relationship between different ecosystems and topography.

area and water system is not as obvious as the terrain. That is, the distribution of water systems is not the main reason for the distribution of natural forests in this area.

3.4.3. Relationship between the natural forest distribution pattern and farms

As can be seen from the distribution pattern of the farms (**Figure 22**), most of the farms are located in the hills, terraces, and coastal plains, while the central mountainous areas have relatively small densities. However, the natural forest patches in the farmland are obviously fragmented. In other words, near the farm, the destruction strength of natural forest is big, otherwise it is small. It can be seen that the distribution of farms directly affects the spatial pattern of natural forests and has obvious negative impacts on the distribution of natural forests.

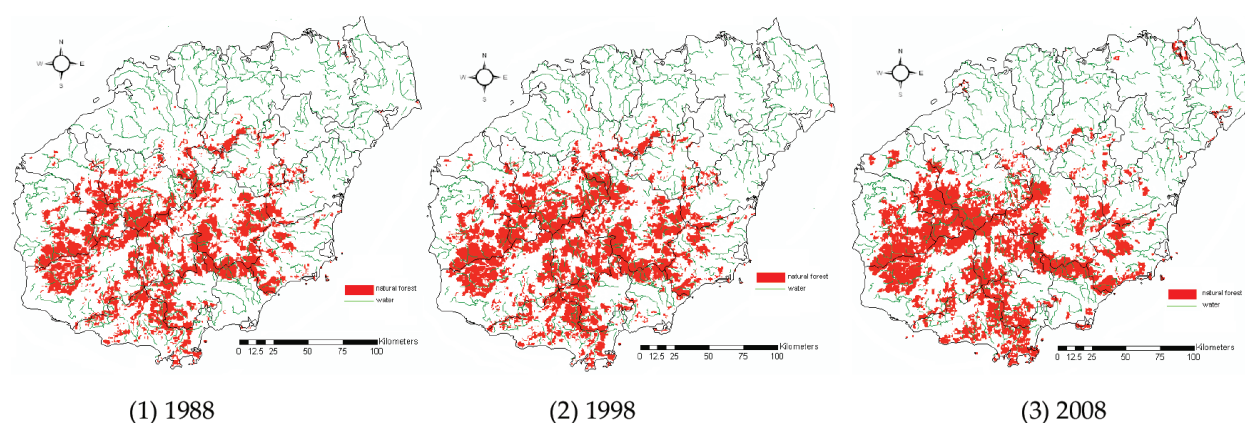


Figure 21. Relationship between natural forest distribution and water system. (1) 1988; (2) 1998; and (3) 2008.

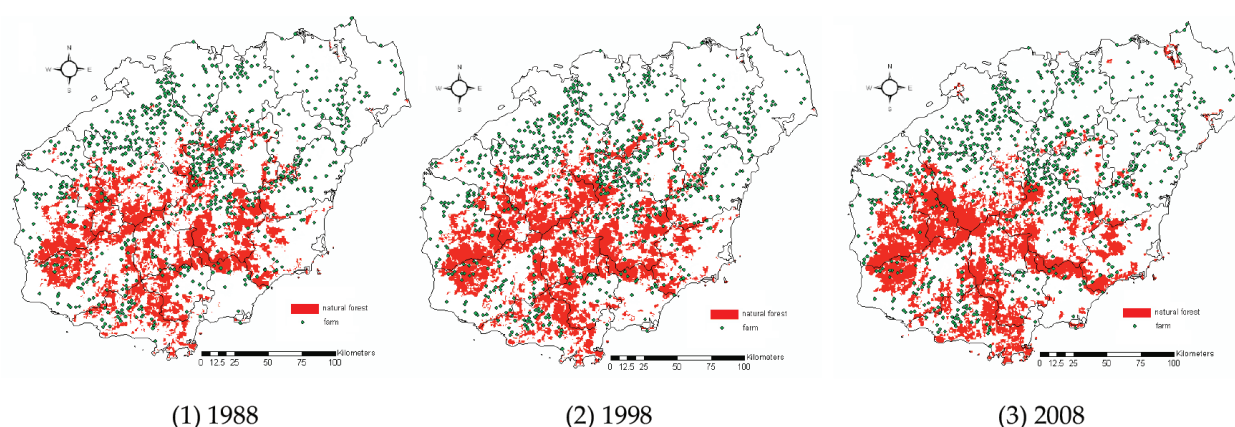


Figure 22. Relationship between natural forest distribution patterns and farms. (1) 1988; (2) 1998; (3) 2008.

3.4.4. Relationship between natural forest distribution and traffic route distribution

The traffic conditions directly affect the spatial distribution pattern of natural forests (**Figure 23**). The areas with convenient transportation are mainly distributed in plains, terraces, and hilly areas. The patches of natural forests on both sides of the traffic line showed fragmented trend. That is, the destruction of natural forests is serious where the traffic line is dense, the terrain is relatively flat, and the distribution of residents and farms is wide. Therefore, the distribution of traffic lines is closely related to the distribution of natural forests.

3.4.5. Relationship between natural forest distribution and nature reserve distribution

In order to better protect the cherished species, there are many provincial and national nature reserves have been successively set up in recent years (**Figure 24**). In this area, 88.71% of the National Nature Reserve area is covered by natural forest in 2008, 94.03% in 1998, and 82.71% in 1988, while the surrounding area of the reserves is often replaced by other features, especially the provincial nature reserves. The natural forest has become an island, such as Hainan Jiaxin Provincial Nature Reserve, Liulianling Provincial Nature Reserve, and so forth. This shows that the establishment of nature reserves played a positive role in the protection of natural forests but also exposed hidden worries of other types of ecosystems to natural forests.

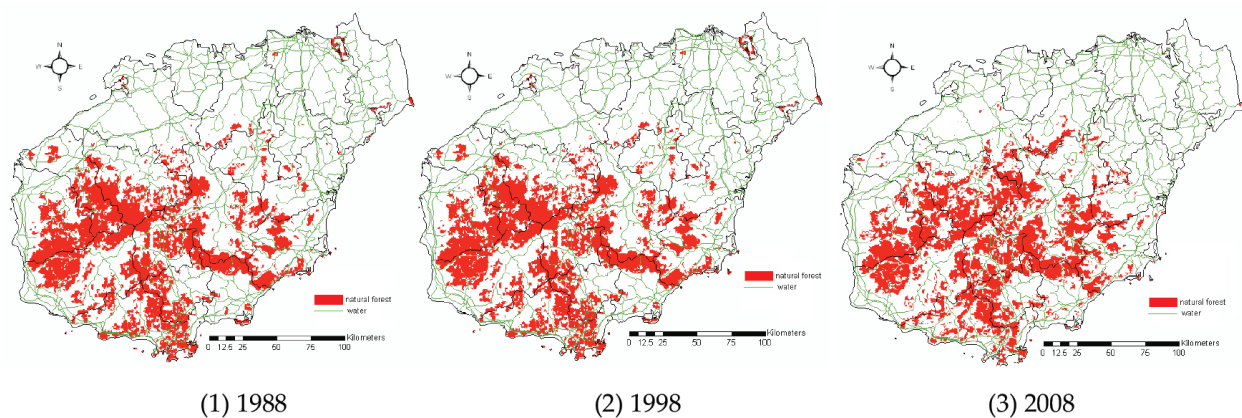


Figure 23. Relationship between natural forest distribution and traffic route distribution. (1) 1988; (2) 1998; (3) 2008.

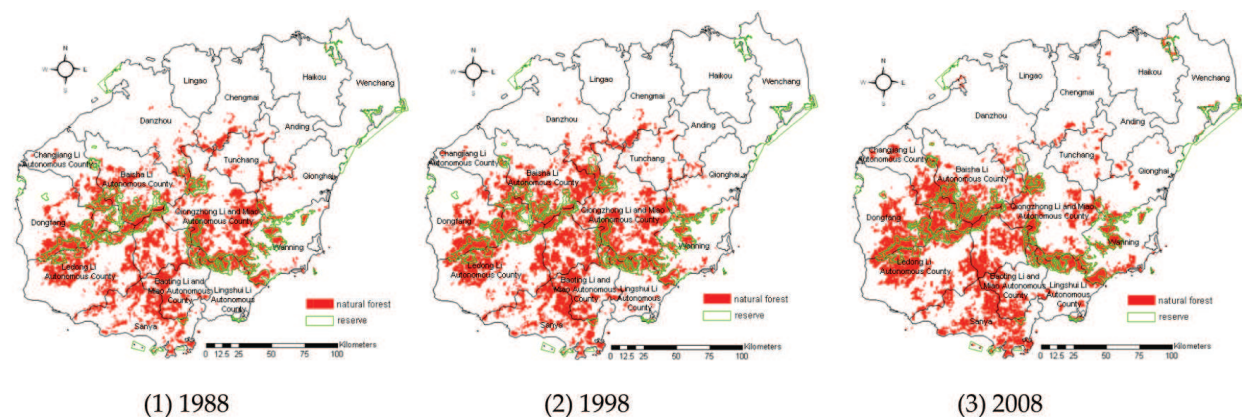


Figure 24. Relationship between natural forest distribution and nature reserve distribution. (1) 1988; (2) 1998; (3) 2008.

3.4.6. Relationship between rubber plantations and farms, traffic lines, water distribution

Figures 25 and 26 are the spatial distribution maps of rubber plantations and settlements in 1988, 1998, and 2008. The farms were mainly distributed in the western and northern parts of Baisha, Zhanzhou, Tunchang and southwest Sanya, Ledong and other counties and cities. Its distribution is more in northwest, north and less in southern, coastal plains in short. Most of the rubber plantations are located near 3–5 km to the farms and settlements, showing that the distribution of farms, settlements, and rubber plantations are closely related. According to the abovementioned analysis, most of the traffic lines in settlements and farms are well developed and are relatively close to the water source. Therefore, it can be considered that most of the rubber plantations were relatively close to the traffic and water source. Therefore, the distribution of water systems, traffic lines, and farm concentration is frequent areas for deforestation and rubber plantations.

3.4.7. Relationship between pulp plantation with farm, traffic lines, and water distribution

The space distribution of pulp plantations shows small block-like but relatively wide distribution. There are a large number of distributions in the vicinity of farms, traffic lines, and waters, as well as widely distributed in coastal plains, central mountains, and terraces, which mostly

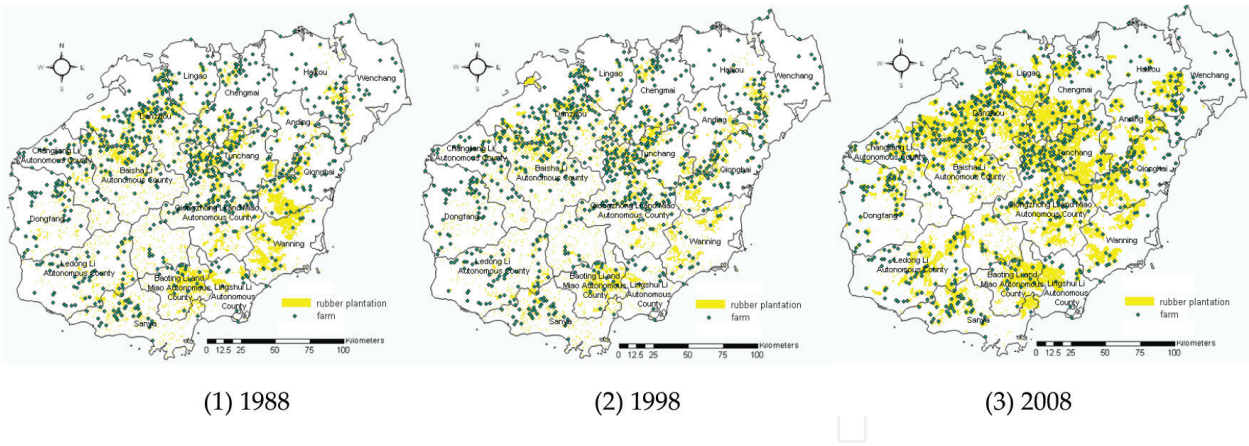


Figure 25. Relationship between rubber plantations and farms, traffic lines, water distribution. (1) 1988; (2) 1998; and (3) 2008.

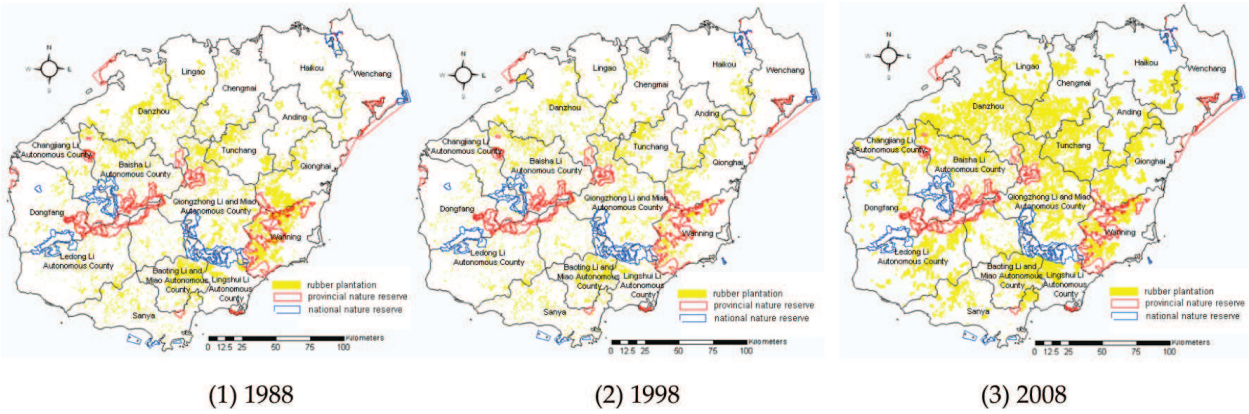


Figure 26. Relationship between rubber plantation area change with other woodlands and nature reserves. (1) 1988; (2) 1998; and (3) 2008.

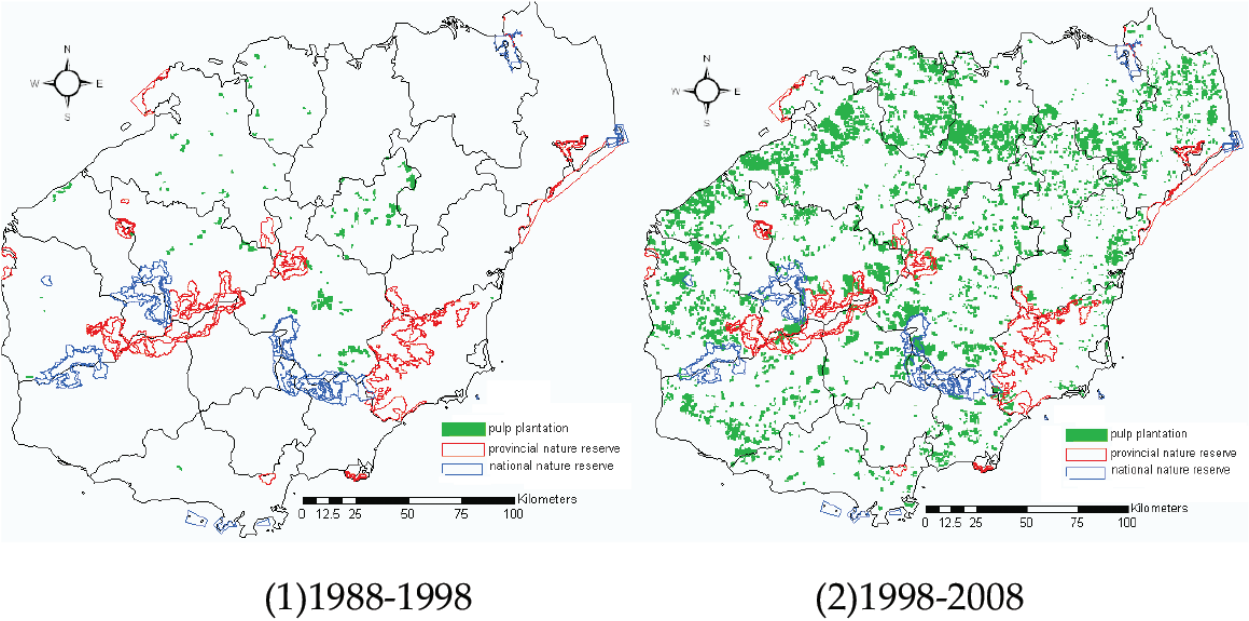


Figure 27. Relationship between pulp plantation area change with other woodlands and nature reserves. (1) 1988–1998 and (2) 1998–2008.

distributed less than 25 degrees slope. It can be seen that the regularity of pulp plantation spatial distribution is not obvious.

3.4.8. Relationship between pulp and rubber plantation with nature reserves

In recent years, natural forest reserves have been established one after another to protect natural forests and other species (**Figure 27**). In National Nature Reserve area, the area 11.29% in 2008, 5.197% in 1998, 17.29% in 1988 was covered with rubber plantation and pulp plantation. This shows that nature reserves play a protective role in natural forests. At the same time, rubber forests and pulp and paper forests gradually penetrate into nature reserves and gradually replace natural forests.

4. Conclusions

The results emphasize that forest monitoring could incorporate remote sensing imagery of specific periods and an object-based decision tree method to identify forest change. The object-based information extraction based on the decision tree method proved applicable and effective in identifying the main forests with complex surface features in a tropical evergreen ecosystem. Based on the results of forest information extraction, it is determined that the tropical forests of the central Hainan Island suffered a significant change during 1988–2008. Initially, the spatial extent of natural tropical forest increased slightly and then experienced a considerable decrease during 1998–2008. Larger amounts of natural tropical forest were replaced by economic forests, resulting in an expansion of economic forests (rubber and pulp plantations). Forests also shifted spatially during 1998–2008. Elimination of some natural tropical forests in the lower piedmont, due to economic development, caused the average location of the remaining tropical forest shift to higher altitudes. The transformation of forests was driven mainly by protection policies and economic development, but economic development exerted a much stronger influence and minimized the protection efforts. Transportation corridors, farmland, slope, and elevation were also important intrinsic dynamics that affected the transformation of tropical forests.

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