Long-term change of protective forest during the past four decades at Dongshan Island, southeastern China

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Abstract The Dongshan Island is a typical protective forest area of the southeastern coastal region of China. In this work, we extract the variation of the Dongshan Island’s protective forest area since the 1970s from the remote sensing data of the LandSAT and the Chinese HJ 1A/B satellites, and we examined the possible reasons for the variation. The results showed that the maximum likelihood classification of the extracted remote sensing data of the Dongshan Island coastal protective forest had a total accuracy of 92.6%. In the last 40 years, the area of the Dongshan Island coastal protective forest experienced a waving variation of decrease (1973-1984), increase (1984-1999) and decrease (1999-2008), in which human activity was the predominant impact factor for this fluctuation pattern. Since the early 1960s to the 1980s, due to the Cultural Revolution and the later deforestation and land reclamation activities, the protective forest of Dongshan Island was severely damaged. The total area declined sharply from 2134.4 ha in 1964 to 1515.74 ha in 1984, and the northern area of the island had the most significant decrease. After 1988, the Fujian Province began to aggressively establish the coastal protective forest system, and the protective forest acreage increased significantly to 3370.22 ha in 1999, an increase of nearly 1.2 times based on the figure of 1984. In the past five years, the area of protective forest declined slightly again, mainly because of the natural aging of the protective forest ecosystem, tourism development and the booming aquaculture industry.

1. Introduction

The coastal protective forest is an essential safeguard of the coastal environment that promotes the sustainable economic development of the coastal region, due to its important effects in sand-fixing, soil and water conservation, typhoon resistance, amelioration of the living environment, maintaining biodiversity, microclimate improvement, etc. (Beese & Bryant, 1999; An et al., 2006; Erefur et al., 2008; Borsie et al., 2011). Under the stress of natural forcing and human activity, how were the protective forests changing globally? Acquiring the answer of this question would certainly help people predict the potential changes in the future and seek strategies for sustainable development. According to the analysis data provided by FAO 2010 (FAO, 2010), the total extent of forests which are designated for protection of soil and water was estimated to be 330 million hectares, increased by 59 million hectares between 1990 and 2010 and equivalent to eight percent of the global forest area. Asia has the highest proportion of forests with a protective function (26%), followed by Europe (9%). The recent increase is primarily due to large scale planting in China for protective purposes.
China is undergoing very rapid economic development, whereas it has a long coast line (~18,340 km for mainland and ~11,159 km for island). Although the Chinese government decided in 1988 to construct the coastal protective forest system covering the entire coast line (Li, 2004), this system faces enormous challenges where forest destruction is not effectively controlled under the booming economic development. The infrastructure and industrial land use has rapidly increased since 2000, and forest land is in fact constantly encroached or illegally occupied by real estate development, tourism and resort construction, farming, quarrying, sand and earth excavation, etc. Consequently, the protective forest continuously declined in acreage and deteriorated in quality. Details are yet clear without a valid way to do the survey.

Here in this study, we took a small island, Dongshan, located in the southeastern China, an area subject to typhoon and storm surge hazard, as a case for assessment of protective forest change (Figure 1). So far few relevant reports are available to make quantitative analysis of the areage change of protective forest in this region. One example is that the calculation showed the total Fujian coastal protective forest area was about 336,000 ha in 2006 which was based on 10 MODIS images solely (Zhang et al., 2007). We used both in situ and remote sensing data, covering the time span of the 1970s-2000s. Our objective is to demonstrate how protective forests change in a typical coastal area of China during the past four decades.

![Figure 1. The map of Dongshan Island at Fujian province](image1)

![Figure 2. Spectral curve of the major tree species and other land feature in the Dongshan Island](image2)

### 2. Detection of Protective Forest

#### 2.1. In situ measurements of reflectance spectrum

We recorded the spectra of the major land features of the Dongshan Island by using a GER 1500 portable spectroradiometer (Spectra Vista Corporation) covering the UV, Visibale and NIR wavelengths from 350 nm to 1050 nm. All reflectance were measured outdoors under natural light without cloud during 8 am to 3 pm. The selected sample regions are required to be homogeneous. The spectroradiometer located at the top of the target and had the angle of 45° with vertical slope. Same features were measured eight times and averaged as representative of feature spectrum. For the trees such as *Casuarina, Eucalyptus* and *Dimocarpus*, because we could not record the spectrum directly on the canopy, we picked a certain amount of the twigs and laid them on the ground with leaves facing up and with no gap, ensured their surroundings were open and unblocked, and then recorded the spectrum of these quasi-leaves. The measurements at each sample point were completed in 5–10 minutes.

It can be seen from the measured spectra (figure 2) that vegetations such as *Casuarina, Eucalyptus, Dimocarpus* have distinct spectral curves and are clearly discernable from water or bare soil. Between different vegetation, the reflectance of *Casuarina* is similar to *Eucalyptus* and *Dimocarpus* in the visible band but significantly lower in the near-infrared band.
2.2 Classification of targets

Satellite data from the U.S. Land Remote Sensing Satellite (LANDSAT) and the Chinese small satellites for environment and disaster monitoring and forecasting (HJ-1A/B) were used to assess the distribution of protective forests. Details of the data are shown in Table 1.

ENVI 4.5 software (ITT Visual Information Solutions Corporation) was used for the data processing. The atmospheric correction was realized through the built-in FLASH atmospheric correction module in ENVI. According to the local latitude and the season of acquired images, Tropical Regional Model was selected from 6 provided atmospheric models. The aerosol type is for rural area. The geometric registration between images used the TM images of September 25, 2006 as the benchmark image. After the geometric precision correction and the polynomial correction using ground control points (GCP), the corrected benchmark image was used for adjusting other images to control the overall error within less than one pixel. For the LANDSAT MSS data of 79 m resolution, during registration we used the nearest neighbor method to reset their spatial resolution to 30 m.

The in situ measured spectrum data (figure 2) demonstrated that different targets showed different colors on satellite RGB composites. It is thus straightforward to identify seven targets basically based on differences in color, including: (1) protective forest (Casuarina, mixed species forest, etc.), (2) orchards and farmland with high vegetation cover, (3) bare soil and farmland with low vegetation cover, (4) land for urban use, (5) dams, (6) salterns and aquaculture farms, (7) tidal zone and water. Meanwhile, the normalized difference vegetation index (NDVI) was also added as one judgment for classification. The NDVI is calculated as $\text{NDVI} = (\text{NIR} - \text{VIS}) / (\text{NIR} + \text{VIS})$, where NIR is the near infrared band and VIS is the visible band. Finally, a classic supervised classification method—the maximum likelihood classification method (Richards, 1999) was used, with the seven target feature and NDVI as input, to classify different targets on each image. Results are shown in figure 3.

| Sensor     | Date                              | Resolution |
|------------|-----------------------------------|------------|
| LANDSAT MSS| October 30, 1973; October 30, 1984| 79 m       |
| LANDSAT TM | September 30, 1999; September 25, 2006 | 30 m       |
| HJ-1B      | November 14, 2008                 | 30m        |

Table 1. Description of satellite data used for classification

Note that visual examination is necessary since mistakes may occur during classification as difference land features might give identical spectrum and the same land feature might generate divergent spectrum. In addition, although the protective forest in Dongshan is dominated by Casuarina, there might be other species such as Dimocarpus mixing in the forest.

3. Validation

We take the November 14, 2008 image extracted from the environmental satellites as an example to demonstrate the accuracy assessment of our classification. The test image of the assessment mainly used the February 28, 2008 QuikBird image of 2.44 m resolution, and the area of comparison is mainly in the northeast Dongshan Island. According to the confusion matrix, the classification is overall quite satisfactory with a total accuracy of about 92.6% and a Kappa coefficient of 0.90. The classification of water bodies had the best accuracy of 100% and that of the protective forest was about 88.3%. Because the classified remote sensing images had a low spatial resolution of only 30 m, there might have been some mixed pixel that negatively affected the accuracy in information extraction. Nevertheless, we further compared the protect forest area derived from remote sensing image classification with the statistics from the Zhangzhou Forestry Bureau (figure 4). It can be seen that in 1999, 2006 and 2008 when both data are available, the data extracted from remote sensing agree well with the statistics. We thus conclude that our classification is reliable and can be used for analyzing the variation of the protective forest in the Dongshan Island since the 1970s.
4. Temporal and spatial variation of the protective forest in the Dongshan Island

It can be seen from figures 3 and 4 that the protective forest area decreased from 2134.40 ha in the early 1960s down to 1871.22 ha in the early 1970s, which is a 12.33% decrease. In 1984 the protective forest area dropped further to 1515.74 ha, which is only about 71% of the acreage in the early 1960s. However, the protective forest area increased substantially afterwards to a maximum of 3370.22 ha in 1999, which is 2.22 times of the acreage in 1984. Since 1999, the protective forest area declined again. The acreage in 2008 is 550.49 ha less compared with that of 1999, which is a decrease of about 16%. The average annual change rate of area of protective forest during 1984-2008 is about ~3.6%, which less than the annual change rate (~4.9%) of protective forest plantations in China during 1990-2000. However, it is comparable with that of Russia Federation (~3.2%) and India (~3.7%) during 1990-2000 (FAO, 2005).

We arbitrarily divide the Dongshan Island by 23°40′N into the northern part and the southern part (figure 5). It can be seen that the northern part had more protection forest than the southern part, but their areas showed different variation trends. From 1973 to 1984, the northern part had declining protection forest area, whereas in the southern part the protection forest area increased slightly. From 1984 to 1999, the protection forest area increased substantially in both parts. From 1999 to date, both the southern and northern parts showed reduced protection forest area, but the magnitude of reduction was much greater in the southern part (about 23%) and less in the northern part (8.9%).
Figure 4. Comparison of protection forest area extracted from remote sensing data (orange bars) with historical statistics (blue bars) of the Dongshan Island.

Figure 5. Comparison of the protective forest area in the northern and southern parts of Dongshan Island.

Figure 6 shows the variation of protective forest land usage in 1973 and 2008, in which the green region represents additional forest planting and the red region represents forest land converted to other use. In the 35 years, for all the forest planted in 1973, 37 ha (nearly 1.98%) was converted into urban land, 537 ha (nearly 28.71%) changed into farmland for the cultivation of longan, lychee or other cash crops, and 54 ha (2.89%) changed into salterns or aquaculture farms. At the same time, an additional 983 ha protective forest has been planted in other areas, and the total protective forest area reaches 2854 ha in 2008, which increased by 53% compared with that of 1973.

From 1973 to 1984, the protective forest of the Dongshan Island had a sharp decrease of about 355.48ha, in which about 27% converted into farmland and other vegetations, 20% became bare soil, and 8% converted into urban land. During this period, the Chinese “reform and opening-up” policy had just begun and there was massive urbanization. Especially, in the northern part of the Dongshan Island, over the 10 years, the urban land use increased quickly from 1600 ha in 1973 to 3800 ha in 1984. During the construction boom, the local forests were converted to farmland and the expansions of quarries and aquaculture farms were disorderly, which resulted in the significant damage to the protective forest and exacerbated soil erosion. Survey has shown that more than 70% of the soil erosion was due to irresponsible quarrying.
In order to improve the coastal environment and promote the economic development in coastal areas, since 1988 the Fujian province initiated the construction of the coastal protective forest system to build a comprehensive multi-species defense network across all coastal counties. Through these efforts, the basic afforestation of barren hills was completed by 1992. From 1988 to 1990, 977.4 hectares of coastal protective forest were built in the Dongshan Island that met standard requirements. Various breakthroughs ensued since then, such as the trunk updating and new forest management projects in 1993 and the new construction projects at sandy and windy coastal areas in 1996. In 2001, the construction of the Fujian coastal protective forest system became financed by national bonds. From 2001 to 2005, the treasury financed 127.13 million Yuan, which effectively supported the construction projects (Lin, 2006). The result of the ten years’ efforts was remarkable. Based on the remote sensing classification results, the extracted protective forest area of Dongshan Island in 1999 is 2.22 times than that of 1984, in which 18.14% came from bare soil and 13.3% came from urban land use change. Clearly, the construction of protective forest system greatly improved the ecological environment of the island.

The Dongshan Island protective forest declined steadily since 1999 and especially notably in the latest five years. The main reasons can be rationalized as follows: (1) Aging and natural degradation of the protective forest ecosystem. Casuarina is the major species in the Dongshan Island protective forest system, which was introduced early and is currently entering the phase of aging and natural death. Meanwhile, due to inefficient management, planting multiple consecutive generations of Casuarina has degraded soil capacity. Combining with the impact of perennial sand attacks and other infrastructure construction, the Casuarina at many sections are now discontinuous, leaving gaps in the forest backbone. Therefore, new seedlings need to be constantly planted and other species should be introduced to update and strengthen the forest backbone. (2) Booming aquaculture. In recent years, due to the development of aquaculture, a number of abalone, shrimp and eel farms were built in the Dongshan county along the forest backbone, which impaired the original protection vegetation system. The Chencheng town in the southern Dongshan Island is the most evident example, where the abalone farming started since 1991 and has rapidly developed into nearly 100 farms throughout the town due to favorable economic return. Each abalone farm took approximately 0.26 ha, and most of the farms were required by the aquacultural needs to be located in the protective forest backbone, which resulted in the massive destruction of the protective forest in the Chencheng town (Wei, 2011). According to the remote sensing classification results, in the southern Dongshan Island the aquaculture farms and salterns were 1900 ha in 2008, which was three times of that in 1999. Thus, the total areage of protective forest in the southern Dongshan Island decreased more rapidly than the northern part (figure 5). (3) In addition, during the rapid economic development and growing tourism in recent years, land use for construction of tourist resorts expanded greatly in a lot of towns. The inadequate management has also virtually eroded the coastal protective forest and resulted in the reduced forest area.
5. Conclusions

Using the multi-spectral data from the LandSAT TM and HJ-1A/B satellites, in this paper we extracted the information of the coastal protective forest in the Dongshan Island of the Fujian province by supervised maximum likelihood classification. The overall accuracy of the extracted data was 92.6% and the forest area extracted from remote sensing data agreed well with the historical statistics. Therefore, the multi-temporal satellite images can be used to quickly and efficiently monitor the changes in the Dongshan Island and quantitatively determine the temporal and spatial distribution of the coastal protective forest, which provides scientific data to support the effective assessment and planning of forest planting.

On this basis, we chose the data in 1973, 1984, 1999, 2006 and 2008 and analyzed the changes of the coastal protective forest in the Dongshan Island over the 35 years. We found that the area of the coastal protective forest in the Dongshan Island experienced a decrease in 1973–1984, then increased in 1984–1999 and declined again in 1999–2008. Human activity has been the major reason of the variations in the protective forest. From 1973 to 1984, due to farmland cultivation and disorderly quarrying, the protective forest of the Dongshan Island lost about 355.48ha, and the reduction was most notable in the northern part of the island. From 1984 to 1999, as the Fujian provincial government implemented the coastal protective forest construction project, the extensive artificial afforestation increased the protective forest area in the Dongshan Island by 1.22 times over 10 years. From 1999 to 2008, the protective forest acreage declined again due to the natural aging of Casuarina, booming aquaculture, tourism development, etc. Therefore, it is necessary to strengthen the forest belt by adjusting the tree species to enhance the biological diversity of the forest, exercise administrative power to manage and coordinate the development of forest and other land use, promote the construction of the coastal protective forest system and reduce coastal forest degradation, so as to eventually realize the long-term ecological, economic and social benefits.

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