Wetlands (2014) 34:277–283
DOI 10.1007/s13157-013-0449-2

ASIA SPECIAL FEATURE

Mapping China's mangroves based on an object-oriented classification of Landsat imagery

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Received: 2 July 2012 / Accepted: 17 June 2013 / Published online: 11 July 2013

Abstract Reliable information on the extent and spatial distribution of mangroves has not been available for China. To create a map assessment of the mangroves for this region, an object-oriented classification technique was applied to Landsat-5/7 imagery at 30 m spatial resolution and verified using ground-truthing. Areal statistics for the mapped mangroves revealed that there were 20778 ha of mangroves located along the southeast coast of China. Extensive tracts of mangrove were found in Guangdong, Guangxi, Hainan, and Fujian Province (9289, 5813, 3576, and 1023 ha, respectively). Based on ground-truthing, the overall accuracy of our mangrove map was 92.6 % and the Kappa confidence was 0.85. Knowledge of the status and distribution of mangroves is important for advancing their management and conservation in China.

Keywords Landsat imagery · Object-oriented classification · Mangrove · China

Introduction

Mangroves are ecologically and socio-economically important, due to their critical roles in shoreline stabilization, reduction of coastal erosion, storm protection, and sediment and nutrient retention (Tam et al. 1997; Bahuguna et al. 2008). Therefore, mapping their distribution and areal extent in China and elsewhere is important for their conservation and management.

Globally, mangroves occupy over 1500 million ha, and are mainly found along the tropical and subtropical coasts of Asia, Africa, Oceania, North/Central America, and South America (Giri et al. 2011). Influenced by warm currents, some species of mangroves grow at extreme latitudes along the coasts of Japan (34° N) and New Zealand (38°S). In recent years, many of these mangrove forests have become threatened by development, so that about one-third of the world's mangroves have been lost over the past 50 years due to coastal development (Alongi 2002).

In China, mangroves naturally grow along the southeast coast of China traversing the provinces of, Guangxi, Guangdong,, Fujian, Hainan and Taiwan, intermittently extending from 18°12′ N to 27°20′ N latitude. According to the latest report issued by the State Forestry Administration (SFA) of China, the total area of mangroves in mainland China was approximately 22000 ha in 2001. This number accounts for slightly more than 0.1 % of the world's total. In spite of their small extent in China, mangroves have important ecological and economical values including providing nursery grounds for aquatic animals, breeding sites for birds, and medicine, food, building and fuel materials for local resident. Accurate and detailed characterization of mangroves is important for supporting their ecological role and management (Heumana 2011). However, no comprehensive estimates of the areal extent and spatial distribution of mangroves at the national scale in China.

Remote sensing provides many advantages over field surveys in monitoring this coastal ecosystem, and in addition, the method is accurate, rapid and cost effective (Spalding et al. 1997; Green et al. 1998). Landsat-5/7 images at 30 m resolution are an important data type for mapping

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large tracts of mangroves (Green et al. 1998). Gao (1999) mapped mangroves in the western Waitemata Harbor in New Zealand and confirmed that mangroves can be more accurately mapped using Landsat-5 data rather than SPOT data at both 20 or 10 m resolution. Landsat-5 images were widely used in mapping mangroves at larger scales, such as the entire world (Spalding et al. 2010; Giri et al. 2011), the Asia (Blasco et al. 2001; Giri et al. 2008), the Brazilian Amazon (Filho et al. 2006), the Vietnam (Seto and Fragkias 2007), and the Philippines (Long and Giri 2011).

In the present study, the object-oriented method is used to classify Landsat-5/7 images. Both pixel-based and object-oriented classification can be used for the classification of mangroves. But the pixel-based method often causes inconsistent classification accuracy (e.g., 75 % to 90 %; Heumana 2011). In contrast, the object-oriented method achieves accuracies of over 90 % (Wang et al. 2004; Conchedda et al. 2008; Myint et al. 2008). The objective of this project was to map the areal extent of mangroves in China using an object-oriented classification of Landsat-5/7 images.

Materials and Methods

Study Site

The study area (Fig. 1) encompassed four coastal provinces (from south to north: Guangxi, Guangdong, Fujian, and Zhejiang), two special administrative districts (Hong Kong and Macao), and the two islands of Hainan and Taiwan. Geographically, the study area extended from 18°12′N to 28°25′N latitude between the longitudes of 108°03′E to 122°00′E. The climate of China’s southeast coastal zones is classified as tropical or subtropical monsoon, hot and moist during summer, warm and humid in winter. Along most of China’s coast, the local dry season is between November and February. The southernmost extent of mangrove in China is in Sanya (Hainan Province), where the climate is tropical oceanic monsoonal with an annual average temperature of 23.8 °C and annual precipitation of 1254 mm. Fuding (27°20′N, 120°43′E) is the northern limit of naturally-occurring mangrove in China. The climate there is subtropical humid monsoonal with the minimum monthly mean temperature of 8.4 °C and an annual precipitation of 1660 mm. Across this large study area, tides vary in type and amplitude. Tides from the northeast of Guangdong to Zhejiang Province are a regular semi-diurnal type with ranges of generally less than 2 m. Tides in the Gulf of Tonkin are diurnal with the average tidal range of 2.24 m (Li and Lee 1997). In the most tropical areas in the islands of Hainan, Hong Kong, Macao, as well as Guangdong Province, tides are irregular and semi-diurnal (Zhang et al. 2010).

In China, the species richness is relatively high with species including true and semi-mangrove species (24 and 12, respectively). Varying by province, in Hainan, Guangxi, Guangdong, Fujian, Taiwan, Hong Kong and Macao, the total number of mangrove species are 36, 19, 20, 10, 18, 16, and 10, respectively (Wang and Wang 2007). Only one planted species occurs in Zhejiang Province (*Kandelia candel*) (Li and Lee 1997).

Since the 1980’s, many national and provincial mangrove reserves have been established. With thirty-four mangrove reserves, including seven national nature reserves (in Hainan, Guangdong, Guangxi, Fujian, and Hong Kong), five provincial nature reserves (in Hainan, Guangxi, Guangdong, and Fujian), and twenty-two local nature reserves (in Hainan, Guangdong, Fujian, Taiwan, and Zhejiang; Fig. 1). Among these nature reserves, six national reserves were listed as Wetlands of International Importance, including Dongzhaigang National Mangrove Reserve, Fujian Zhangjiangkou National Mangrove Nature Reserve, Guangxi Beilun Estuary National Nature Reserve, Mai Po Marshes & Inner Deep Bay, Shankou Mangrove Nature Reserve, and Zhanjiang Mangrove National Nature Reserve (Ramsar sites 53, 1726, 1728, 750, 1153, and 1157, respectively).

Landsat Imagery and Reference Dataset

Cloud-free Landsat-5 Thematic Mapper (TM) images were used (USGS 2010). In cases with no cloud-free image available, Landsat-7 Enhanced Thematic Mapper Plus (ETM+) images that were acquired during 2010 were used (International Scientific Data Service Platform of China 2010). Gaps between these images were filled by the local linear histogram-matching technique (Scaramuzza et al. 2004). In total, twenty-five Landsat TM and ETM+ images were obtained, most of them were acquired during local low tide conditions in the dry season (Table 1). All of these images were geo-rectified to 1: 50000 topographic maps using ground control points (GCPs). Each scene had at least 20 evenly distributed sites, which served as GCPs. With these GCPs, Landsat images were geo-rectified with root mean square errors of less than one-half pixels. Ultimately, a complete cloud-free image mosaic of the whole study area was created. Geo-rectification and mosaicking of TM/ETM+ images were completed with ENVI version 4.8 software (ITT 2010) and ArcGIS 9.3 software (ESRI 2008).

In this study, ground surveys were conducted by three teams along the southeast coasts of China from June to November 2011. Two teams completed the ground survey on foot along the coastlines of Zhejiang and Fujian and the other team drove a vehicle along the coastlines from Guangdong to Guangxi, and Hainan Island. The location of each sampling point was measured using a global positioning system (GPS), with an error less than 10 m. The observations collected in

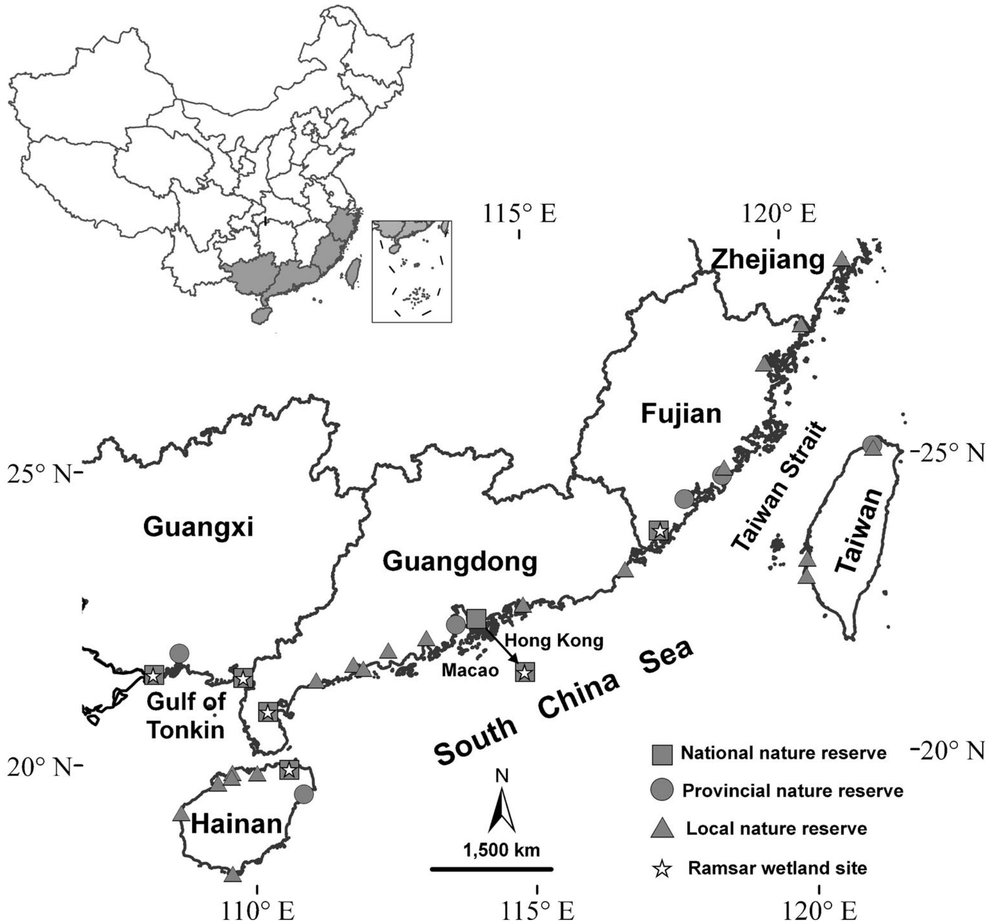

Fig. 1 Location of the study area and distribution of coastal mangrove reserves along the coasts of China

these surveys contained 457 mangrove points and 386 non-mangrove points. A vector file of ground survey points with the attributes of location (longitude and latitude), land cover types, and photos was created with ArcGIS (ESRI 2008).

Because the core area of mangroves are inaccessible and the island of Taiwan, Hong Kong, and Macao were not ground surveyed, we collected information via visual inspection from high resolution images available on the web (Google Earth v.6.0 2011), photos, literatures, and interviews with local experts. As a result, 50, 20, and 5 reference points were selected in Taiwan, Hong Kong, and Macao, respectively. Moreover, 124 additional reference points selected from mainland China were also added to the reference data collected in southeast coastal provinces of China. In total, the reference data set consisted of 592 mangrove and 460 non-mangrove points. Among these points, 120 mangrove and 108 non-mangrove points were selected as training samples for the classification. These training samples were selected on the basis of their distinct spectral characteristics, and they were all located in the core area of a certain land cover. The remaining 472 mangrove and 352 non-mangrove points were used to validate the accuracy of classification results. These validation samples were randomly distributed along the coastline of eight coastal provinces (or districts; Table 2).

Object-Oriented Classification Method

An image-analysis program (eCognition Developer 8.64; Definiens 2011), was used to perform the object-oriented classification. Segmentation is the first step of object-oriented method, which is the process of segmenting an image into groups of homogeneous pixels so that the variability within the object was minimized (Baatz and Schape 2000). Images segmentation parameters include scale, shape and compactness. The scale determines the maximum size of the created object, the shape factor balances spectral homogeneity vs. shape of objects, whereas the compactness factor balances compactness and smoothness (Myint et al. 2008; Definiens 2011). Users could apply weights from 0 to 1 for the shape and compactness factors to determine objects at a certain level of scale. Mangrove objects are irregularly shaped, so that less weight was assigned to the shape than spectral homogeneity (the shape factor was set as 0.1). The compactness parameter was set at 0.6 to give a little more weight to compactness than

Table 1 General characteristic of the Landsat images for provinces in China with coastal mangroves including the path, row and type of Landsat-5/7 images, date of acquisition and tide status (CNSS 2012)

Path	Row	Acquisition data	Landsat type	Tide status	Province
117	43	May, 2009	7	low	Taiwan
117	44	Oct, 2010	7	low	Taiwan
117	45	Oct, 2010	7	low	Taiwan
118	40	Nov, 2010	7	low	Zhejiang
118	41	Nov, 2010	7	low	Fujian, Zhejiang
118	42	Apr, 2009	5	low	Fujian
118	43	Nov, 2010	7	low	Taiwan
118	44	Nov, 2010	7	low	Taiwan
119	41	May, 2009	7	low	Fujian, Zhejiang
119	42	Jun, 2009	5	high	Fujian
119	43	Jun, 2009	7	high	Fujian
120	43	Oct, 2010	7	low	Fujian
120	44	Oct, 2009	5	high	Guangdong, Fujian
121	44	Jan, 2010	5	low	Guangdong
121	45	Jan, 2010	5	low	Hong Kong
122	44	Nov, 2009	5	high	Guangdong, Hong Kong
122	45	Nov, 2009	7	high	Guangdong, Macao
123	45	Nov, 2009	7	low	Guangdong
123	46	Jul, 2010	7	low	Guangdong, Hainan
123	47	Sep, 2009	7	low	Hainan
124	45	Nov, 2009	7	low	Guangxi, Guangdong
124	46	Nov, 2010	5	high	Guangdong, Hainan
124	47	Jan, 2008	7	low	Hainan
125	45	Nov, 2009	5	low	Guangxi
125	47	Nov, 2008	7	low	Hainan

smoothness. After a series of tests, a satisfactory match between image objects and landscape features was achieved when the scale parameter was determined to be 8.

After the objects in the images were segmented, image objects were classified into mangrove or non-mangrove classes using nearest neighbor (NN) classifiers as well as visual interpretation. (Singh 2001; Definiens 2011). Objects containing training samples (see: Landsat Imagery and Reference Dataset) were used as inputs for training the NN classifier. Subsequently, the NN classifier was operated in eCognition Developer 8.64 to form an initial classification result. To obtain the best interpretation, visual interpretation was carried out to confirm the extraction of mangroves by inspecting high-resolution images (years 2008–2011) available in Google Earth. To facilitate visual interpretation, a false color composite of TM/ETM+ Bands 5 (red), 4 (green), and 3 (blue) was generated. This band color combination that was deemed the best for detecting mangroves was dark green (Spalding et al. 2010).

The accuracy of mangroves extraction was assessed based on validation samples (Table 2). The confusion matrix was used

Table 2 Validation samples used to validate the accuracy of classification results including mangrove and non-mangrove samples, which were obtained from field survey and visual inspection from high resolution images along the coast of China

Province (district)	Mangrove samples	Non-mangrove samples
Guangdong	136	109
Guangxi	102	83
Hainan	98	64
Fujian	49	38
Zhejiang	35	42
Taiwan	38	12
Hong Kong	10	3
Macao	4	1
Total	472	352

to measure the agreement between our mapping result and ground-truthing. The confusion matrix increases the user's accuracy, producer's accuracy, overall accuracy, and Kappa coefficient. Overall accuracy expresses the overall degree of agreement in the matrix. User's accuracy represents the likelihood that a classified object matches the ground situation. Producer's accuracy shows the percentage of an object type, which was correctly classified. Kappa coefficient states how well the classification results agree with the reference data (Conchedda et al. 2008). In this study, the accuracy assessment was carried out using ArcGIS 9.3 (ESRI 2008).

Results

Status and Distribution of China's Mangroves

Based on Landsat image analysis, our classification indicated that the total area of mangrove in southeast China was about 20778 ha in 2010 (Fig. 2). The area of mangroves in Guangdong, Guangxi, Hainan, Fujian, Taiwan, Zhejiang, Hong Kong and Macao was 9289, 5813, 3576, 1023, 293, 382, 389, and 11 ha, respectively. Mangrove areas in each national reserves were estimated for Dongzhaigang National Mangrove Reserve, Fujian Zhangjiangkou National Mangrove Nature Reserve, Guangxi Beilun Estuary National Nature Reserve, Mai Po Marshes & Inner Deep Bay, Shankou Mangrove Nature Reserve, and Zhanjiang Mangrove National Nature Reserve (1592, 72, 961, 369, 184, and 5706 ha, respectively).

Accuracy Assessment

Accuracy assessment could state how well the mapping agrees with ground-truthing. The accuracy of mapping mangrove in China was good as indicated by the overall accuracy of 93 % and Kappa coefficient of 0.85 (Table 3).

Fig. 2 Distribution of mangroves along the coast of China mapped with object-oriented classification of Landsat images

Discussion

Mangrove Extent in China

Remote sensing studies to determine the distribution of vegetation types such as the mangroves on the coast of China are critical for their conservation. Previous studies have estimated the area of mangroves in China; e.g., Spalding et al. (2010) estimated that the coast of China had 20756 ha of mangrove (not including Taiwan), the SFA calculated that the area of mangroves in mainland China (not including Taiwan, Hong Kong, and Macao) was 22025 ha. The Spalding et al. (2010) estimation is very similar to ours except that they found a

Table 3 Confusion matrix, overall accuracy, producer's accuracy, user's accuracy and Kappa coefficient for the classification of Landsat TM/ETM+ images based on field survey of mangroves on the coasts of China

Type	Classification			
	Mangrove	Non-mangrove	Total	Producer's accuracy
Mangrove	426	46	472	90 %
Non-mangrove	15	337	352	96 %
Total	441	383	824	
User's accuracy	97 %	88 %		

Table 4 Comparison of mangrove areas (ha) along the coast of China as estimated by our study based on the object-oriented classification of Landsat TM/ETM+ images and that of the State Forestry Administration (SFA; Chen et al. 2009) by province ("no estimate" indicates that no value was estimated)

Province	Area (ha)	
	This study	SFA
Guangdong	9,289	9,084
Guangxi	5,813	8,375
Hainan	3,576	3,930
Fujian	1,023	615
Zhejiang	293	21
Taiwan	382	no estimate
Hong Kong	389	no estimate
Macao	11	no estimate
Total	20,778	22,025

larger area of mangrove in Beihai and smaller area in Zhanjiang than we did. However, our estimate may be more accurate than Spalding et al. (2010), because we used the Landsat TM/ETM+ images obtained during 2009 to 2010, while Spalding et al. (2010) used data which collected earlier between 1999 and 2003. The areal extent of mangrove calculated in this study is approximately 9.1 % smaller than the SFA's assessment. The differences are quite different at provincial level (Table 4). Compared to SFA's result, our estimate of the mangrove area in Guangxi, Hainan, Guangdong, Fujian and Zhejiang is 30.6 % and 9.0 % lower, 2.3 %, 66.4 %, and 1300 % higher than the SFA's value, respectively. Our estimate may also be more accurate than SFA's, because SFA's mapping work was done in 2001 which is nearly ten years earlier than ours.

Mangrove Losses in China and Elsewhere

When compared with other countries worldwide, the loss of mangroves in China may be less. In China, the mangrove area was reported to be 42000 ha in 1950s (Zhang and Sui 2001). By contrast, the present study indicates a mangroves area of 20778 ha in 2010, representing an area decrease of nearly 48 % of the pristine mangroves in 50 years. At the same time, in other developing countries the losses were much higher. For instance, in the Philippines, about 73 % of mangroves were lost during last century (Brown and Fischer 1920; Primavera 2000), and Vietnam, about 62 % of the mangroves were lost (Valiela et al. 2001).

Nevertheless, the losses of mangrove in China have been extensive, largely due to development for agriculture (Chen et al. 2009). Agricultural development of mangrove swamp for rice paddy fields has been a serious threat to mangroves of China, especially in the 1960s and 1970s as China experienced a rapid growth in its population. For example, 4667 ha (47 %) of mangroves were embanked in Hainan Province (Chen et al. 1991) during this period. In Guangxi Province, there were 10000 ha of mangroves in the 1950s, but only 4667 ha remained in the early 1980s (Zhang and Sui 2001).

The agricultural developments of mangrove swamps are also primary drivers for the loss of mangroves in other countries. Globally, the conversion of mangroves into shrimp/fish ponds is the major factor contributing to loss of mangroves (Primavera 2005), representing more than 50 % of global mangrove losses (Walters et al. 2008). Specifically, in some regions of Indonesia, the conversion of mangroves for aquaculture caused the loss of 50 % to 80 % of the total mangroves (Wolanski et al. 2000). In China, during the 1980s and 1990s large amounts of mangrove forest were logged for shrimp/fish ponds, e.g., 98 % (7768 ha) of mangrove forests were removed for aquaculture in Guangdong Province (He et al. 2006). Additionally, logging mangroves for the purpose of urban and tourism infrastructures, agriculture, and aquaculture are primarily responsible for the loss of mangroves in the United States of America, the Caribbean countries, Mexico and many other countries (FAO 2007).

Conclusions

An object-oriented classification of Landsat images was used to map the mangroves in China at the national level using Landsat-5/7 imagery. The mapping result shows that China's mangrove area was 20778 ha in 2010. The map of China's mangrove demonstrated had a high accuracy (overall accuracy was 92.6 % and Kappa coefficient was 0.85). The mangrove status and distribution serves as a foundation for conservation and management of China's mangroves.

Acknowledgments This study was supported by the National Basic Research Program of China (No. 2013CB430401, No. 2012CB956103), the CAS/SAFEA International Partnership Program for Creative Research Teams, the professor fund for NEIGAE, CAS (Y2H1071001) and the Key Deployment Project of Chinese Academy of Sciences (NO. KZZD-EW-08-02). We thank the editor and three anonymous reviewers for their help in improving the manuscript.

References

Alongi M (2002) Present state and future of the world's mangrove forests. Environmental Conservation 29:331–349

Baatz M, Schape A (2000) Multiresolution segmentation: an optimization approach for high quality multi-scale image segmentation. In: Strbl J, Blaschke T (eds) Angewandte geographische informationsverarbeitung. Wichmann, Heidelberg, pp 12–23

Bahuguna A, Nayak S, Roy D (2008) Impact of the tsunami and earthquake of 26th December 2004 on the vital coastal ecosystems of the Andaman and Nicobar Islands assessed using RESOURCESAT AWiFS data. International Journal of Applied Earth Observation and Geoinformation 10:229–237

Blasco F, Aiapuru M, Gers C (2001) Depletion of the mangroves of continental Asia. Wetlands Ecology and Management 9:245–256

Brown WH, Fischer AF (1920) Philippine mangrove swamps. In: Brown WH (ed) Minor products of Philippine forests I, Bureau of Forestry Bull. No. 22. Bureau of Printing, Manila, pp 9–125

Chen GZ, Li MS, Lan CY, Tam FY (1991) Conservation and utilization of mangrove ecosystems. Ecological Science 1:116–119

Chen L, Wang W, Zhang Y, Lin G (2009) Recent progresses in mangrove conservation, restoration and research in China. Journal of Plant Ecology 2:45–54

CNSS (2012) Available at: http://app.cnss.com.cn/tide_search.php

Conchedda G, Durieux L, Mayaux P (2008) An object-based method for mapping and change analysis in mangrove ecosystems. ISPRS Journal of Photogrammetry and Remote Sensing 63:578–589

Definiens AG (2011) Definiens Professional 8.6 User Guide. Definiens AG, Munchen, Germany

ESRI (2008) ArcGIS 9.3. Environmental Systems Research Institute (ESRI), Redlands, California, USA

FAO (2007) The World's mangroves 1980–2005: a thematic study in the framework of the global forest resources assessment 2005. Rome, Italy

Filho PWMS, Martins ESF, Costa FR (2006) Using mangroves as a geological indicator of coastal changes in the Bragança macrotidal

flat, Brazilian Amazon: a remote sensing data approach. Ocean & Coastal Management 49:462–475
Gao J (1999) A comparative study on spatial and spectral resolutions of satellite data in mapping mangrove forests. International Journal of Remote Sensing 20:2823–2833
Giri C, Zhu Z, Tieszen LL, Singh A, Gillette S, Kelmelis JA (2008) Mangrove forest distributions and dynamics(1975–2005)of the tsunami-affected region of Asia. Journal of Biogeography 35:519–528
Giri C, Ochieng E, Tieszen L, Singh A, Loveland T, Masek J, Duke N (2011) Status and distribution of mangrove forests of the world using earth observation satellite data. Global Ecology and Biogeography 20:154–159
Google Earth v.6.0 (2011) Available at: http://earth.google.com
Green EP, Clark CD, Mumby PJ, Edwards AJ, Ellis AC (1998) Remote sensing techniques for mangrove mapping. International Journal of Remote Sensing 19:935–956
He KJ, Lin SM, Lin ZD (2006) Mangrove resource and Iits dtrategy of conservation and management in Guangdong Province. Science and Technology of Guangdong Forestry 22(2):89–93
Heumana BW (2011) Satellite remote sensing of mangrove forests: Recent advances and future opportunities. Progress in Physical Geography 35:87–108
International Scientific Data Service Platform of China (2010) Available at: http://datamirror.csdb.cn/
ITT (2010) ENVI User's Guide: Version 4.8. Boulder, CO
Li M, Lee S (1997) Mangroves of China: a brief review. Forest Ecology and Management 96:241–259
Long JB, Giri C (2011) Mapping the Philippines' mangrove forests using landsat imagery. Sensors 11:2972–2981
Myint SW, Giri CP, Wang L, Zhu Z, Gillette SC (2008) Identifying mangrove species and their surrounding land use and land cover classes using an object-oriented approach with a lacunarity spatial measure. Giscience & Remote Sensing 45:188–208
Primavera JH (2000) Development and conservation of Philippine mangroves: institutional issues. Ecological Economics 35:91–106
Primavera JH (2005) Mangroves, fishponds, and the quest for sustainability. Science 310:57–59
Scaramuzza P, Micijevic E, Chander G (2004) SLC gap-filled products: Phase one methodology. Available via DIALOG. http://landsat.usgs.gov/data_products/slc_off_data_products/documents/SLC_Gap_Fill_Methodology.pdf
Seto KC, Fragkias M (2007) Mangrove conversion and aquaculture development in Vietnam: A remote sensing-based approach for evaluating the ramsar convention on wetlands. Global Environmental Change 17:486–500
Singh S (2001) Nearest-neighbor classifiers in natural scene analysis. Pattern Recognition 34:1601–1612
Spalding M, Blasco F, Field C (1997) World mangrove atlas. Samara Publishing Co, Okinawa
Spalding M, Kainuma M, Collins L (2010) World atlas of mangroves. Earthscan, London
Tam NY, Wong YS, Lu CY, Berry R (1997) Mapping and characterization of mangrove plant communities in Hong Kong. Hydrobiologia 352:25–37
USGS (2010) http://glovis.usgs.gov/
Valiela I, Bowen JL, York JK (2001) Mangrove forests: one of the world's threatened major tropical environments. BioScience 51(10):807–815
Walters BB, Rönnbäck P, Kovacs JM, Crona B, Hussain SA, Badola R, Primavera JH, Barbierf E, Dahdouh-Guebas F (2008) Ethnobiology, socio-economics and management of mangrove forests: a review. Aquatic Botany 89:220–236
Wang WQ, Wang M (2007) The mangroves of China. Science Press, Beijing (in Chinese)
Wang L, Sousa WP, Gong P (2004) Integration of object-based and pixel-based classification for mangrove mapping with IKONOS imagery. International Journal of Remote Sensing 24:5655–5668
Wolanski E, Spagnol S, Thomas S et al (2000) Modelling and visualizing the fate of shrimp pond effluent in a mangrove-fringed tidal creek. Estuarine, Coastal and Shelf Science 50:85–97
Zhang Q, Sui S (2001) The mangrove wetland resources and their conservation in China. Journal of Natural Resources 16:28–36
Zhang B, Chen S, Gu G (2010) Tidal types and characteristics of the harbors along the Guangxi coast. Journal of Marine Sciences 28(3):9–16