

# Coastal Wetlands of China: Changes from the 1970s to 2007 Based on a New Wetland Classification System

Ping Zuo · Yun Li · Chang-An Liu · Shu-He Zhao · Dao-Ming Guan

Received: 12 January 2012 / Revised: 30 October 2012 / Accepted: 5 November 2012 / Published online: 28 November 2012  
© Coastal and Estuarine Research Federation 2012

**Abstract** A new classification of coastal wetlands along the coast of China has been generated that is compatible with the Ramsar Convention of 1971. The coastal wetlands have been divided into two broad categories with overall nine subcategories. On this basis, a series of coastal wetland maps, together covering the coast of mainland China, have been produced based on topographic maps acquired in the 1970s and satellite images acquired in 2007. These documents substantial wetland losses over this period. In the 1970s, the total coastal wetland area in China was  $5.76 \times 10^4 \text{ km}^2$ , whereas in 2007, it was  $5.36 \times 10^4 \text{ km}^2$ , indicating a loss of 7 %. Over this approximately 40-year period, the area of natural coastal wetlands decreased from  $5.74 \times 10^4$  to  $5.09 \times 10^4 \text{ km}^2$ , while that of artificial coastal wetlands increased from 240 to 2,740  $\text{km}^2$ . Due to shoreline and sea-level changes, newly formed coastal wetlands amounted to 2,460  $\text{km}^2$ , while coastal wetland loss amounted to 6,310  $\text{km}^2$  in the period from the 1970s to 2007. When excluding shallow coastal waters (depths between 0 and –5 m), nearly 16 % of Chinese coastal wetlands have been lost between the 1970s and 2007.

**Keywords** Coastal wetland classification · Coastal wetland mapping · Chinese coastal wetlands

## Introduction

The term “wetlands” refers to areas covered by natural or artificial, permanent or temporal, still water or running water, freshwater, saltwater marshlands, peatlands, and water bodies <6 m in depth, including seawater bodies below low tide (Ramsar Convention 1971). To date, the Ramsar sites’ database is being built focusing on mapping the distribution of Ramsar sites across global eco-regions and identifying various wetland types and regions by the application of remote sensing and geographic information system (Lehner and Döll 2004; Lowry 2006; Davidson and Finlayson 2007; Rebelo et al. 2009). At the same time, advancements in Earth Observation coupled with ground analyses have provided opportunities for identifying, describing, and mapping the distribution of wetlands at a range of scales from local to global level (Sahagian and Melack 1996; Darras et al. 1999; Lehner and Döll 2004; Fernandez-Prieto et al. 2006; Rebelo et al. 2009). However, as a consequence, there are some major gaps in wetland inventory and inconsistencies in methods (e.g., wetlands identification and wetlands classification) to assess the extent and condition of wetlands, the estimation rate of wetland loss, and degradation globally are incomplete or based on unsubstantiated assertions (Finlayson et al. 2005).

In the past, no wetland map existed for China that was based on a consistent mapping standard (Gong et al. 2010). Before 2010, the total area of Chinese wetlands basically depended on local administrative reports. In the meantime, Niu et al. (2009) and Gong et al. (2010) have produced first Chinese wetland maps based on satellite images acquired between 1990 and 2000, which is an important step to be involved in the global wetland database. They broadly classified China’s wetlands into inland, coastal, and artificial wetlands, subdividing these into altogether 15 subcategories. Although a step in the right direction, this classification is not accurately with the coastal wetlands classification of the

---

P. Zuo  
Key Laboratory for Coast and Island Development,  
Nanjing University, Nanjing 210093, China

P. Zuo (✉) · Y. Li · S.-H. Zhao  
School of Geographic and Oceanographic Sciences,  
Nanjing University, Nanjing 210093, China  
e-mail: zuoping@nju.edu.cn

C.-A. Liu · D.-M. Guan  
National Marine Environmental Monitoring Center,  
State Oceanic Administration, Dalian 116023, China

international Ramsar Convention of 1971. In addition, there has been no detailed documentation of the rapid change in coastal wetland area that has taken place over the past 40 years due to intensification of human activities.

In view of this situation, the purpose of this paper is twofold: (a) to present a new coastal wetland classification for China that is consistent with the international Ramsar wetland classification system ([http://www.ramsar.org/ris/key\\_ris\\_e.htm#type](http://www.ramsar.org/ris/key_ris_e.htm#type)), the primary consideration being to make it both consistent with topographic maps and satellite images, and adaptable to the use of remote sensing data; (b) to document the rapid changes that have taken place between the 1970s and 2007 by applying the new classification system and using topographic maps published in the 1970s and satellite images acquired in 2007. Given the extent of wetland degradation globally, largely due to agricultural and industrial activities, specific attention on the China's coastal wetlands change is directed towards the usefulness of Earth Observation in providing information that can be used to more effectively manage wetlands.

## Study Area

The study area covers the entire mainland coast and Hainan Island, including the provincial districts of Liaoning, Hebei, Tianjin, Shandong, Jiangsu, Shanghai, Zhejiang, Fujian, Guangdong, Guangxi, and Hainan Province. Based on accessible data, the coastal wetland area of the 1970s is defined as the region between the mean high-water line and the  $-5$  m bathymetric contour line in the 1970s. The study area of 2007 refers to the region between the modern mean high-water line, which was provided by the No. 908 project of the State Oceanic Administration (SOA), and the  $-5$  m submarine contour line in the 1970s. The area that used to be wetland in 1970s but was transferred to other land uses in 2007 was defined as “newly decreased” area. In turn, the area that did not belong to the coastal wetlands in 1970s but was changed into coastal wetland in 2007 was defined as “newly formed” coastal wetland (Fig. 1).

## Materials and Methods

### On-Site Investigations

On-site investigations were carried out from October 1 to 30, 2006 using a hand-held Geographic Positioning System (GPS) in a vehicle traveling from Liaoning Province to Guangxi Province. The positional information obtained for wetland classification and distribution in the ten coastal provinces of China was of great help to the visual interpretation of satellite images. Various wetland identifications,

sampling, and interviews with local stakeholders, focusing on the pros and cons of wetland usage, were also conducted during the on-site survey.

### Data Collection

Eleven Landsat Thematic Mapper images (Landsat TM) and 46 China Brazil Earth Resources Satellite images (CBERS-1) were geometrically corrected using a series of topographic maps published by the Surveying and Mapping Bureau of the PLA General Staff Headquarters at scales of 1:100,000 (743 maps) and 1:50,000 (453 maps), which include the whole coast of China. The corrected satellite images provided the fundamental data for wetland identification, classification, and verification, with on-site GPS positioning information as complementary data. All satellite images were chosen to match the growing season from May to October in 2007, which represents the best available data for the purpose of this study. In addition, some images of 2006 and 2005 were chosen to substitute some hazy images of 2007. The modern mean high-water line was acquired from the latest data provided by the No. 908 project of SOA.

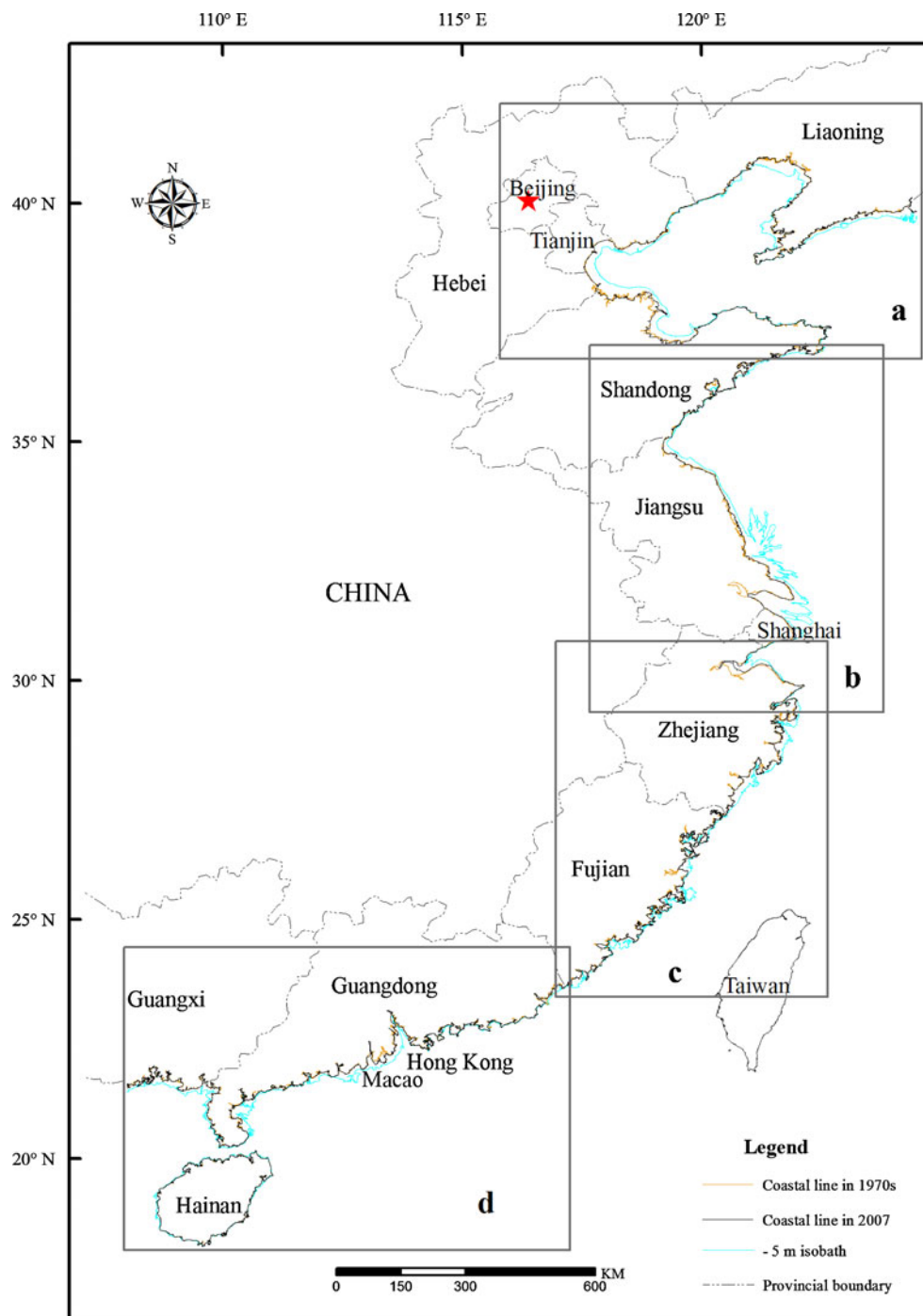
### Data Processing

Topographic maps were scanned at a resolution of 300 dpi. Subsequently, 20 control points were chosen for geometrical correction with an error of  $<0.1$  m. Satellite images were corrected using primary corrected topographic maps and on-site positioning as reference. Quadratic polynomials were applied to correction equations according to the distribution of the 20 control points on every image. All images were then resampled at a resolution of  $30\text{ m} \times 30\text{ m}$  with a root mean square error of  $<1$  pixel. In the flow chart of Fig. 2, the general data processing procedure applied to all images is illustrated.

Because the landscape patterns of China's coastal wetlands are very complicated, it is difficult to apply a standard computer-assisted image classification algorithm to classify them. Instead, manual interpretation was used to ensure mapping accuracy. In order to ensure geometric accuracy in careen-based wetland delineation, careen scales of 1:30,000 to 1:40,000 were used. In situ verification was carried out in the coastal marshes of Jiangsu Province, achieving a 95 % accuracy. ERDAS Imagine 9.1 and ArcGIS 9.0 software were used for all data processing in the study.

Shallow coastal waters were excluded, as it was impossible to determine the water depth from remote sensing data. However, as the submarine contour lines of the  $-2$ ,  $-5$ , and  $-10$  m isobaths are readily available from topographic maps, shallow marine waters were defined as being  $<5$  m of water depth, rather than using the depth of 6 m recommended by Ramsar (1971). Small islands located beyond the  $-5$  m isobath were excluded from the mapping.

**Fig. 1** The coastline of China showing the four geographic subdivisions in which wetland changes between the 1970s and 2007 have been documented



## Results

### A New Classification of Chinese Coastal Wetlands, Which is Compatible with the Ramsar Convention of 1971

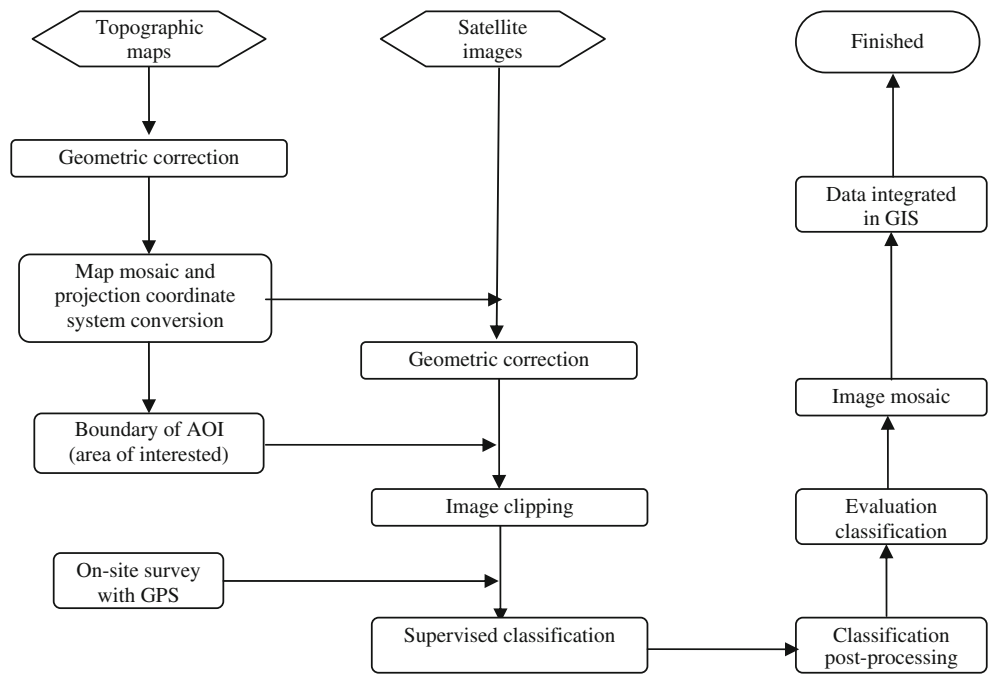
In the present paper, the wetland classification for China initially proposed by Gong et al. (2010) has been simplified to encompass natural coastal wetlands and artificial coastal wetlands, with altogether nine subcategories (Table 1). This

makes it consistent with the international Ramsar wetland definition and classification of 1971.

### Coastal Wetlands Changes in China from the 1970s to 2007

As shown in Table 2, the area of China's coastal wetlands in the 1970s was  $5.76 \times 10^4 \text{ km}^2$ . Of this, the area of natural coastal wetlands was  $5.74 \times 10^4 \text{ km}^2$ , making almost 100 % of the total area. By comparison, the area of artificial coastal

**Fig. 2** Flow chart illustrating the data processing procedure for this study



wetlands was 240 km<sup>2</sup>, occupying 0.41 % of the total area. Of the natural coastal wetlands, the area contributed by shallow marine waters was 3.23×10<sup>4</sup>km<sup>2</sup>, accounting for 56 % of the natural coastal wetlands. The total area of tidal zone/beaches, coastal marsh/swamps, estuarine waters, and estuarine deltas made up 44 % of the natural coastal wetlands. The area of tidal zones/beaches was 10,400 km<sup>2</sup>; the area of coastal marsh/swamps was 190 km<sup>2</sup>; the total area of estuarine waters; and estuarine deltas were 14,500 km<sup>2</sup>.

Also shown in Table 2 is the total area of China’s coastal wetlands in 2007, which amounted to 5.36×10<sup>4</sup>km<sup>2</sup>. Of this, the area of natural coastal wetlands was 5.09×10<sup>4</sup>

km<sup>2</sup>, making up 95 % of the total area. By contrast, the area of artificial coastal wetlands was 2,740 km<sup>2</sup>, occupying about 5 % of the total area. Of the natural coastal wetlands, the area of shallow marine waters was 3.39×10<sup>4</sup>km<sup>2</sup>, making up 67 % of the natural coastal wetlands. The total area of tidal zones/beaches, coastal marsh/swamps, estuarine waters, and estuarine deltas accounted for 33 % of the natural coastal wetlands. The area of tidal zones/beaches was 4,640 km<sup>2</sup>; the area of coastal marsh/swamps was 440 km<sup>2</sup>; and the total area of estuarine waters and estuarine deltas was 12,000 km<sup>2</sup>. Between 1975 and 2007, 160 km<sup>2</sup> of coastal wetlands have been converted into industrial or residential usage.

**Table 1** The new Ramsar-compatible coastal wetland classification system of China, which is suitable for both topographic map identification and satellite image application

| Class and code              | Subtype and code                 | Description  |
|-----------------------------|----------------------------------|--|
| Natural coastal wetlands    | 1 Shallow marine waters          | Perennial flooding, water depth <5 m   |
|                             | 2 Tidal zones/beaches            | Marine beach areas with less than 30 % vegetation cover, including subtidal marine beds, rocky marine shores, sand, shingle or pebble shores, intertidal mud, sand or salt flats |
|                             | 3 Coastal marshes./swamps        | Vegetation cover exceeding 30 %, including mangroves, giant reeds, salt marshes, meadows, swamps   |
|                             | 4 Estuarine waters               | From upstream tidal limit to freshwater fronts in coastal waters or permanent estuarine waters, with water depths of <5 m  |
|                             | 5 Estuarine deltas/sandy islands | Estuarine delta systems, sandy beaches and islands (including ?under water), vegetation cover <30 %  |
| Artificial coastal wetlands | 1 Reservoirs                     | Artificial wetlands for water storage and hydropower generation  |
|                             | 2 Aquacultural ponds             | Artificial wetlands for fish/shrimp/crab farming   |
|                             | 3 Rice pads                      | Rice fields or water-covered crop fields   |
|                             | 4 Salt pads                      | Artificial wetlands for salt production  |

**Table 2** Area changes of coastal wetlands in China between the 1970s and 2007 (areas in km<sup>2</sup>)

| Class                            | Subtype                         | Coastal wetlands in 1970s | Coastal wetlands in 2007 | Newly decreased coastal wetlands | Newly formed coastal wetlands | Amount of change | Percent change |
|----------------------------------|---------------------------------|---------------------------|--------------------------|----------------------------------|-------------------------------|------------------|----------------|
| Natural coastal wetlands         | Shallow marine waters           | 32,300                    | 33,900                   | 1,880                            | 1,990                         | 1,600            | 5 %            |
|                                  | Tidal zones/Beach               | 10,400                    | 4,640                    | 2,210                            | 10                            | -5,760           | -55 %          |
|                                  | Coastal marshes/ Swamps         | 190                       | 440                      | 40                               | 0                             | 250              | 132 %          |
|                                  | Estuarine waters                | 10,900                    | 9,500                    | 1,350                            | 450                           | -1,400           | -13 %          |
|                                  | Estuarine deltas /Sandy islands | 3,600                     | 2,460                    | 780                              | 10                            | -1,140           | -32 %          |
|                                  | Total                           | 57,400                    | 50,900                   | 6,260                            | 2,460                         | -6,500           | -11 %          |
| Artificial coastal wetlands      | Reservoirs                      | 0                         | 160                      | 0                                | 0                             | 160              |                |
|                                  | Aquacultural ponds              | 110                       | 1,370                    | 20                               | 0                             | 1,260            | 1150 %         |
|                                  | Rice pad                        | 40                        | 370                      | 20                               | 0                             | 330              | 830 %          |
|                                  | Salt pad                        | 90                        | 840                      | 10                               | 0                             | 750              | 830 %          |
|                                  | Total                           | 240                       | 2,740                    | 50                               | 0                             | 2,500            | 1040 %         |
| Industrial/residential land uses |                                 | 0                         | 160                      | 0                                | 0                             | 160              |                |
| Total coastal wetlands           |                                 | 57,600                    | 53,600                   | 6,310                            | 2,460                         | -4,000           | -7 %           |

A detailed geographic comparison of the situation in the 1970s and that of 2007 is illustrated in Figs. 3, 4, 5, and 6. As outlined earlier, these maps were uniformly generated on the basis of topographic charts and satellite images using the new Ramsar-compatible wetland classification.

During the approximately 40-year period between the 1970s and 2007, the coastal wetlands decreased overall by 6,310 km<sup>2</sup>, with natural coastal wetland loss accounting for 6,260 km<sup>2</sup> and artificial coastal wetland loss 50 km<sup>2</sup>. Over the same period, newly formed coastal wetlands amounted to about 2,460 km<sup>2</sup>, which belongs to the natural coastal wetland. Changing coastal conditions contributed substantially to both loss in coastal wetlands and new formation of coastal wetlands, especially shoreline shifts caused by natural coastal dynamics or intensified human activities.

The overall loss of natural coastal wetlands was 6,500 km<sup>2</sup>, while the gain of artificial coastal wetlands was 2,460 km<sup>2</sup> between the 1970s and 2007. The area loss of tidal zones/beaches was 5,760 km<sup>2</sup>, a reduction by 55 % in comparison with 1970s, and accounting for the largest wetland loss in comparison with any other wetland type over this period. The shallow marine water area increased by 5 %, estuarine waters increased by 13 %, estuarine deltas reduced by 32 %, and coastal marsh/swamp increased by 133 % between 1970s and 2007. By contrast, the area of artificial coastal wetlands increased by 1,260 km<sup>2</sup> in aquaculture ponds, 330 km<sup>2</sup> in rice pads, 750 km<sup>2</sup> in salt pads, with a gain of 1,700 %, 875 %, and 725 %, respectively, in comparison with that in the 1970s.

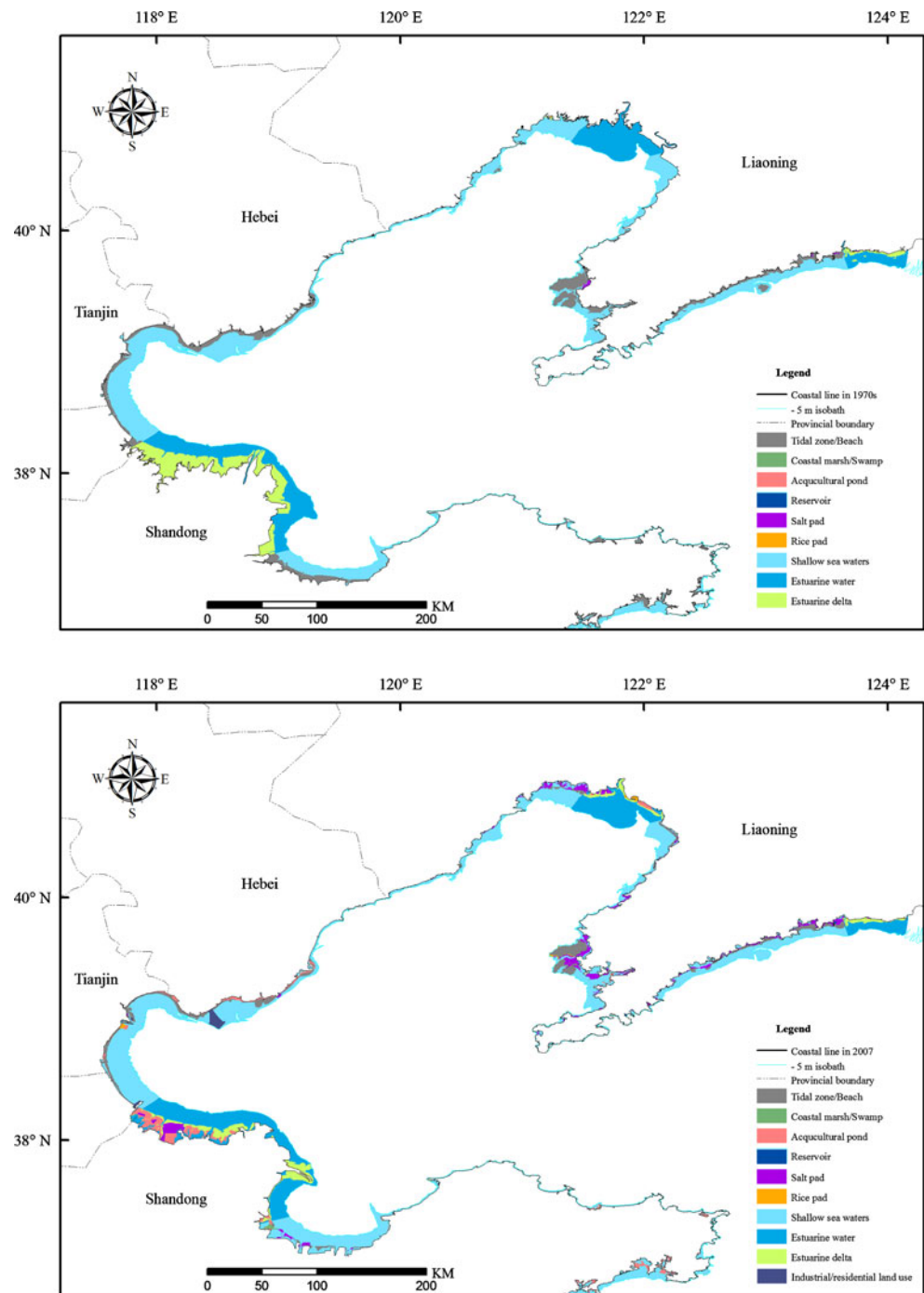
The total area of China's coastal wetlands thus decreased from 57,600 km<sup>2</sup> in 1975 to 53,600 km<sup>2</sup> in 2007, with a loss of 4,000 km<sup>2</sup> or 7 %. This amounts to a loss of 16 % if the area of shallow marine waters is excluded.

#### Systematic Error Analysis Related to Wetland Changes

Systematic errors are caused by paper deformation, scanning deformation, and uncertainty of the true value relative to the observed value in the registration and digitizing of topographic maps. The latter were mostly generated by ground mapping, which was handicapped by historical technical limitations. For example, the area of the tidal zone/beach could not be mapped as accurately as desired because in many places it was inaccessible to human entry. However, it is the only data source available for an assessment of China's coastal wetland changes during the past 40 years.

Systematic errors are also caused by satellite image co-ordination within single pixels. Interpretation errors arise from uncertainties in the satellite images, which is the basic information for wetland-type classification. For example, a vegetation cover of 30 % is the defined boundary value for differentiating between the tidal zone/beach and coastal marsh/swamp categories. This boundary, however, was difficult to determine during image interpretation. It is also difficult to distinguish the edges of freshwater and shallow estuarine waters. These vary with the tide level, whereas an image only catches a snapshot of the scenario. In the present study, the boundary was estimated by visual interpretation, and caution is therefore advisable because misinterpretation of these subtypes could be high. Moreover, the wetland

**Fig. 3** Comparison of wetlands in the 1970s and 2007 in subsection a

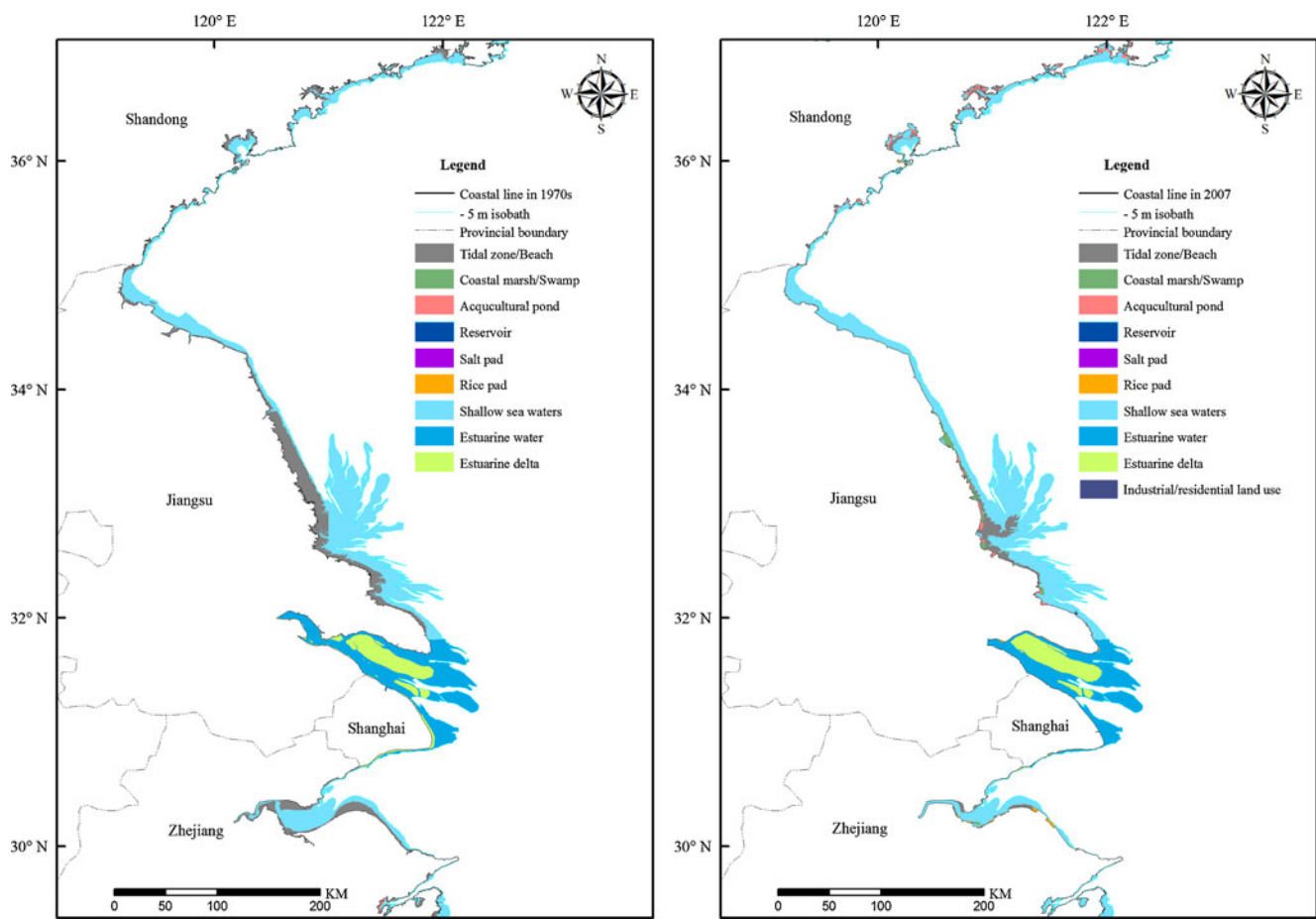


region between the tidal zone in estuarine waters and estuarine delta was very difficult to classify.

Besides the abovementioned systematic errors, also errors caused by uncertainties in the definition of coastal wetland subtypes should be taken into account. Artificial wetlands contain less uncertainty in general. Consistency of subcategories of coastal wetlands was taken into account between topographic maps and satellite images. For example, the Ramsar definition of shallow marine water was modified to the area <5 m water depth below low tide, this

criterion being used as boundary value in both the 1970s and 2007 evaluation. In this way, the historical data was used to remedy the limitation of remote sensing mapping in identifying the seaward boundary of shallow marine water.

The mapping study presented here has, for the first time, provided basic information on distribution and area statistics of mainland coastal wetlands in China. The availability of higher-resolution satellite images, additional field surveys, as well as field validations would obviously contribute to greater accuracy of data interpretation in the future. In



**Fig. 4** Comparison of wetlands in the 1970s and 2007 in subsection b

addition, trans-discipline studies should be carried out focusing on coastal wetland ecosystem service evaluation, sea-level changes, biomass estimation of coastal marshes, and carbon fluxes in the coastal zone in annual wetland monitoring programs based on the new coastal wetland mapping system.

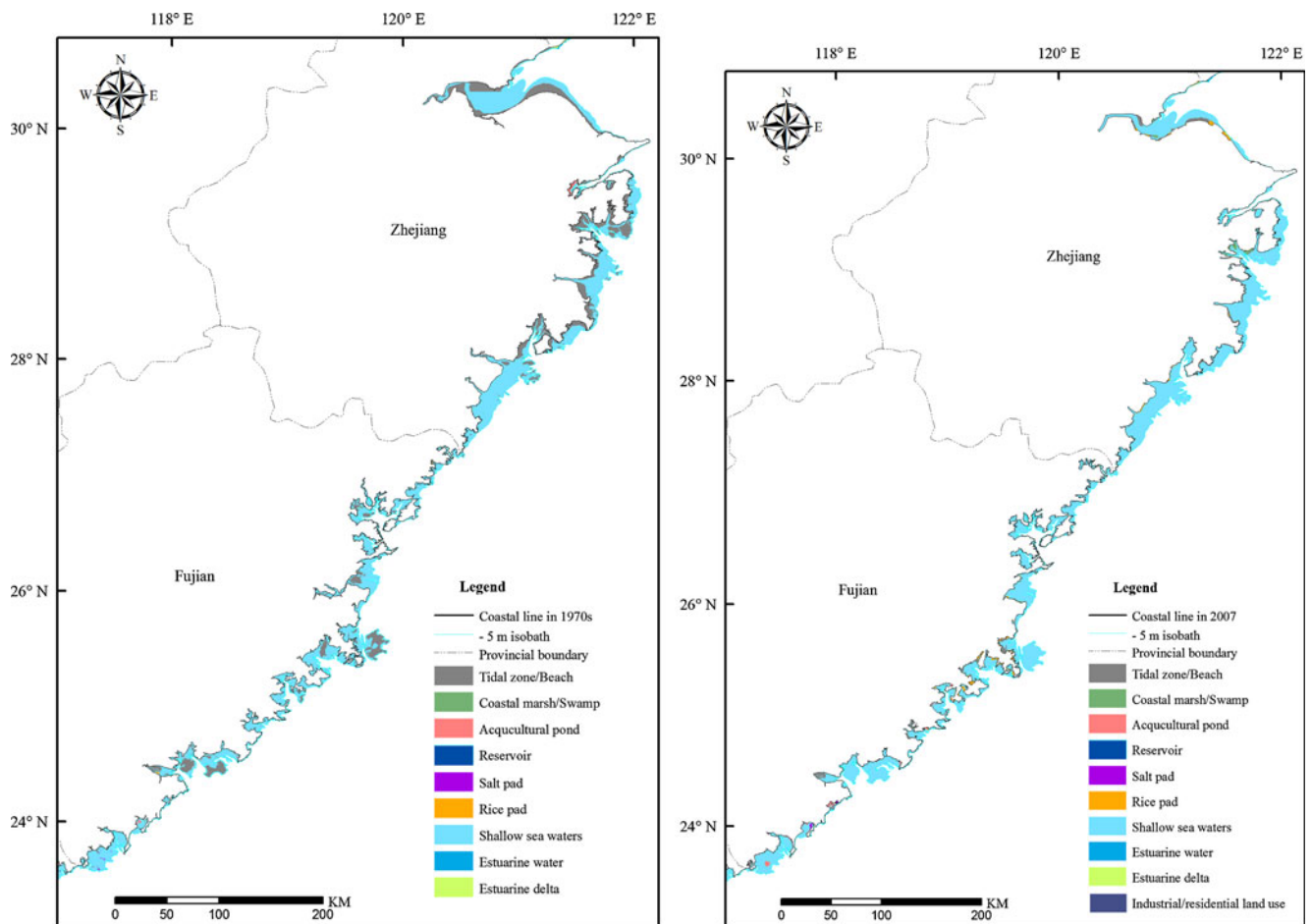
## Discussion

### Feasibility Analysis of the Comparability of Topographic Maps and TM Images

Topographic maps used the Beijing Geodetic Coordinate System 1954 with 3° Gauss–Kruger CM 102E projection (Transverse Mercator). Those maps at scale of 1:10,000 published in late 1960s and early 1970s belong to the only original maps till today covering the whole country area, which were drawn from both aerial mapping and ground surveying data simultaneously by expert surveying and mapping groups. Those maps at scales of 1:50,000 and 1:100,000 used in this paper were reduced gradually based on those original maps at the scale of 1:10,000. Satellite

images used in this paper were corrected using both primary corrected topographic maps and on-site positioning as reference. Satellite images, especially TM data, can be used to facilitate the mapping of topographic maps at the scale of 1:100,000, which basically belonging to the same scale. Gong et al. (2009) discussed the scales and the best spatial resolution in mapping topographic maps based on satellite data, implying that TM data was comparable with and could be used to update topographic maps at the scale of 1:100,000 if without aerial photographs of higher resolution.

The basic method used for classification of different types of natural coastal wetlands in this paper was expert visual interpretation, or supervised classification, supplemented by topographic maps recognition. There was detailed information of different types of coastal wetlands in topographic maps with clear boundary, which helped greatly in interpretation and recognition of different coastal wetlands types in satellite data. Figure 7 compares different legends illustrated in topographic maps and satellite images, which was easy to interpret different types of coastal wetlands in the same area by expert visual interpretation.



**Fig. 5** Comparison of wetlands in the 1970s and 2007 in subsection c

### Historical Data of the Area of China's Coastal Wetlands

Uncertainties caused by registration errors and interpretation errors cannot be ignored in the process of mapping China's coastal wetlands in such a large region. The degree of uncertainty is described by the variability of observations around the true value when the true value is unknown (Gong et al. 2010). The error is the difference between observation and the true value (Gong et al. 1995). If the true value is unknown or uncertain, then a comparison of the results of this study with different data sources would provide proof for data accuracy because this was the first consistent mapping of China's coastal wetlands using satellite images.

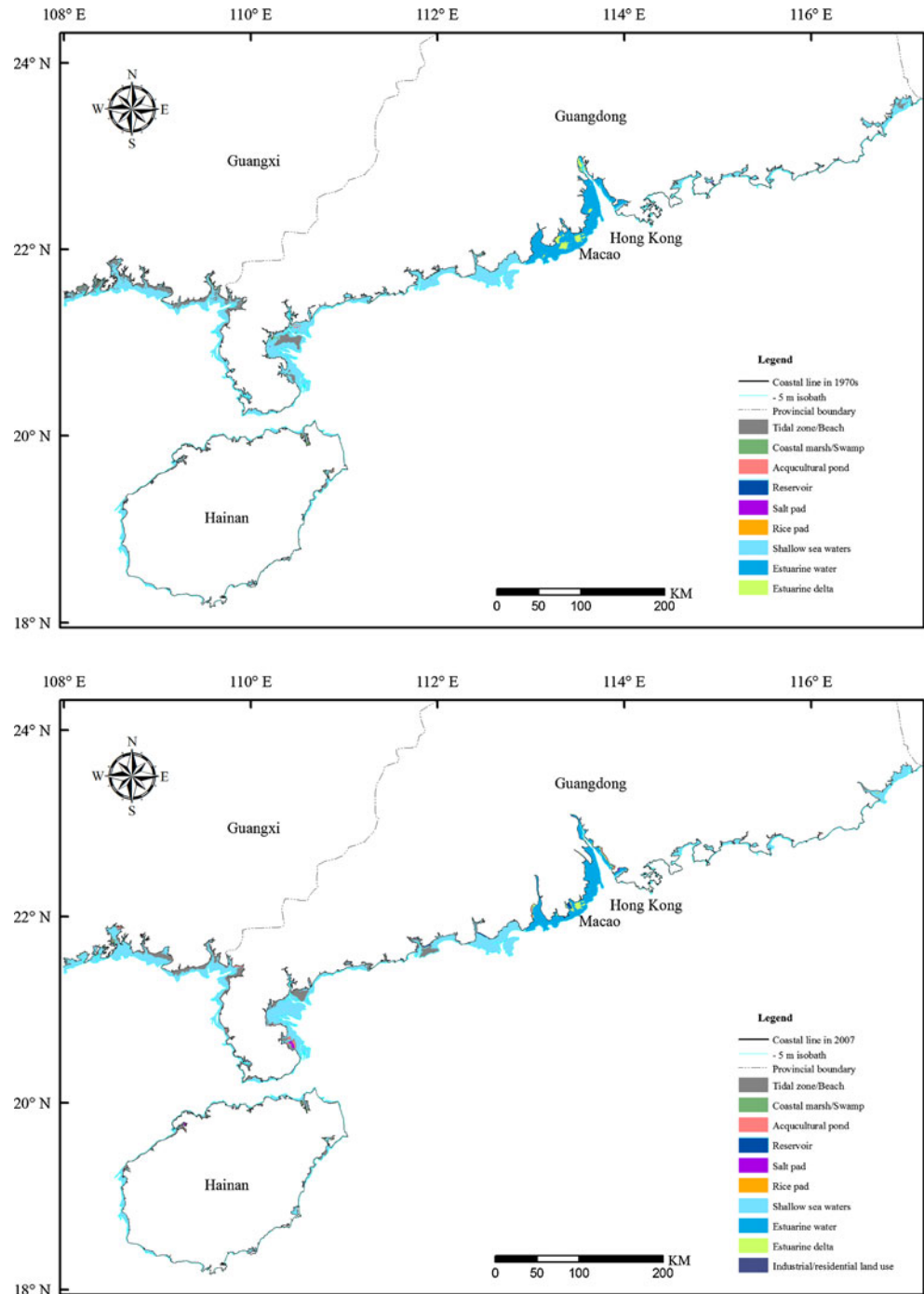
There are seven data sources that provide area statistics relating to China's coastal wetlands (Table 3). The State Forestry Administration of China reported  $5.94 \times 10^4 \text{ km}^2$ , which is the largest area reported of all sources (Lei and Zhang 2005). The "China National Wetlands Conservation Action Plan" lists an area of  $4.87 \times 10^4 \text{ km}^2$ , of which  $2.17 \times 10^4 \text{ km}^2$  are contributed by the tidal zone and  $2.7 \times 10^4 \text{ km}^2$  by shallow marine waters, respectively (State Forestry Administration 2000). Neither of these studies revealed the

data procedure for the area statistics. China's coastal zone survey, which was issued in 1980–1985, lists an area of  $2.35 \times 10^4 \text{ km}^2$  for tidal zones/beaches (Yang et al. 1997). A remote sensing survey on land use in China determined an area of  $6,400 \text{ km}^2$  for tidal zones/beaches in 2000 (Niu et al. 2009), whereas Niu et al. (2009) report an area of  $1.76 \times 10^4 \text{ km}^2$  for tidal zones/beaches based on Landsat images of 2000. Gong et al. (2010), in turn, list a tidal zone/beach area of  $1.44 \times 10^4 \text{ km}^2$  for 1990 and  $1.2 \times 10^4 \text{ km}^2$  for 2000. In the present study, an area of coastal wetlands amounting to  $5.76 \times 10^4 \text{ km}^2$  was calculated for the 1970s and  $5.36 \times 10^4 \text{ km}^2$  for 2007.

Of the above studies, only the methods and data sources of Niu et al. (2009), Gong et al. (2010) and this study are strictly comparable. These suggest that the area of the tidal zone/beach lies somewhere between 12,000 and  $17,600 \text{ km}^2$ . Even the data of 1970s, which was based on topographic map evaluation, are more reasonable with respect to the above area range than the other studies quoted above and listed in Table 3. Evidently, different classification systems, variable satellite images and object extraction procedures, annual changes in land use, and systematic



**Fig. 6** Comparison of wetlands in the 1970s and 2007 in subsection d



errors all contributed to the differences in the observational values.

#### Driving Forces for Coastal Wetland Change

Wetlands, along with oceans and forests, are among the most important ecosystem on Earth with rich biodiversity far beyond any other ecosystem (Mitsch and Gosselink 2000). Therefore, coastal wetlands, in conjunction with the oceans and the land, are a very complex ecosystem with

both dynamic balances with its surrounding and human interference since early civilization. For a long time, many cultures have learned to live in harmony with wetlands and have benefited economically from surrounding wetlands (Nicholas 1998). However, in the past 200 years, human activity and settlement have drastically reduced wetlands (Brinson and Malvarez 2002). From the 1780s to 1980s, America's wetlands were reduced by 53 % (Dahl 1990.). In UK, since the Rome times, 23 % of the river deltas, 50 % of marsh and 40 % of the bog have disappeared (<http://>

| Subtype & code            | Topographic maps | Satellite images | Subtype code &                    | Topographic maps | Satellite images |
|---------------------------|------------------|------------------|-----------------------------------|------------------|------------------|
| 1 Shallow marine waters   |                  |                  | 4 Estuarine waters                |                  |                  |
| 2 Tidal zones /Beaches    |                  |                  | 5 Estuarine deltas /Sandy islands |                  |                  |
|                           |                  |                  | 1 Reservoirs                      |                  |                  |
|                           |                  |                  | 2 Aquacultural ponds              |                  |                  |
| 3 Coastal marshes /Swamps |                  |                  | 3 Rice pads                       |                  |                  |
|                           |                  |                  | 4 Salt pads                       |                  |                  |
|                           |                  |                  |                                   |                  |                  |

**Fig. 7** Comparability of different illustration in topographic maps and corresponding images in satellite data. Table in blue indicates natural coastal wetlands, while table in yellow means artificial coastal wetlands

**Table 3** Comparison of different coastal wetland datasets of China (areas in km<sup>2</sup>)

| Data source                                      | Coastal wetland area | Tidal zone/beach | Shallow sea waters (-5 m) | Artificial wetland | Notes   |
|--|----------------------|------------------|---------------------------|--------------------|---|
| State Forestry Administration                    | 59,400               |                  |                           |                    | China's wetland resource survey of 1995–2003            |
| China National Wetlands Conservation Action Plan | 48,700               | 21,700           | 27,000                    |                    | Published in 2000                                       |
| Coastal zone survey                              |                      | 23,510           |                           |                    | China's coastal zone and tidal flat survey of 1980–1985 |
| Land use mapping                                 |                      | 6,400            |                           |                    | China's land use mapping by remote sensing data of 2000 |
| Niu et al.                                       |                      | 17,610           |                           |                    | Remote sensing data of 2000                             |
| Gong et al.                                      |                      | 14,355           |                           |                    | Remote sensing data of 1990                             |
|  |                      | 12,015           |                           |                    | Remote sensing data of 2000                             |
| This paper                                       | 57,600               | 25,100           | 32,300                    | 240                | Topographical maps of 1970s                             |
|  | 53,600               | 17,000           | 33,900                    | 2,740              | Remote sensing data of 2007                             |

[www.ramsar.org/about/about\\_wetland\\_loss.htm](http://www.ramsar.org/about/about_wetland_loss.htm), 1996) (Davidson et al 1991). In China, the natural coastal wetlands in Yancheng coastal salt marshes have lost 159,000 ha from 1976 to 2007 with a decrease from 95 % to 72 % of the total area (Zuo et al. 2012). Wetlands in Pearl River Estuary have lost 4,600 km<sup>2</sup> from 1979 to 2009, with nearly half of them being changed to urban landscape (Zhao et al. 2010).

Based on the general statistics of coastal wetland change in China, natural wetlands are clearly disappearing rapidly, whereas artificial wetlands are increasing. There is a tendency of shifts in land use as natural wetlands are being converted into artificial wetlands and industrial/residential area usages. During the interpretation process, it has become clear that most of the coastal marshes have been converted into aquaculture ponds. It is therefore quite certain that the main driving force of wetland change is primarily the intensification of human activity in the coastal zone.

Our results indicate that the areas of tidal zones/beaches are gradually decreasing with the intensification of human activities. Provinces with higher marine economic outputs experience larger natural coastal wetland losses. Thus, the provinces of Zhejiang, Jiangsu, and Guangdong register a loss of 1,500, 1,000, 800 km<sup>2</sup>, respectively, in the period from the 1970s to 2007. On the other hand, artificial coastal wetlands have increased in the provinces of Shangdong, Liaoning, Fujian, and Guangdong, with a total area of 1,980 km<sup>2</sup>. Most of these artificial wetlands are limited to aquaculture of primarily fish/shrimp/crab production. From a wetland conservation point of view, high-quality wetlands are being removed to be replaced by poor-quality ones. What is more serious, however, is the fact that many industrial parks constructed in the coastal zone dump much of their wastewater and solid waste into the shallow-marine water. As a consequence, eutrophication has become an annual occurrence in nearshore waters. Pollution has not only caused economic loss to local stakeholders but has also increased the risk level to the coastal ecosystem. To assess whether or not ecological risks have increased, it is necessary to set up a well-balanced monitoring system based on the new coastal wetland mapping system outlined in this study. This is the challenge for the future.

**Acknowledgments** Funding for this study was provided by the National Science Foundation of China (40606025), the National Oceanic 908 Plan (908-01-ZH3; 908-ZC-II-03), and the Priority Academic Program Development (PAPD) of Jiangsu Higher Education Institutions. As a large-scale survey of China's coast, the authors are greatly appreciative of the tremendous amount of advice and direction received from the funding organizations. We also acknowledge Professor Burghard W. Flemming from University of Bremen for his advice on paper revision and English editing. Dr. Jackson, Dr. Chen G., and the anonymous reviewer are also appreciated for their valuable suggestion on paper revision.

## References

- Brinson, M.M., and A.I. Malvarez. 2002. Temperate freshwater wetlands: Types, status, and threats. *Environ Cons* 29(2): 115–133.
- Dahl, T.E. 1990. Wetlands losses in the United States 1780's to 1980's. Washington: Fish and Wildlife Service, US Department of the Interior.
- Darras, S., M. Michou, and C. Sarrat. 1999. *IGBP-DIS wetland data initiative: A first step towards identifying a global delineation of wetlands*. Toulouse: IGBP-DIS Office.
- Davidson, N.C., D. Laffoley, J.P. Doody, et al. 1991. Nature conservation and estuaries in Great Britain. Peterborough: Peterborough Nature Conservancy Council.
- Davidson, N.C., and C.M. Finlayson. 2007. Earth observation for wetland inventory, assessment and monitoring. *Aquatic Conservation: Marine and Freshwater Ecosystems* 17: 219–228.
- Fernandez-Prieto, D., O. Arini, T. Borges, N. Davidson, M. Finlayson, H. Grassl, H. MacKay, C. Prigent, D. Pritchard, and G. Zalidis. 2006. The glob-wetland symposium: summary and way forward. Proceedings Glob-Wetland: Looking at Wetlands from Space, October 2006, Frascati, Italy.
- Finlayson, C.M., R. D'Cruz, and N.J. Davidson. 2005. *Ecosystem services and human well-being: Water and wetlands synthesis*. Washington: World Resources Institute.
- Gong, M.J., Y. Zhang, and Y. Zhang. 2009. Discussion of the relationship between the scale and the best spatial resolution in making cartographies with remote sensing data. *Science of Surveying and Mapping* 34(4): 232–233. in Chinese.
- Gong, P., X. Zheng, and J. Chen. 1995. Boundary uncertainties in digitized maps II: An experiment on digitization errors. *Geogr Inf Sc* 1: 65–72. in Chinese.
- Gong, P., Z.G. Niu, X. Cheng, K.Y. Zhao, D.M. Zhou, J.H. Guo, L. Liang, X.F. Wang, et al. 2010. China's wetland change (1990–2000) determined by remote sensing. *Sci China Earth Sci*. 53: 1036–1042.
- Lehner, B., and P. Döll. 2004. Development and validation of a global database of lakes, reservoirs and wetlands. *Journal of Hydrology* 296(1–4): 1–22.
- Lei, K., and M.X. Zhang. 2005. The wetland resources in China and the conservation advices. *Wetland Sciences* 2: 81–86 (in Chinese).
- Lowry, J.B.C. 2006. The application of low-cost GIS software and data for wetland inventory, assessment and monitoring. Ramsar Convention Secretariat, Gland, Switzerland. [http://www.ramsar.org/lib/lib\\_rtr\\_index.htm](http://www.ramsar.org/lib/lib_rtr_index.htm). Ramsar Technical Report No. 2.
- Mitsch, W.J., and J.G. Gosselink. 2000. *Wetlands*. New York: Wiley.
- Nicholas, G.P. 1998. Wetlands and hunter-gatherers: A global perspective. *Current Anthropology* 39: 720–730.
- Niu, Z.G., P. Gong, X. Cheng, J.H. Guo, L. Wang, H.B. Huang, S.Q. Shen, Y.Z. Wu, et al. 2009. Geographical characteristics of China's wetlands derived from remotely sensed data. *Sci. China Ser. D-Earth Sci* 52: 723–738.
- Rebelo, L.M., C.M. Finlayson, and N. Nagabhatla. 2009. Remote sensing and GIS for wetland inventory, mapping and change analysis. *Journal of Environmental Management* 90: 2144–2153.
- Sahagian, D., and H. Melack (eds.). 1996. *Global wetland distribution and functional characterization: Trace gases and the hydrologic cycle*. Stockholm IGBP Report No: IGBP Secretariat. 46.
- Yang, B.G., Y. Wang, and D.K. Zhu. 1997. The tidal flat resource of China. *Journal of Natural Resources* 4: 307–316. in Chinese.
- Zhao, H., B.S. Cui, H.G. Zhang, X.Y. Fan, Z.M. Zhang, and X.X. Lei. 2010. A landscape approach for wetland change detection (1979–2009) in the Pearl River Estuary. *Environmental Sciences* 2: 1265–1278.
- Zuo, P., Y. Li, S.H. Zhao, X. Zhou, H.F. Teng, and H. Chen. 2012. Landscape changes of Jiangsu Yancheng coastal wetlands and their driving forces since 1976. *Acta Oceanologica Sinica*. 34 (1): 101–108 (in Chinese).