RESEARCH ARTICLE

Seagrass distribution changes in Swan Lake of Shandong Peninsula from 1979 to 2009 inferred from satellite remote sensing data

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Abstract: Seagrass and associated bio-resources are very important for swan's overwintering in Swan Lake in Rongcheng of Shandong Peninsula of China. The seagrass distribution changes, which are usually affected by the regional human activities, can indirectly affect swan's habitat. In this study the satellite remote sensing data in years 1979–2009 together with in-situ observations in recent years were used to examine the seagrass distribution changes in Swan Lake. The band ratio of band 1 to band 2, Lyzenga's methods and band synthesize of band 1, band 2 and band 3 were used for seagrass retrieval. The band ratio of band 1 to band 2 with ranges greater than 4.5 was used for estimating the seagrass coverage greater than 50%. Results showed that in years 1979–1990 seagrass coverage greater than 50% occupied more than half of the surface area of Swan Lake. In years 2000–2005, the total area with seagrass distributions reduced greatly, only about one sixth to one fourth of Swan Lake's surface area. After 2005, the seagrass area in Swan Lake increased gradually and occasionally was greater than one third of the total surface area of the Lake. It was shown that human activities such as the dam and fish pond establishment and the awareness of seagrass importance and protected actively result in the seagrass distributions changes in Swan Lake which decreased first and then increased afterwards.

Keywords: seagrass; distribution change; satellite remote sensing; Swan Lake

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1. Introduction

Seagrass is one of very important elements for coastal ecosystems, and it can be used as an indicator for evaluating the coastal healthy status. Seagrass can provide shelter and food for fish, waterfowl and some seagrass dependent creatures, such as dugongs, seacow and turtles. With increased human activities over coastal waters, however, seagrass has declined greatly in recent years.

Globally, about 33000 km^2 of seagrass disappeared in recent 20 years (Short *et al*., 2000), with about 27 km^2 of the seagrass area loss from 1879 to 2006 annually (Waycott *et al*., 2009). Seagrass reduction can result in not only ecological devastation but also changes in the geological structure of coastal waters. Some researchers found that silt coastlines turned to rocky coastlines when seagrass disappeared in some regions along the coast of the North Atlantic Ocean (Thayer *et al*., 1984). Many governments and non-government organizations made great efforts on the study of seagrass distributions to investigate seagrass distributions over coastal waters of world oceans. There are, however, still unknown seagrass distributions in most of the world oceans.

In China, seagrass has also declined seriously, about 80% of seagrass disappeared since 1960s due mainly to the rapid development of coastal economy (Yang, 1979; Yang *et al*., 2016). The total area of 8 seagrass beds in Guangxi Province, for example, decreased from about 104.5 hm^2 in 1987 to about 28.7 hm^2 in 2001 (Li *et al*., 2007). Currently, seagrass in China mainly distributes spottily (a) in the northeast region of China around the coast of Bohai Sea and north coast of the Yellow Sea, including the coast area of Shandong provinces, Liaoning Province, and Hebei Province; and (b) in the southeast region along the northwest coast of the South

China Sea including coast areas of Hainan, Guangdong, and Guangxi Provinces (Yang *et al*., 2016; Zheng *et al*., 2010). These two regions belong to the geographical classification of region 4 (Temperate North Pacific Region) and region 5 (Tropic Indian ocean-pacific Region) respectively suggested by Short *et al*. (2017).

Seagrass beds are very important for maintaining the basic function of seagrass ecosystems, including the recovery ability of seagrass itself and biodiversity of related ecological components. Previous studies showed that there are about 62 seagrass beds in China, and only 27 seagrass beds have areas of more than 10 hectares (ha) (Yang *et al*., 2016). In the northeast region of China, there are only 4 seagrass beds with the total area greater than 10 ha. Because of the long coastline and versatile climate, about 22 seagrass species were found in China (Zheng *et al*., 2013). In the northeast region of China, there are about five species of seagrass and the species were mainly *Zostera marina* Linn., *Zostera japonica* Asch. et Graebn, *Zostera caespitosa* Miki, *Phyllospadix iwatensis* Makino and *Phyllospadix japonicus* Makino (Zheng *et al*., 2010; Yang *et al*., 2016). Among these five species, *Zostera marina* Linn. is the dominant species in the northeast China (Yang *et al*., 2016).

Large areas of continuous distributions of seagrass beds along the coast of Shandong Peninsula were observed in 1960s (Yang *et al*., 1979), especially in Jiaozhou Bay, Qingquan Bay, Sanggou Bay and other bays. Seagrass grew luxuriantly and the coverage was more than 80% on average over these coastal waters (Yang *et al*., 1993). However, with significant economic development over coastal areas such as new land creations and port constructions, seagrass distribution areas have reduced rapidly. It was reported that about 1334 ha of *Zostera marina* were found around Furong Island, Jiaozhou Bay in 1960s, and a large area of seagrass disappeared in 2000 (Liu *et al*., 2012).

Seagrass in Swan Lake in Rongcheng of Shandong Peninsula was studied only recently. *In-situ* observations were made between June 2009 and June 2010 (Liu *et al*., 2011), between September 2011 and January 2012 (Zhang, 2013), and between August 2012 and July 2013 (Li *et al*., 2014). These studies mainly focused on the seagrass shoot density, height, and eelgrass detritus, which act as food sources for the deposit feeder but also seagrass ecology itself. Some researchers suggested that decaying eelgrass debris was good food sources for sea cucumbers and the eelgrass-meadow restoration is imperative and could be not only of a significant ecological benefit, but also of potential economic value (Liu *et al*., 2013). Some studies on *Zostera marina*'s height, densities and biomass showed that the shoot height, density and biomass of eelgrass all varied seasonally (Zhou *et al*., 2014). The studies on *Zostera japonica* in Swan Lake during the period between September 2011 and January 2012 also showed the similar tendency (Zhang *et al*., 2013) with the density, height and biomass of *Zostera japonica* varying seasonally. In addition to the ecological importance, the seagrass ecosystem is very important for the coastal carbon sink. Along the coast of Shandong Peninsula, especially in Swan Lake, the seagrass carbon cycle and storage were studied (Li *et al*., 2014). In order to calculate the seagrass carbon sink accurately, the ecological structure of seagrass was also studied in the area (Nie *et al*., 2014).

Satellite remote sensing data were found to be very useful for seagrass retrieval, especially since the satellite remote sensing data can be used to document historical information. Lyzenga (1978, 1981) developed invariant indexes, which are independent on water depths. These indexes were widely used for the seagrass distribution retrieval from the satellite remote sensing data (Pu *et al*, 2012). Some researchers developed water column correction methods to improve the accuracy of seagrass estimations from the satellite remote sensing data to some degrees (Yang *et al*., 2010; Yang *et al*., 2015).

Up to the date, however, the historical seagrass distribution changes in Swan Lake of Shandong Peninsula have not been studied. Good knowledge about the seagrass distribution changes and physical processes affecting these changes is very important for the seagrass management and protection in the Lake. In this paper, satellite remote sensing data combined with in-situ observations were used to determine the seagrass distribution changes in Swan Lake. The first objective of the paper is to present suitable methods for the regional seagrass distribution retrieval from the satellite remote sensing data. The second objective is to quantify the seagrass distribution changes in Swan Lake from 1979 to 2010 and to provide scientific explanations for these changes. The third objective is to provide information of the seagrass distribution and living state in the area for the local government and various stakeholders to understand how to preserve and protect the seagrass in the Lake.

2. Material and Methods

2.1 Study Sites

Swan Lake is located between 37°20’00’’N and 37°22’00’’N and between 122°32’45” and 122°35’30” with the total surface area of about 4.8 km^2. The Lake is a small cove of a marine lagoon in the southeast of Chengshan Town in Rongcheng City of Weihai of Shandong Peninsula in northeastern China. The Lake is connected to the Yellow Sea by a very narrow inlet (Figure 1).

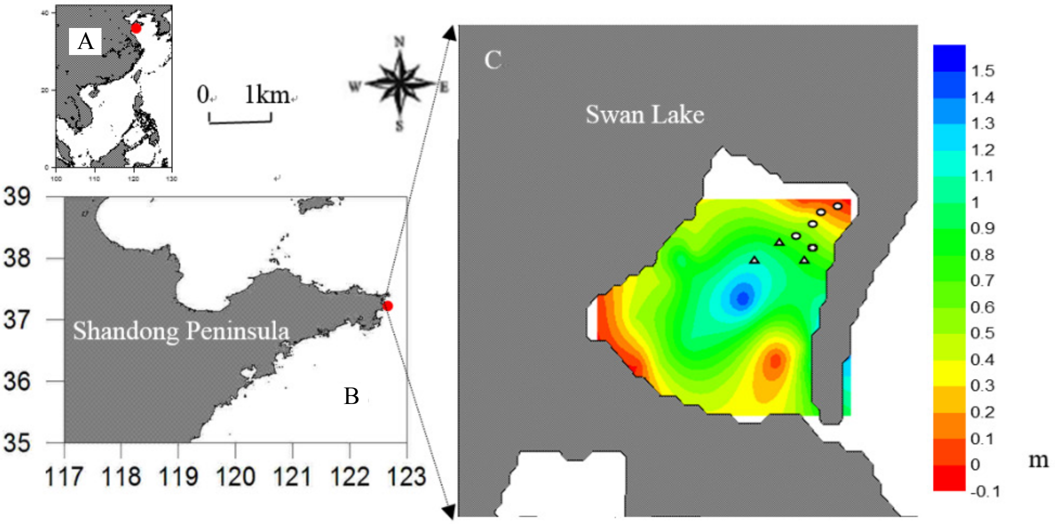

Figure 1. Maps showing (**A**) the China Seas, (**B**) coastal waters of Shandong Peninsula and (**C**) waters depths in Swan Lake. The red dots in (**A**) and (**B**) denote the area of Swan Lake.

The water temperature in Swan Lake varies typically from about -0.5 °C in January to about 26 °C in June, with the annual mean of 12 °C (Zhou *et al*., 2014). The coldest water temperature in the Lake is in January, which is about 0.9 °C on average. Salinity in the Lake varies between 30 and 32. Swan Lake has an average tide range of ca. 0.9 m with a maximum tide range of 1.65 m (Xue, 2000; Jia, 2001; Zhou *et al*., 2014; Zhang *et al*., 2015). The tides in the Lake are the irregular semi-diurnal mixed type, with the dominant period of about 12.5 h.

Swan Lake is relatively shallow, with water depths varying from 0.5 to 1.5 m over most parts. Over the central part of Swan Lake, the water depth is relatively deep with the maximum water depth of greater than 1.5 m (Zhou *et al*., 2014; Zhang *et al*., 2015). Along the west and north coast of Swan Lake, the water depth is relatively shallow. Over the southeast part of Swan Lake, a shallow shoal is emerged as land during the low tide.

The substrate of Swan Lake is mainly sandy. Sediments in Swan Lake can be divided as the gravelly-sand, muddy-sand, sand-mud, and mud types (Jia, 2001). Among these four types, the mud-type sediments were found mainly in the central part of the Lake. The clay-sand type sediments were found mainly in the southern and northern parts of the Lake. The gravel-sand type sediments were found mainly along the southeast and southwest of the Lake (Jia, 2001; Zhang, 2013).

Two species of seagrass (*Zostera marina* Linn. and *Zostera japonica* Asch. et Graebn) were found in Swan Lake. Because of the existence of seagrass, Swan Lake is an ideal overwintering habitat for wetland birds, especially for the whooper swan *C. cygnus*. Every year approximately ten thousands of swans overwinter in the lagoon and nearby areas of the Lake due to relatively very low-winds with plentiful food in the areas (Jia, 2001). Seagrass and associated bioresources such as sea cucumbers, shellfish and fish, are important food sources for swans and other waterfowl. The establishment of the Rongcheng Swan Nature Reserve in 1985 by Rongcheng city and upgraded later as the National Nature Reserve of China in 2007 has contributed to the survival and expansion of seagrass in Swan Lake (Zhang *et al*., 2015). In order to protect the regional environment, the local government had transplanted seagrass in Swan Lake to protect the seagrass ecosystem.

2.2 Ground-truthing Data Observations and Gathering

In April 2015, *in-situ* observations were made in Swan Lake and seagrass shoots densities in the Lake were measured. The Global Positioning System (GPS) was used to determine positions of study sites. Seagrass and associated bioresources samples together with other environmental information were collected in the field and some water and sediment samples were then brought to the laboratory for further analyzing. Each observation site was designed as 1 m × 1 m in area. Plant composition and total plant percent cover were also established in each observation site, and photos were taken and archived for further analyzing later.

The following seagrass fived indexes were used in this study: (1) seagrass density, (2) leaf length, (3) leaf area index, (4) stem biomass, and (5) above-ground biomass. The seagrass density was estimated by counting the total number of seagrasses in a white square frame of 1 m 1 m from photographs. The leaf length was measured with a ruler *in-situ*. The stem biomass and above-ground biomass were determined by weighing before (wet weight) and after (dry weight) seagrass being dried at 60 °C in an oven. The seagrass height was recorded by measuring the height of the canopy and then calculating the average. The leaf area index (LAI) was computed by accumulation of seagrass leaf density (*μ)* and height (Z). This can be described as the following equation (Yang *et al.*, 2009):

$$LAI = \mu Z \tag{1}$$

The seagrass density (D) is defined as the number of seagrass plants (*N*) over a given area (*S*):

$$D = N / S \tag{2}$$

The seagrass distribution change, ΔX, is determined from the following equation:

$$\Delta X = \frac{X_i a - X_i b}{X_i b} \tag{3}$$

where X_i is the frequency, density, or area of seagrass distribution; X_ia is seagrass indexes at one time; and X_ba is seagrass indexes at another time.

Some *in-situ* seagrass observational data in Swan Lake were also gathered from published papers for periods of June 2009–June 2010 (Liu *et al.*, 2011), September 2011–January 2012 (Zhang, 2013), and August 2012–July 2013 (Li *et al.*, 2014).

2.3 Satellite Image Processing

2.3.1 Satellite Data

Satellite data used in this study were obtained from the Global Land Cover Facility (GLCF) and the Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences. More than 10 satellite data of Landsat MSS, TM and ETM+, and aerial photography from 1979 to 2015 were used in this paper for physical and biological index retrieval. Visible and near-inferred bands of satellite remote sensing data (band 1 (0.45–0.52 μm), band 2 (0.52–0.59 μm), band 3 (0.63–0.69 μm), and band 4 (0.77–0.89 μm)) were utilized for determining seagrass distributions in Swan Lake. More details of the satellite data used in this paper are given in Appendix 1.

2.3.2 Sunglint Correction

Sunglint is usually stronger than water-leaving radiance and contains substrate information. In the process of retrieving substrate information, sunglint is generally corrected. The effect of sunglint may be reduced or removed by considering that near-infrared radiance is essentially completely absorbed in the water. Thus, the observed radiance can be regarded as either being reflected from the surface or scattered in the atmosphere. In order to obtain reliable results, an infrared band (band 4 of the Landsat data) was used to determine surface reflectance. In this study, Goodman's equations (2008) were utilized for the sunglint corrections:

$$L_i(\lambda) = L_i^{'}(\lambda) - L_i(band4) - \Delta \tag{4}$$

$$\Delta = A + B[L(band3) - L(band4)] \tag{5}$$

with $A = 0.000019$ and $B = 0.1$.

2.3.3 Atmospheric Correction

The FLAASH module in ENVI software was used for atmospheric corrections. The parameter of the atmosphere model was chosen as the "mid-latitude summer", and "Maritime" was chosen for the aerosol model.

2.3.4 Water Column Correction

Water column correction is critical for seagrass retrieval. In this paper, the water correction was maded based on (Maritorena *et al.*, 1994):

$$A = R_\infty + (R_0 - R_\infty) \cdot \exp(-2K_d H) \tag{6}$$

where A is the backscattering coefficient of down-welling irradiance of the bottom, R_0 is reflectivity just above the sea surface, and R_∞ is the reflectivity of water bodies.

2.3.5 Land-water Line Determination

The land-water line separates the water bodies and land areas. Water bodies' area was utilized for retrieving substrate information. In this study, the values of band 4 and band 5 were used for dividing the land-water line. In addition, a pixel with a negative value was considered as the land area, a pixel with a positive value as the water area, and a pixel with the zero value as the land-water line. It should be noted that, however, this method is imperfect for coastal areas covered with floating vegetation with large errors in determining the land-water lines.

2.3.6 Image Classification

ENVI 4.5 software was used for processing the satellite remote sensing data. Region of interesting (ROI) module was used for transferring image data to ASC II. Surfer 8.0 software was employed for mapping seagrass distribution within the base map. In this study, the regional sediment type mapping was not used because sediments in Swan Lake are mainly sands. Seagrass can be easily differentiated from sediments based on the satellite remote sensing data since reflectivity differ evidently.

The supervised classification technique was used in the study. The different substrates were discerned by the digital number (DN) ranges. One of main challenges is that the DN of the same substrate in different images varied greatly. In order to make accurate classifications, a typical ground object, such as sand on the southeast coast of Swan Lake, was utilized to normalize the DN of the whole image (Yang *et al*., 2009; Yang *et al*., 2011).

3. Results

3.1 Comparison of Different Methods for Seagrass Retrieval with Satellite Remote Sensing

The satellite data of Landsat series 4, 5, 6, and 7 were used for retrieving seagrass distributions for satellite signals in the coastal band (band 1). The following three main algorithms for retrieving seagrass distributions with satellite remote sensing were used: (a) the ratio between band 1 and band 2, (c) Lyzenga's methods, and (d) synthesis of bands 1, 2, and 3. The ratio of band 1 and band 2 with a range greater than 4.5 was also used for a sensitivity study. Figure 2 presents the seagrass distributions retrieved using the above-mentioned four algorithms. Results presented in Figure 2 demonstrate that the general patterns of seagrass distributions inferred using different methods are very similar. This indicates that the seagrass distributions can well be obtained with the ratio of band 1 and band 2, Lyzenga's methods, and a synthesis of bands 1, 2, and 3.

3.2 Seagrass Distribution Changes from 1979 to 2009 in Swan Lake

The satellite remote sensing data in the late spring, summer, autumn, and early winter during the period from 1979 to 2010 were analyzed to examine the long-term seagrass distribution changes in Swan Lake. The seagrass occurred mainly in the central area to the southwest and east of Swan Lake, with a distance away from the bank of tens of meters. Although seagrass density was found to be normal in the main seagrass bed, seagrass distributions with different densities existed from the outside to the central area of the main seagrass bed. Results shown in Figure 3 demonstrate that seagrass appeared in the southeastern and central areas of Swan Lake in 1979 and 1989. Significant changes in the seagrass distribution occurred in 2004, with most of seagrass appearing over the central and central-eastern areas of the Lake. In 2009, seagrass appeared mainly over the central area of the Lake. Detailed information on the seagrass distributions such as those in Figure 3 is essential for determining the seagrass density distribution and can be utilized as the basis for determinging seagrass

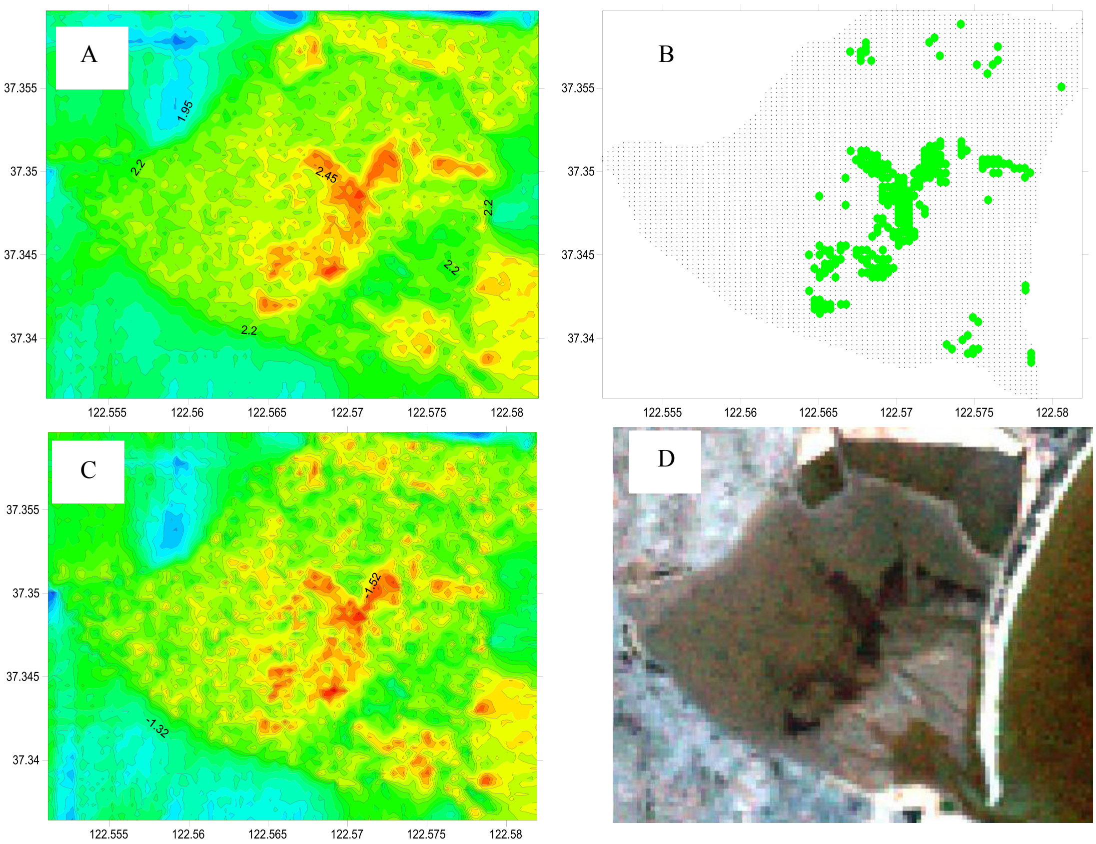

Figure 2. Seagrass distributions retrieved from satellite remote sensing data on 23 March 2005 using techniques of (**A**) the ratio between band 1 and band 2, (**B**) the ratio of band 1 and band 2, with a range greater than 4.5, (**C**) Lyzenga's methods, and (**D**) synthesis of bands 1, 2, and 3.

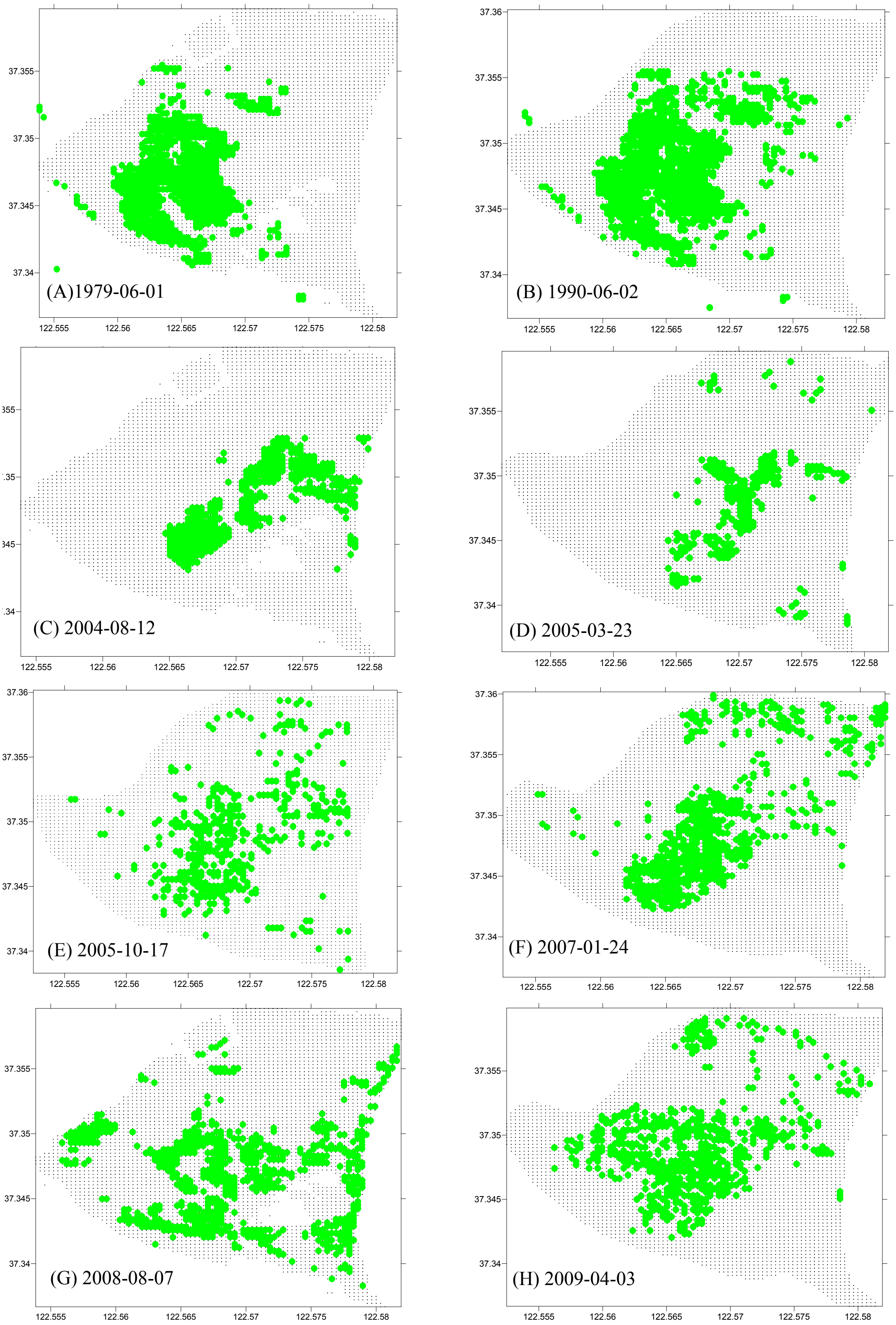

Figure 3. Seagrass (green spots in the figures) distributions inferred from the satellite remote sensing data in Swan Lake on (**A**) 12 June 1979, (**B**) 6 June 1990, (**C**) 12 August 2004, (**D**) 23 March 2005, (**E**) 17 October 2005, (**F**) 24 January 2007, (**G**) 7 August 2008, and (**H**) 3 April 2009.

distribution changes.

Landsat series satellite remote sensing data were used to investigate the seagrass distribution changes in Swan Lake. The satellite signals in the coastal band were relatively strong, and the distributions and patterns of seagrass could clearly be determined, which was sufficient for examining the seagrass distribution changes in the Lake.

Figure 3 also demonstrates that the total area with seagrass coverage greater than 50% was more than half of the total surface area of Swan Lake prior to 1990. From 2000 to 2005, the total area with seagrass reduced significantly to only approximately one-sixth to one-fourth of the total area of Swan Lake. After 2005, the total area of seagrass in the Lake increased gradually, and was occasionally more than one-third of the Swan Lake area.

Seagrass species in Swan Lake are mainly *Zostera marina* Linn. and *Zostera japonica* Asch. et Graebn. However, we could not differentiate one species from another with Landsat series satellite remote sensing data.

3.3 Relationship Between Seawater Temperature and Seagrass Density and Height

The seagrass height and density can be used as indexes to estimate the seagrass biomass. seawater temperature is one of important factors that affects the seagrass growth, maturity and reproduction, especially at high latitudes. Swan Lake is located at a relatively high latitude, in which water temperature is low in the winter and high in the summer. During the low temperature period, seagrass will wither to protect itself from cold weather. In summer months, seagrass flourishes because the temperature is conducive to seagrass growth. Seasonal variation of seagrass in Swan Lake indicated that water temperature constitutes an essential factor that controls seagrass growth in the area. *Z. marina* in Swan Lake distributed in areas with different water depths, from the mid-intertidal zone to the subtidal zone. Seasonal differences in shoot height revealed that the shoot height of eelgrass changed with water temperature. In addition, Pearson's correlation analysis demonstrated that the shoot height was positively correlated with seawater temperature (Figure 4). The seagrass density, however, was different from the seagrass height. No apparent relationship could be found between the seagrass density and water temperature, as shown in Figure 5. These results indicated that the seagrass distributions retrieved from the satellite remote sensing data in different seasons can be used to study the seagrass distribution changes in the Lake.

4. Discussion

Landsat series data were used in this paper for the seagrass and related environmental factor retrieval. The Thematic Mapper (TM) and The Enhanced Thematic Mapper Plus (ETM) sensors were very useful for coastal band signals, which were relatively stronger than those at other bands. Three algorithms were used in this study for seagrass retrieval in Swan Lake of Shandong Peninsula of China. They are (a) the band ratio of band 1 to band 2, (b) Lyzenga's methods, and (c) band synthesis of band 1, band 2, and band 3. It was found that the band ratio of band 1 to band 2 with a range greater than 4.5 can be used for representing seagrass coverage greater than 50%. Some factors such as water transparency, however, will affect the satellite remote sensing retrieval accuracy. Thus, determining how to control these uncertainties requires addition studies.

Factors that affect the seagrass living status are mainly human activities, hydrodynamic effects, water transparency, and water temperature. Water temperature in Swan Lake was found to be a dominant factor influencing seagrass seasonal variations. Analysis of environmental factor variations can provide some guidance for identifying the causes of seagrass distribution in the Lake. Analysis of *in-situ* observations made during a series of field surveys demonstrates

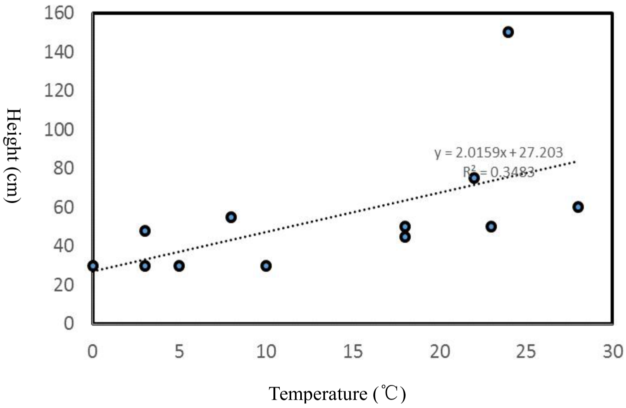

Figure 4. Relationship between seagrass height and temperature

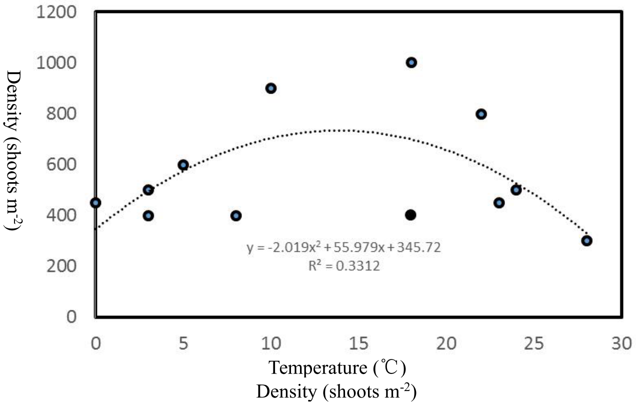

Figure 5. Relationship between seagrass density and temperature

seagrass meadows in Swan Lake face some major threats. However, public awareness of the importance of seagrass is essential for seagrass to flourish in the area. Some threats to, and actions towards, seagrass protection are analyzed in the following.

4.1 Threats of Human Activities to Seagrass Distribution

4.1.1 Lake Topography Deformed as A Fish Pond

Lake topography constitutes a critical index for human activities in the area. From satellite data in Appendix 2, the topography of Swan Lake has changed greatly. The following are the major economic activities that have some negative effects on the seagrass in Swan Lake.

(1) Dam construction

Local fishermen constructed a dam at the inlet in 1979 (Jia, 2001) to prevent the escape of cultured sea cucumbers from the Lake. This dam can be seen in an aerial photograph in 1984 (Appendix 2). The construction of the dam prolonged the water exchange period from 10 days to 14 days, resulting in water quality deterioration. Consequently, sea cucumber production decreased from 1500 kg/y from the 1970s to 150 kg/y in 1985. Being aware of the harmful effects, the local government removed the dam in 1986. However, some remnants of the dam still exist.

(2) Fish ponds

Two fishponds in Swan Lake were constructed in 1986 (Jia, 2001; Xue, 2000; Appendix 2). One of them was near the inlet and the other was located in the northwest of the Lake (Appendix 2). Even though the dam was removed, the remains of the dam and the fish pond near the inlet still limit the water exchange between Swan Lake and the Yellow Sea. In 2000, the remains of the dam and the fish pond in the inlet area were completely removed. The construction and elimination of fish ponds were the result of the balance between exploitation and protection. The establishment of a nature reserve was the primary reason for the removal of fish ponds.

In recent years, especially in the 1990s, more fish ponds were created along the west coast of Swan Lake. This resulted in the destruction of a large area of seagrass, and more nutrients were disseminated from the fishpond, which negatively affected seagrass downstream of these ponds.

Digging shellfish is ubiquitous over most of the seagrass meadows along the coastal area. Shellfish are an important source of food and income for the local people, and thus they dig in the seagrass meadows of Swan Lake. Shellfish digging, however, is very destructive, exposing rhizomes and loosening mud to flow, and thus covers the seagrasses.

4.1.2 Building Indexes Around Swan Lake Increased

Building indexes are very important indexes for human activities. The red band and inferred band were used in this paper for retrieving building indexes. In 1979, building indexes were relatively low, and only in spot distributions. Since 2010, However, building indexes were increased and distributed continuously (Appendix 3). Some published data (Zhang *et al.*, 2010a; Zhang *et al.*, 2010b) showed that in Rongcheng, the ratio of the construction area to the total area increased from 7.3% in 1969 to 15.42% in 2010. However, the ratio of intertidal zone to the total area of Swan Lake decreased from 4.13% in 1969 to 2.82% in 2010.

Increasing building indexes indicate that more people lived in the area. Consequently, human activities increased dramatically, which greatly affected seagrass distribution.

4.1.3 4.1.3 Increase in Tourist Population

Tourist resorts in Swan Lake were established in 1992. Since then, the area of land for living usage, roads, tourism-related reclamation, and polluted-water discharge increased.

4.1.4 4.1.4 Dredging

The local government and the Mashan Company began dredging in sites near the inlet in 1999. This dredging activity made the inlet wider and the water exchange more rapidly. Some previous studies demonstrated that the effects of dredging do not facilitate seagrass growth in Swan Lake (Jia, 2001).

4.1.5 Sedimentary Proofs for Seagrass Distribution Variation

Carbon contents in sediments revealed that seagrass carbon increased greatly in 1930 and 1980 (Zhao *et al.*, 2014), which means that seagrass distribution density and area were also increased greatly during the period.

4.2 Benefits of Human Activities for Seagrass Distributions

4.2.1 Seagrass Transplant

Local governments facilitated the transplant of seagrass in Swan Lake. Some scientists obtained grants for transplanting seagrass in the Lake. This action caused seagrass expansion in the area.

4.2.2 Solid Waste Landfill Sites Changed

A solid waste landfill site near Swan Lake was closed in 2006, and a new solid waste landfill site far from Swan Lake was constructed. This reduced the effects of underwater water pollution on seagrass in Swan Lake.

4.2.3 Sewage Treatment Plant Construction

Three sewage treatment plants were constructed in upstream towns, which decreased pollution in Swan Lake.

5. Conclusions

Three different algorithms were used in this study for retrieving seagrass distributions in Swan Lake from the satellite remote sensing data. These three algorithms are: (a) band ratio of band 1 to band 2; (b) Lyzenga's methods; and (c) synthesis of band 1, band 2, and band 3. It was found that the band ratio of band 1 to band 2 with a range greater than 4.5 was the best technique for estimating the seagrass coverage greater than 50% from the satellite data.

The study region of this paper is Swan Lake in Rongcheng of Shandong Peninsula, China. Seagrass distribution in Swan Lake has decreased and then increased since the 1970s. From 1979 to 1990, seagrass coverage greater than 50% occupied approximately half of Swan Lake. From 2000 to 2005, the total area with seagrass distributions reduced greatly, covering only approximately one-sixth to one-fourth of Swan Lake's surface area. After 2005, the area of seagrass in Swan Lake increased gradually, and was occasionally greater than one-third of the Swan Lake area.

Dam and fish pond establishment resulted in a decrease in seagrass area in Swan Lake. Due to the public awareness of seagrass importance and the initiation of protective actions, the seagrass area in the Lake had increased in recent years.

Acknowledgements

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References

Goodman J A, Lee Z, Ustin S L. (2008). Influence of atmospheric and sea-surface corrections on retrieval of bottom depth and reflectance using a semi-analytical model: A case study in Kaneohe Bay, Hawaii. *Applied Optics*, 47(28): F1–F11. http://dx.doi.org/ 10.1364/AO.47.0000F1

Jia J J. (2001). Sediments dynamic processes and evolution of small tidal inlet system. Doctoral Dissertation of Chinese Academy of Sciences, Qingdao.

Li Y. (2014) Study on the carbon fixation function of seagrasses in the coastal area of Shandong Peninsula: A case study of *Zostera marina* in Swan Lake in Rongcheng. Master dissertation of Ocean university of China, Qingdao.

Li Y H, Huang X P, Xu Z Z, *et al.* (2007). Threat and protection measurement of Hepu seagrass beds in Guangxi. *Marine Environmental Sciences*, 26(6): 587–590.

Liu K, Liu F L, Wang F J, *et al.* (2012). Survey and identification of Zosteraceae along Shandong Peninsula coast. *Progress in Fishery Sciences*, 33(6): 99–104.

Liu P. (2013). A study on ecophysiological characteristics of bivalves in seagrass meadow and ecological restoration of the eelgrass *Zostera marina* L. Master dissertation of University of Chinese Academy of Sciences, Qingdao.

Lyzenga D R. (1978). Passive remote sensing techniques for mapping water depth and bottom features. *Applied Optics*, 17: 379–383. http://dx.doi.org/10.1364/AO.17.000379

Lyzenga D R. (1981). Remote sensing of bottom reflectance and water attenuation parameters in shallow water using aircraft and Landsat data. *International Journal of Remote Sensing*, 2: 71–82. http://dx.doi.org/10.1080/01431168108948342

Nie M. (2014). Preliminary study on the structure of epiphytic and benthic algal community in the eelgrass (*Zostera marina*) meadows of the typical coastal area of Shandong Peninsula. Master dissertation of Ocean university of China, Qingdao.

Pu R L, Bell S, Meyer C, *et al.* (2012). Mapping and assessing seagrass along the western coast of Florida using LandsatTM and EO-1 ALI/Hyperion imagery. *Estuarine, Coastal and Shelf Science*, 115: 234–245. https://dx.doi.org/10.1016/j.ecss.2012.09.006

Short F, Carruthers T, Dennison W, *et al.* (2007). Global seagrass distribution and diversity: A bioregional model. *Journal of Experimental Marine Biology and Ecology*, 350(1–2): 3–20. https://dx.doi.org/10.1016/j.jembe.2007.06.012

Short F T and Wyllie-Echeverria S. (2000). Global seagrass declines and effect of climate change. In: Shepperd C R C. (editor), Seas at the Millennium: An Environmental Evaluation, vol. III. Pergamon, Elsevier, Amsterdam, pp. 10–11.

Thayer G W, Kenworthy W J and Fonseca M F. (1984). The ecology of eelgrass meadows of the Atlantic Coast: A community profiles. *U.S. Fish and Wildlife Service*, 2: 147.

Waycott M, Duarte C M, Carruthers T J B, *et al.* (2009). Accelerating loss of seagrasses across the globe threatens coastal ecosystems. *Proceedings of the National Academy of Sciences of the United States of America*, 106 (2009): 12377–12381. https://dx.doi.org/10.1073/pnas.0905620106

Xue Y C. (2000). Sediments transfer and pile up in the tidal inlet in Yuehu Lake, Shandong province. Doctoral Dissertation of Chinese Academy of Sciences, Qingdao.

Yang C, Yang D. (2015). An improved empirical model for retrieving bottom reflectance in optically shallow water. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, 1939–1404: 1266–1273. https://dx.doi.org/10.1109/JSTARS.2015.2398898

Yang C Y, Yang D T, Cao W, *et al*. (2010). Optical properties of the Seagrass using a water column correction model. *International Journal of Remote Sensing*, 31(17–18): 4595–4608. https://dx.doi.org/10.1080/01431161.2010.485138

Yang D T, Yang C Y. (2009). Detection of seagrass distribution changes from 1991 to 2006 in Xincun Bay, Hainan, with satellite remote sensing. *Sensors*, 9(2): 830–844. https://dx.doi.org/10.3390/s90200830

Yang D T, Yang Y, Yang C, *et al*. (2011). Detection of seagrass in optical shallow water with Quickbird in the Xincun Bay, Hainan province, China. *IET Image Processing*, 5(5): 363–368. https://dx.doi.org/10.1049/iet-ipr.2009.0392

Yang D T and Huang D J. (2011). Impacts of typhoon tianying and dawei on seagrass distribution in Xincun Bay, China. *Acta Oceania Sinica*. 2011, 30(1): 32–39. https://dx.doi.org/10.1007/s13131-011-0088-5

Yang D T. (2017). Seagrass distribution, ecological structure and carbon sink flux in China. Science Press, Beijing.

Yang Z D. The geographical distribution of seagrass. *Limnology and Oceanography Bulletin*, 1979, 2: 41–46.

Zhang X M. (2013). A study on the fundamental biology and ecological restoration of *Zostera japonica* along the coastlines of Shandong province, China. Master Dissertation of University of Chinese Academy of Sciences, Qingdao.

Zhang X M, Zhou Y, Liu P, *et al*. (2015). Temporal pattern in biometrics and nutrient stoichiometry of the inter tidal seagrass *Zostera japonica* and its adaptation to air exposure in the temperate marine lagoon (China): Implication for restoration and management. *Marine Pollution Bulletin*, 94: 103–113. https://dx.doi.org/10.1016/j.marpolbul.2015.03.004

Zhang M M, Wang Q, Li X G, *et al*. (2010). Research on land cover changes and driving forces alongshore the Rongcheng Bay based on 3S. *Oeanologia et Limnologia Sinica*, 42(1): 20–26

Zhang$_b$ M M, Wang Q and Liu Y L. (2010). Research on landscape pattern changes in the recent 40 years of Yuehu Lake in Shandong peninsula. *Marine Geology & Quaternary Geology*, 30(3): 47–51.

Zhao N, Yang Y, Gao J H, *et al*. (2014). The influences of natural and human sctivites on sources and evolution of organic matter in the Yeehu Lagoon sediments. *Geochimica*, 43(4): 365–374.

Zheng F Y, Qiu G L, Fan H Q, *et al.* (2013). Diversity, distribution and conservation of Chinese seagrass species. *Biodiversity Science*, 21(5): 517–526. https://dx.doi.org/10.3724/SP.J.1003.2013.10038

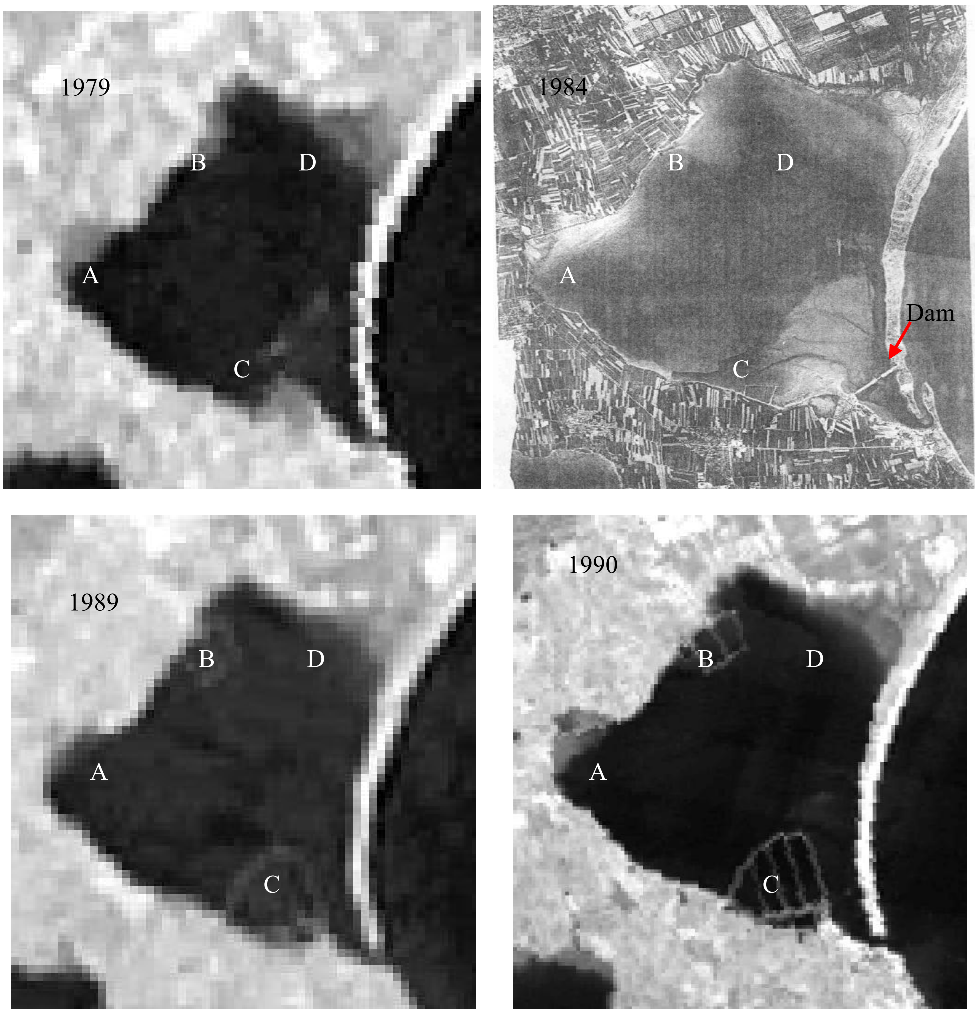
Zhou Y, Liu X J, Liu B J, *et al*. (2014). Unusual patterns in characteristics of the eelgrass *Zostera marina* L. in a shallow lagoon (Swan Lake), north China: Implications on the importance of seagrass conservation. *Aquatic Botany*, 120: 178–184. https://dx.doi.org/10.1016/j.aquabot.2014.05.014

Appendix

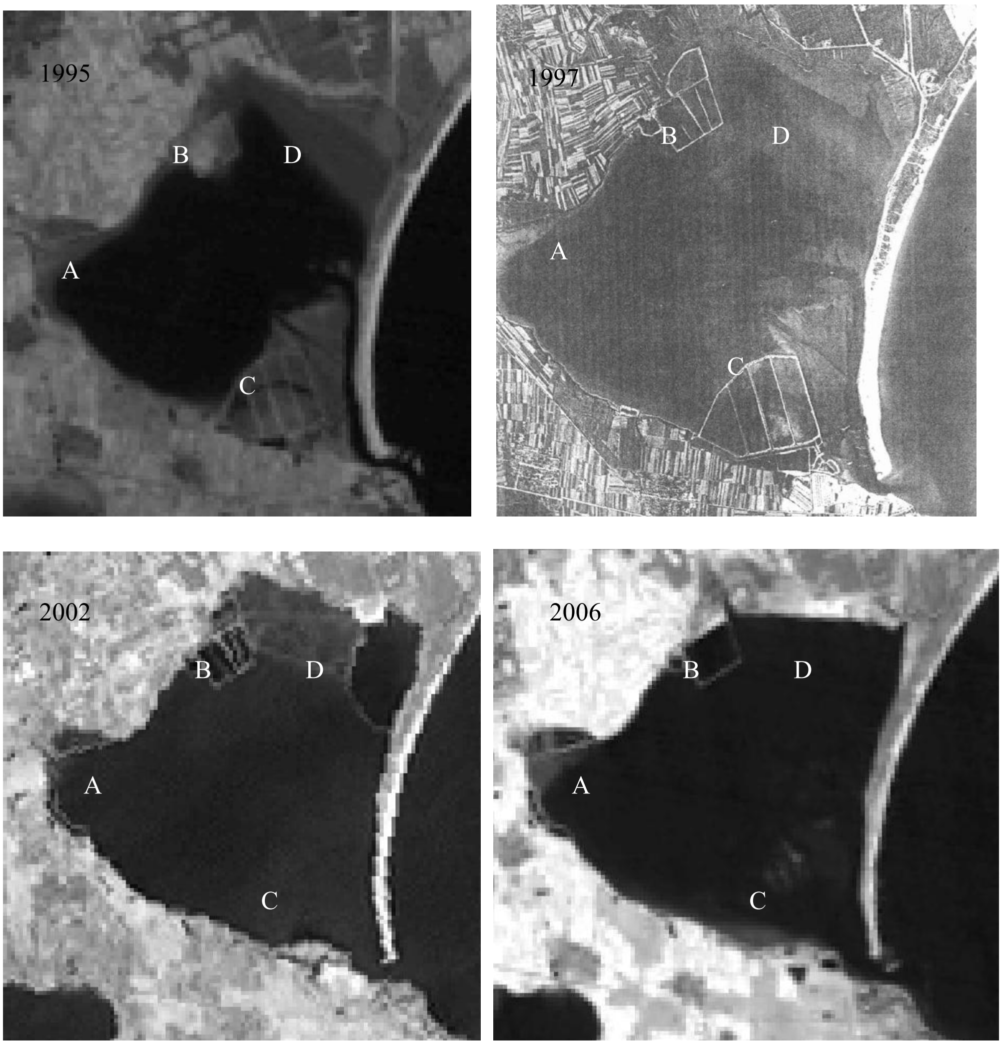
Appendix 1. Details of satellite and airborne remote sensing data used in the paper

Date	Image type	Season	Band coverage	Cloud coverage above the Swan Lake	Resolution (m)
1979-06-12	Landsat MSS	Summer	4	no	80
1984	Aerial photography	–	1	no	2
1989-05-01	Landsat MSS	Summer	4	no	30
1990-06-02	Landsat TM	Summer	7	no	30
1995-12-09	Landsat TM	Winter	7	no	30
1997	Aerial photography	–	1	no	2
2001-09-21	Landsat TM	Autumn	7	no	30
2002-06-11	Landsat ETM+	Summer	7	no	30
2004-08-12	Landsat ETM+	Autumn	7	no	30
2005-03-23	Landsat ETM+	Autumn	7	no	30
2005-10-17	Landsat ETM+	Autumn	7	no	30
2006-03-21	Landsat ETM+	Autumn	7	no	30
2006-08-17	Landsat ETM+	Autumn	7	no	30
2007-01-24	Landsat ETM+	Autumn	7	no	30
2008-08-07	Landsat ETM+	Autumn	7	no	30

Appendix 2. The Swan Lake contour variations from 1979 to 2009, showing dam construction and enclosed as fish pond near the inlet and in the west, north coastal area of the lake.



Appendix 2. Continued.



Appendix 3. Building Indexes (red in the figure) from 1979 to 2009 showing that building area increased significantly in 2009 in comparison with that of 1979