Reed land change and its relationship to water level change in Baiyangang Lake

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By

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Dedicated
To my grandparents,
To my parents,
&
To my wife
Abstract

Wetlands are among the world's most productive environments. Meanwhile, they are also among the most threatened ecosystems in the world. Reed land is among the wetland types that recently received quite some attention. Reed land is the main land cover type in Baiyang Lake which situated in North China. Reed land here provides great commercial and biodiversity values. But recently area of reed land changed greatly and reed production decreased sharply. Reed land change is attributed to the change of environmental factors. In this paper, the relationship between reed land change and water level dynamics was analyzed, which can contribute to a monitoring programme for sustainable use of reed lands.

In this study, using supervised classification, land cover maps in 1987, 1991, 1996, 2000 and 2003 were produced based on the Landsat TM (ETM+) images in these years. These maps showed that the study area had the smallest reed land in 1991, and largest reed land in 2000. Also they indicated that most of reed lands distributed in areas close to lakes and rivers. Post-classification revealed that more and more reed land were converted to agricultural crops in the northwest area (Zone 1) and southwest area (Zone 3), and reed land expanded to rivers and lakes in north, middle, south and east areas (Zone 2). The relationships between area of reed land change and trend of water level fluctuation were then analyzed. In Zone 1 and Zone 3, there were no clear relationships. But an obvious negative relationship was shown in Zone 2. Besides, using the historical statistical data, the relationship between reed production and water level indicated that extremely high and low water level might reduce reed production, and a medium water level may cause a relatively high reed production.

In a spatial content, it shows that reed stems in Zone 2 were significantly denser, higher and thicker than those in Zone 1. The differences might be caused by the different elevation from surface of reed land to water table. The further analysis in Zone 2 revealed the relationships between stem properties and water depth. Within the range of water depth that root can reach, stem density showed a significantly positive relationship to water depth, but stem height and diameter showed a significantly negative one. Considering reed quality and reed production, a relative high water depth is required.

With these relationships above, a medium water level is required for reed harvest. Due to limitation of the data, a precise water level was not identified. But for the sustainable reed use in Baiyang Lake, an optimal level is needed, which should consider other values of reed land such as biodiversity conservation and tourism. Also steady water input from reservoirs upstream and reasonable management is necessary to keep such a water level.
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Abbreviations and Acronyms

Zone 1 – Northwest area of Baiyang Lake
Zone 2 – North, middle, south and east areas of Baiyang Lake
Zone 3 – Southwest area of Baiyang Lake
CAS – Chinese Academy of Sciences
ETM+ – Enhanced Thermal Mapper Plus
GPS – Global positioning system
GTP – Geospatial Technology Program
TM – Thematic Mapper
USGS – U.S. Geological Survey
1. Introduction

1.1. Background

"Wetlands" is the collective term for marshes, swamps, bogs, and similar areas (Mitsch and Gosselink 2000). Wetlands can be broadly divided into two categories: coastal wetlands and inland wetlands (Cowardin 1979). Recently the functions and the values of wetlands are widely valued by society and humans. Wetlands help regulate water levels within watersheds; improve water quality; reduce flood and storm damages; provide important fish and wildlife habitat; and support hunting, fishing, and other recreational activities (Brinson, Kruczynski et al. 1994; Mitsch and Gosselink 2000; Schweiger, Leibowitz et al. 2002; Leibowitz 2003). Wetlands are among the world's most productive environments.

Wetlands are also among the most threatened ecosystems in the world (Bank 1991). With the rapid growth of population in many countries, together with increase of human activities from agriculture, commercial and residential development and road construction, etc., wetlands loss and degradation have extensively occurred (Davis and Froend 1999; Edyvane 1999; Finlayson and Rea 1999; Nedeau, Merritt et al. 2003). Many of the original wetlands are drained and converted to farmland, and many wetlands are losing their original function and services because of that. How to manage wetlands has become a big issue in front of us.

Land of common reed (Phragmites australis, hereafter referred to as reed) is among the wetland types that recently received quite some attention (Hawke and Jose 1996; Cizkova, Brix et al. 1999; Clevering, Brix et al. 2001; Bodensteiner and Gabriel 2003). It is found mostly in river floodplains and low-lying coastal plains. It also occurs in artificial clay pits, natural lake margins and estuaries. The values of reed land are increasingly recognized. They are mostly used for both biodiversity conservation and commercial purpose (Cowie, Sutherland et al. 1992; Ditlhogo, James et al. 1992). Reed land provides habitat for wildlife and many animals and plants rely on reed for some or all of their life cycle (Hawke and Jose 1996). Reed land also provides materials for mat making, papermaking, roofing construction and fence building (McKean 2001; Poulin and Lefebvre 2002). Besides, reed land has recently been recognized as natural "filters" for the effective removal of organic matter and ammonia-nitrogen from industrial and agricultural drainage (Sun, Gray et al. 1999).

Management of reed land is necessary for keeping the values and functions of reed land (Poulin and Lefebvre 2002). “Reed swamp” may represent the early stages of succession from open water to woodland. In some places, without management reed land will gradually dry out, becoming colonized by other grasses and tall herbs. In these cases Reed land management and rehabilitation will slow down the colonization or even reverse (Hawke and Jose 1996).
1.2. Characteristics of Common Reed

Common reed, *Phragmites australis*, is a perennial grass. Its culms erect, 2–4 m tall, occasionally up to 6 m. Its leaf-blades are broad, flat, 15–60 cm long, 1–6 cm broad, glabrous (Duke. 2004). Its distribution is widespread throughout Europe, Africa, Australia, Asia and North America between 10’ and 70’ latitude (Hawke and Jose 1996).

1.2.1. Biological characteristics of common reed and environmental factors

The natural cycle of common reed starts from seeds. Seed production is very variable and tends to be less on degraded sites where the reed is poor quality. Some seed-heads may contain no seeds at all or a proportion may be infertile. Once a plant has established from seed, it may spread by vegetative propagation from a rhizomatous root. The rhizome grows both horizontally and vertically through soil and sometimes across the soil surface. The rate of growth of a horizome can vary greatly from place to place. In Europe, new shoots mainly emerge from the rhizome in April, growing vertically to produce stems, leaves and flowers, that are mature in August-October. In winter, the aerial parts die and harden to form a rigid cane. The dead stems may persist for two or three seasons whereafter they break off close to the ground to form a litter layer, which takes several years to decompose (Haslam 1972; Hawke and Jose 1996).

Environmental factors such as temperature, water depth and flood fluctuation, soil condition, and salinity, control the distribution and performance of reed (Bodensteiner and Gabriel 2003). Reed is reported to tolerate annual temperature of 6.6 to 26.6°C (Duke. 2004). The tolerance ability to water level differs in different life stages. Seed germination usually requires shallow water (<5cm) or mudflat (Haslam 1971). Reed can survive droughts until the soil dries out, and it can also tolerate a water depth of 200 cm below soil surface (Rodwell 1995; Vretare, Weisner et al. 2001). Reed can tolerate considerable flooding, and it does best where water level fluctuates from 15 cm below the soil surface to 15 cm above (Duke. 2004). It grows best in firm mineral clays. Common reed is especially common in alkaline and brackish (slightly saline) environments, and it can tolerate pH of 3.6 to 8.6. Apart from these, other factors including humans activities, grazing, sedimentation and decreased water quality (eutrophication) can effect the distribution and growth of reed (Ostendorp 1989).

Researches on biomass mostly focused on the aboveground proportion. The dense clone growth of reed and its relative large height make reed relatively highly productive. Live aboveground biomass of reed may range from 980 to 2642 g dw per m² in freshwater tidal marshes, and from 727 to 3663 g dw per m² in brackish marsh, which is higher than other plant species in the reported paper (Meyerson, Saltonstall et al. 2000).

1.2.2. Main use of reed

Before maturity common reed provides high quality warm-season forage and is readily eaten by cattle and horses. Young shoots are sometimes used as a vegetable to people. After maturity it becomes tough and unpalatable. It is extensively used in Mediterranean region and elsewhere for building dwellings, lattices, fences, arrows by Indians, and for weaving mats and carrying nets. It is also harvested in large quantities as raw material for the paper and chemical industries (Hawke and Jose 1996; Duke. 2004).
1.2.3. Species diversity in reed communities

Many animals and plants rely on reed for some or all their life cycle (Hawke and Jose 1996). About 50 species of North American birds have been reported to breed in reed communities (Meyerson, Saltonstall et al. 2000). At least 700 species of invertebrates have been found to be associated with reedbed in England. While invertebrates, especially insects, can be an important food source for birds (Hawke and Jose 1996).

1.2.4. Reed land in China

Common reed appeared in China about 3,000 years ago (Jiarong 2002). It distributed all over the country, mainly in the low-lying areas of the rivers, lakes and costal areas (Wu 1980).

As in Europe, common reed starts to shoot up from April, growing very fast from May to June. Around the middle of July, it reaches 70-80% of its final height. After that, growth slows down until the reed reaches its final height early September. From early November, when almost all the leaves of reed died, people start to harvest the reed (Jiarong 2002).

In China, common reed is widely used in different ways. It is not only one of the main materials for paper making and for construction works and weaving, but also a kind of food source for animals, and it is used as a medical plant (Jiarong 2002). Besides, as the main species in the wetland, it serves as water purifier in the lakes and rivers and habitat for the other species in the reed communities (Wang Weidong, Wang Dali et al. 2001).

1.3. Problem statement

Baiyang Lake, the largest freshwater lake in North China, is known as “Pearl of North China” and “kidney of North China” for its abundant products and conservation values. Common reed, lotus (Nelumbo nucifera), Gordon euryale (Euryale ferox SaliSb.) and water caltrop (Trapa taiwanensis L.) are the main products. Baiyang Lake is also known for its biodiversity richness, including 36 bird species of which 2 species are listed as class one and 6 are class two in the list of wildlife under special state protection. Also includes 14 mammal species (5 are in the list of wild life under special state protection), 18 fish species, 48 vascular species and 408 algae species. Baiyang Lake became a provincial nature reserve in 2002 (Yumei 1994; Tian Yumei 1995; Junjie 2000; Wang Wenhua 2002).

Common reed is the key-species in the lake, including two ecotypes with the names of hengcao and planted reed. Hengcao is characterized by yellow stems and big flowers and is distributed in the whole area, but largely in middle and east parts of Zone 2 (north, middle, south and east areas of Baiyang Lake, shown in figure 2). It is used for both weaving and construction materials. Planted reed is characterized by relative white stems and small flowers and is distributed almost in the Zone 1 (northwest area of Baiyang Lake, shown in figure 2) and Zone 3 (southwest area of Baiyang Lake, shown in figure 2), where elevation is relatively high. It is the ideal material for weaving especially for mats making. But there is no clear boundary between the two ecotypes. Reed land is the main land cover here. Landscape characteristics of reed land differ in different areas. In Zone 1 and Zone 3, reed lands are in relative large patches. But in Zone 2, reed lands are in relative small patches and regular shapes. Reed lands in Zone 2 are isolated by the lakes and rivers connected with each others (Yin Chengqing 1999).
Reed is also the main economic crop in local area. Most of reed is harvested annually as the materials for mats knitting and construction materials. The production of reed was once about 40% of the total production of the whole country (Liu Chunhua 1991). Mats knitting is the main income source for local people, and production of reed mats was once a quarter of the total production in the whole country (Li Aiguo 1996). Reed land is also the main habitat for birds such as red-crown crane (Junjie 2000).

Area of reed land was about 36% of the whole lake area but declined very fast since 1960s. In Zone 1 and Zone 3, reed lands are almost replaced by agricultural crops. The reed production also decreased from 80 million kg in the 1960s to 45 million kg in 1996 (Junjie 2000). Research on reed land change trend will be of significance for the sustainable use, which should be related to local environmental conditions. Many studies reported that the distribution and composition of reed communities were closely determined by aquatic environment condition (Haslam 1970; Meyerson, Saltonstall et al. 2000). Reed communities would therefore be expected to respond to the changes in hydrological conditions such as water depth or the duration of flooding (Baldina, De Leeuw et al. 1999). Bodensteiner and Gabriel (Bodensteiner and Gabriel 2003) reported that water level increase somehow explained the decline of reed stands. However, few detailed descriptions have been made of the response of reed land to the water level decline, which is the case in Baiyang Lake (Junjie 2000).

1.4. Research objectives

The main objective of this study is to describe the current state of the reed stands in Baiyang Lake and establish the relation with water level dynamics. This study can contribute to a monitoring programme for sustainable use of reed lands.

1.5. Research questions

The study aims to answer the following research questions:

(2) How did the reed area and distribution of reed change over the period from 1987 to 2003?
(3) Is there a relation between reed areas and water levels in previous years?
(4) Is there a relationship between reed production and water level in previous years?
(5) Are there any differences between physical properties of reed (stem density, stem height, and stem diameter) in Zone 1 and Zone 2?
(6) Are there any relationships between physical properties of reed (stem density, stem height, and stem diameter) and different water depths?
(7) Are there any relations between physical properties of reed (stem density, stem height, and stem diameter) and spectral characteristics of the TM image 2003?
(8) How can this study contribute to sustainable management of Baiyang Lake?
1.6. **Hypotheses**

The following null hypotheses were tested:

1. There are differences between physical properties of reed (stem density, stem height and reed diameter) between Zone 1 and Zone 2.

2. There are relationships between physical properties of reed (stem density, stem height and reed diameter) and water depth of reed lands in Zone 2.

3. There are relationships between physical properties of reed (stem density, stem height and reed diameter) and spectral characteristics of TM image 2003.
2. Materials and methods

2.1. Study area

The study area of this research is Baiyang Lake (figure 1), the largest freshwater lake in North China. It lies between 115˚45'E-116˚07'E and 38˚44'N- 38˚59'N in Anxin county, Hebei Province. It is a lake group of about 140 lakes and 3700 ditches with a total area of approximately 366 Km². Most of the area has an altitude between 5.5m and 6.5 m (Junjie 2000).

Figure 1 Map of study area

2.1.1. Formation of Baiyang Lake

In the history, the differential accumulations of various rivers formed Baiyang Lake, lakes between alluvia fans and rivers. In Beisong Dynasty (from about the year 906 to 1127), because of human activities, the lakes were connected with each others by establishing rivers and ditches between them (Wu Chen 1998). The figure of Baiyang Lake was formed at that time.

2.1.2. Climate

Baiyang Lake has a temperate continental climate. The mean annual temperature is 12.2 °C. It becomes warm in July and cold in January with the monthly mean temperature of 26.4 °C and -4.5 °C separately. The annual mean precipitation is 529.7mm, 73% of which is in summer and only 2% of which is in winter (Junjie 2000). And the annual mean evaporation is about 1002.0 mm (Tian Yumei 1995).

2.1.3. Topography

Baiyang Lake is a relatively flat area, higher in the west and lower in the east. In Zone 1 and Zone 3, it’s a very flat platform. While in Zone 2, it is a complicated area with lakes, ditches and some land interlaced. Sub sandy soil is the dominant soil in Baiyang Lake (Junjie 2000).
2.1.4. Hydrology

Water level is the critical factor for the whole ecosystem in Baiyang Lake. When water level is below 6.50 m and 5.50 m, Baiyang Lake is regarded as partly and total drying up separately (Junjie 2000). When water level reaches to 10.5 m, the whole area is flooded (Lanting 1987).

But water level decreased after the establishment of reservoirs. Start from 1958, 134 reservoirs were established in the upstream with the total capacity of 3.62 billion $\text{m}^3$. Water from the rainfall and runoff in the upstream was reserved in the reservoirs, and water will be released only when necessary. Besides, the reservoirs mainly provide water to the irrigation of agricultural crops and industry. In such a condition, water input to Baiyang Lake decreased from 2.2 billion $\text{m}^3$ in 1955 to 0.57 billion $\text{m}^3$ in 1976, although the annual rainfalls in the two years were close (He Naihua 1992).

Besides, Baiyang Lake is under organic pollution since 1960s’ (Cui Xiuli 1999). The pollution was mainly from a lack of wastewater treatment in Baoding City and the villages in Baiyang Lake. Pollution differed in different areas. Water was seriously polluted in northwest area, slightly polluted in north area, but clean in east area. The pollution got serious with the decrease of water level. Recently, wastewater from Baoding was treated before flowing into Baiyang Lake. But the wastewater from the villages was not treated.

2.1.5. Species diversity

There was a wide diversity of flora and fauna in Baiyang Lake before 1950s (Lanting 1987). Since then, flora and fauna changed because of the draught and pollution in several years. Aquatic vascular increased from 30 species in 1958 to 46 species in 1980. While fish species decreased greatly from 54 species in 1958 to 18 species in 1989. Bird species also decreased, especially the important and rare species were close the edge of extinction (Junjie 2000).

2.1.6. Land cover

The study area encompasses a variety in land cover. Land cover features such as bare land, dry grass land, agricultural crops, reed land, wood land, floating vegetation, open water, and build up area are common in this area. Wheat, corn and cotton are among the main crops species in Baiyang Lake.

2.1.7. Effect of human activities in the reed and reed land

Book of Baiyang Lake (Li Aiguo 1996) described the human activities in reed land. At about Bei Song Dynast (from about the year 906 to 1127) reed appeared in Baiyang Lake. Since then, reed was mainly used to make mats by the local people. Because Baiyang Lake was flooded very often in the history, reed was the main crop and making mats was the main economic source for the local people. Till now, reed in Baiyang Lake is still mainly used for mats. It is also used to construction materials nowadays.

Due to the long history of making mats, relative high and thick reed was selected from generation to generation. Most of the reed here has a height of about 3 m, which is the minimum requirement for mats making. But the height of above 3.5 m is needed for the mats with good quality.

Besides, for a good quality and quantity of reed harvest, fertile soil in the bottom of lakes was put on the surface of reed lands. Thus, many reed lands (mainly in west and middle parts of Zone 2, where
most of villages located) were heightened to the elevation of about 8 m. For the convenience of
management and harvest, many reed lands (mainly in Zone 2) were also shaped in small patches.

2.2. Materials

A number of thematic maps, aerial photographs, satellite images, hydrologic data and various
softwares and field tools were used in this study.

A 1:40,000 administrative map of Anxin County was obtained from Anxin County government, which
indicates the boundary of Baiyang Lake.

A series of aerial photographs was selected from the Aerial and remote center, Geologic Survey
Sector. The aerial photographs area true color and were taken in June 1990 on a scale of 1:25,000.
They covered about 80% of the study area and were used for the image classification of 1991.

Direct information of land cover was obtained from satellite images, which is shown in table 1. The
Landsat images of 1987, 1996 and 2003 were from China remote sensing satellite ground station,
CAS, the one of 2000 from Aerial and Remote Center, Geologic Survey Sector, and the one of 1991
from USGS.

Table 1 Data sources

<table>
<thead>
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<th>Type of data</th>
<th>Scale</th>
<th>Date</th>
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</tr>
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</tbody>
</table>

Monthly water level data and rainfall data from 1960 to 2003 in the study area were used as ancillary
data. The former was obtained from hydrologic bureau of Anxin County, and the latter was from
Weather Bureau, Hebei Province. Reed production data was from Book of Anxin County (Gao Junjie,
2000).

Hardware and software used in this research include Computer, Internet, ILWIS, ERDAS 8.6,
ARCGIS 8.1, ARCVIEW 3.2, SPSS statistical package, Excel XP, Word XP. Other field equipment
and tools that were used for fieldwork included Garmin 12XL global positioning system (GPS)
receiver, Metric ruler, vernier caliper and camera.
2.3. Over view of research methods

The methods adopted can be divided into 3 stages. In the pre-field stage, sampling design, data collection and logistics were prepared. In the field stage all data were collected. In the post-field stage, all the data from the field were ordered and analyzed and reported in this thesis.

The methods used in each stage are described in detail below.

2.4. Pre-field stage research methods

2.4.1. Literature review

Prior to proceeding with the analysis, literature review was carried out to find the biologic characteristics of common reed and environmental factors that influence the common reed. Based on this, parameters were chosen and sampling was designed.

2.4.2. Image processing and preliminary classification

Because the TM image 2003 was not available before fieldwork, the Aster image 2002 was used for fieldwork preparation. The aster image, geo-referenced to UTM/WGS 84 coordinate system, was preliminary classified into 30 classes using unsupervised classification.

2.5. Field work

In order to study the current land cover situation and physical properties of reed in Baiyang Lake, a field survey was carried out in September and November 2003. Also second data were collected during this time.

2.5.1. The land cover survey

To get the ground truth for image classification and accuracy assessment, 216 sample points were surveyed in the field using a stratified sampling method (Scheaffer, Mendenhall et al. 1996). These sampling points covered all the land cover classes of the classified Aster image. Considering the accessibility, these points were not randomly distributed but practically and representatively selected and covered the whole study area (shown in figure 2). In each point, the land cover types and coverage of each layer were recorded in the data collection sheet designed in advance (Appendix 1).

2.5.2. Survey on physical properties of reed

A survey on physical properties of common reed was carried out to compare the situation of common reed in different areas. Since the physical property of reed is analyzed related to water levels, these sample points should be located in the reed land with different height above the water table. In view of that, samples were distributed along the Daqing River, the main river of Baiyang Lake. Because along the river, the elevation decreases gradually from west to east. In the transversal direction, the height above the water table to the northern and southern parts is more or less the same. Hengcao and planted reed were also considered during the survey since they are the two ecotypes of common reed in Baiyang Lake. The whole sample set was divided into two parts. The first part of the samples (part A shown in figure 2) included four transects to the Daqing River, two in Zone 1 (one for hengcao and one for planted reed), one in the west of Zone 2 (combining hengcao and planted reed), and one in the
east of Zone 2 (hengcao). In the second part (part B shown in figure 2) close to the Daqing River, samples were taken about every 200 meters including both hengcao and planted reed.

![Figure 2 Distribution of sampling points in Baiyang Lake](image)

In each sample point, stem density, stem height and stem diameter of reed were measured within a frame of 1*1m². Specific methods were shown in table 2 and appendix 2. Stem density, counting the stem number within one square meter, was straightforward. Measurement on stem height and stem diameter was relatively time consuming. Because measuring all stems in each square would take too much time, a ranked set sampling method was used (Patil 2002). First 3 stems were randomly selected, from which the largest one was measured for height. Then randomly another 3 stems were selected, of which the medium one was measured. Finally another 3 stems were randomly selected of which the smallest one was measured. The same method was applied in measuring stem diameters.

**Table 2 Variables measured in the field survey**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Method/Tools</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location of sample spot</td>
<td>GPS receiver</td>
</tr>
<tr>
<td>Water depth (m)</td>
<td>Measure depth from surface of reed land to water surface with ranging pole</td>
</tr>
<tr>
<td>Density of reed stem</td>
<td>Count the number of reed stem within 1 m²</td>
</tr>
<tr>
<td>Height of reed stem</td>
<td>Measure height using a ranging pole</td>
</tr>
<tr>
<td>Stem diameter of reed stem (mm)</td>
<td>Measure diameter of reed stems using vernier calipers. Measurements were</td>
</tr>
<tr>
<td></td>
<td>taken at the height of 0.40m from stem bottom.</td>
</tr>
<tr>
<td>Plant species richness</td>
<td>Count the number of plant species and write down names of each different</td>
</tr>
<tr>
<td></td>
<td>plant species within 9 m²</td>
</tr>
</tbody>
</table>
Water depth was also measured in each point. In the area close to river, the distance from soil surface to river surface was measured as water depth. In the area far from river, the depth was measured after punching with a metal stick. In Zone 1, since water table was very deep and the area was very flat, the water depth here was measured from the irrigation well nearby. The water depth was used for the whole Zone 1.

2.5.3. The ground control points survey

Ground control points were measured using a GPS receiver in several clearly recognizable locations in the images such as road crossings, central points of bridges and other obvious points. These ground control points covered the whole study area.

2.6. Post-field stage research methods

Figure 3 shows the research approach in this stage.

2.6.1. Field data processing and analysis

After the fieldwork, the field data were ordered and put into computer. The ground control points were prepared for geo-reference. All the images were converted to the readable format by ERDAS and ILWIS.

2.6.2. Image classification

Prior to image classification, a boundary map, geo-reference and ground truth points were prepared. The administrative map was scanned and digitized in Arcview 3.2, from which the boundary map of Baiyang Lake was produced. In ERDAS 8.6, the Landsat image of 2003 was geo-referenced to UTM/WGS 84 coordinate system using the 12 ground control points from the field. Using the geo-referenced TM image as the master image, other Landsat images were geo-referenced. For the ground truth points from filed, half of them were used for image classification and the other half were used for accuracy assessment. The aerial photographs of 1990 were scanned, and used for image classification and accuracy assessment of 1991.

The Build-up areas were digitized before classification. Since those areas were relatively fixed, the build-up area that was digitized from Landsat image 2003 was used to map the build-up area in the other years.

Landsat image of October 2003

Using supervised classification, the Landsat TM image of October 2003 was classified into 6 classes of 7 classes shown in table 3. Floating vegetation was not included because the leaves and stems of floating vegetation were almost withered, and it was difficult to distinguish floating vegetation from open water. Agricultural crops such as cotton, wheat and vegetable were listed separately based on the record from the field because there were great differences of reflection between them in October in Baiyang Lake. After classification, all the agricultural crops were merged into one class. Based on the ground truth points from the field, a signature was created. Figure 4 (A) and (B) shows the means values of these signatures in a feature space plot of Band 3 and Band 4, and Band 4 and Band 5 separately.
REED LAND CHANGE AND ITS RELATIONSHIP TO WATER LEVEL CHANGE IN BAIYANG LAKE

Historical Water level data

Images interpretation and classification


Post-classification comparison

Trends analysis between reed production and water level

Field data, and other maps


Regression analyze between physical properties of reed and water depth

Regression analyze between physical properties of reed and spectral characteristics of image 2003

Relationship between reed production and water level

Historical reed production

Trends analysis between reed production and water level

Change maps of reed lands between different years

Relationships between reed production and water depth

Relationships between reed properties and spectral characteristics of image 2003

Relationship between area of reed land and water level

Relationship between reed properties and spectral characteristics of image 2003

Integrated analysis

The relationships between reed land and water level (depth), with the aim to contribute sustainable management

Figure 3 Research approach in the post field stage
Table 3 Land cover classes in Baiyang Lake

<table>
<thead>
<tr>
<th>Classes</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Bare land</td>
<td>Bare land is composed of bare rock, sand, silt, gravel or other earthen material with little or no vegetation regardless of its inherent ability to support life.</td>
</tr>
<tr>
<td>2. Agricultural crops</td>
<td>Land used primarily for production of food and fibre (Corn, cotton, wheat, vegetables, yellow bean, grain sorghum, rice)</td>
</tr>
<tr>
<td>3. Dry grassland</td>
<td>The Grassland category includes land s covered by natural and managed herbaceous cover.</td>
</tr>
<tr>
<td>4. Reed land</td>
<td>Reed</td>
</tr>
<tr>
<td>5. Open water</td>
<td>All areas of open water with &lt;30% cover of shrubs, persistent emergent plants, emergent mosses, lichens, or other land cover are grouped under the heading</td>
</tr>
<tr>
<td>6. Woodland</td>
<td>The Woodland class includes any species with an aerial stem that persists for more than one season (White poplar; elm)</td>
</tr>
<tr>
<td>7. Floating vegetation</td>
<td>All the aquatic vegetation except common reed (Lotus, Typha, water chestnut)</td>
</tr>
</tbody>
</table>

Figure 4 Feature space plots and the mean values of signature sets used for supervised classification of the landsat TM image of October 2003, Baiyang Lake

These figures indicate that bare land and open water can be easily distinguished from other land cover types because of the high reflection (for bare land) and low reflection (for open water) in the Band 5 (Mid-Infrared Band). Wood can also be easily distinguished from other land cover types because of the relative low reflection in Band 5 (it is only higher than open water). Because most of the trees in Baiyang Lake area are deciduous trees, and there are few leaves on the tree left in October, it shows that trees have a relative low reflection. Cotton, wheat and vegetables are the main agricultural crops during late of October. Vegetables are clearly distinguished from other vegetation. Vegetable normally has a short living period and can be harvested for several times each year. In October it is still in its peak living stage, which results in the relatively high reflection in Band 4 (Near-Infrared Band). Wheat has a characteristic to differ from other vegetation. Wheat is planted during the early of October after corn is harvested, thus it is still in its seedling stage and most of the wheat land is bare soil. Therefore wheat has a high reflection in the Band 3 (Red band) and low reflection in the Band 4. The signature set of reed land shows some overlap with that of cotton. This may be because both reed and cotton were in the end of their live periods and not vigorous. Besides, the signature set of reed land is also close to that of dry grassland. This situation caused some problems in classifying those land cover types using only spectral characteristics. Therefore, after classification those areas were digitized based on field observations improving the final classification.

Based on the signatures described above, supervised classification was carried out using the Maximum Likelihood decision rule. After that, some alternation was carried out in reed land, dry grassland and cotton land by means of visual interpretation. The alternation was effective in improving the final classification because in Baiyang Lake, cotton land had a very rectangular pattern while reed land did not, reed was distributed in relative large area (Yin Chengqing 1999), and dry grass was scattered. The produced classification was merged into 6 classes including bare land, agricultural crops, dry grassland, reed land, open water and woodland.

User-producer matrix and Kappa statistics were applied for accuracy assessment in this study. User-producer matrix was done in EXCEL by comparing the final classification data and reference data, which was from ground truth. In the matrix, columns represent the reference data and rows represent the classified data (Congalton and Green 1999). Kappa statistics, a measure of actual agreement between image data and the reference data, was carried out with the equation below (Hudson 1997):

$$\hat{k} = \frac{N \sum_{i=1}^{r} X_{ii} - \sum_{i=1}^{r} X_{i+}X_{+i}}{N^2 - \sum_{i=1}^{r} X_{i+}X_{+i}}$$

Note that $r$ is the number of rows in the matrix; $x_{ii}$ is the number of observation in row $i$ and column $i$; $x_{i+}$ and $x_{+i}$ are the marginal total row $i$ and column $i$ respectively; $N$ is the total number of observation.

**Landsat image of June 1991**

Using supervised classification, the Landsat TM image of June 1991 was classified into 7 classes shown in table 3. Based on the aerial photographs, signature of the following land cover types was created. Figure 5 (A) and (B) depict the means values of these signature sets in feature space plots of Band 3 and Band 4, and Band 4 and Band 5.
Figure 5 Feature space plots and the mean values of signature sets used for supervised classification of the Landsat TM image of June 1991, Baiyang Lake

A: plot of Band 3 and Band 4; B: plot of Band 4 and Band 5.


As shown in the figures, bare land and open water can be clearly distinguished from other land cover types from Band 5. Reed land can be also very easily differed from others in that reed has the highest biomass in June and thus has a highest reflection in Band 4. Wood also has a high biomass and can be distinguished from others in Band 4. Compared to grasses and agricultural crops, floating vegetation, mainly lotus, has the lowest reflection in Band 3 and is different. Agricultural crops can be distinguished from dry grasses in that the former has the much lower reflection in Band 4.

Based on the signatures described above, supervised classification was carried out using the Maximum Likelihood decision rule. Using the same methods as the image 2003 accuracy was assessed by comparing the reference data from aerial photographs. Land cover map of 1991 was produced in the end.

Landsat image of September 1987, July 1996 and May 2000

There were no ground truth and aerial photographs for the images classification of 1987, 1996 and 2000. However, the same signatures to 1991 were created based on the following reasons.

To some extend and in some area, the locations of land cover types are fixed. Some reed lands in western part of Zone 2 have an elvation of about 8 meters. These reed lands are relatively fixed in September 1987, July 1996 May 2000 and October 2003, when water level is below 8 meters (Li Aiguo 1996). Some lakes in Baiyang Lake have the bottom altitude about 5 meters (Jiarong 2002).
Open water in those lakes does not dry up even the water level is below 5.5 m. In the high land close to dikes, agricultural crops are also fixed. Because of this, it is very useful to consider the land cover maps of close years (1991 or 2003 or both) during the classification.

**Land cover information of these years was collected in the fieldwork.** During the period of fieldwork, the land cover information of previous years was collected in many locations from the local people. The information is also helpful for the images classification.

**The spectral information of image 2003 and image 1991 was also used for other years.** For the image of 1987, the spectral information of image 2003 is very useful because both images are from the same season, and in both years water level is relatively low. The land cover types of these two years are more or less the same. For the images of 1996 and 2000, the spectral information of image 1991 was used.

Based on the signatures and analysis above, supervised classification was carried out using the Maximum Likelihood decision rule. In the end land cover maps were produced without accuracy assessment. Because there is no field data set or ground truth data set available to perform an accuracy assessment.

**2.6.3. Land cover change detection**

Post-classification comparison was used for land cover change detection. Images of two dates were classified independently, and the changed areas were extracted by comparing the classification result of two images. In this way the need to normalize atmospheric and sensor differences between 2 years was minimized. This method also provides detailed from–to change information (Arzandeh and Wang 2003).

After classification, all the land cover maps were converted to vector maps and the area of each class was calculated. Then the general change detection was done between 1987 and 2003 in Arcview 3.2. Since the images were from the same season, the changes between them reflected the real change of reed land from 1987 to 2003. In addition, changes between each two sequent years were detected to reflect the trend. Changes between 1991 and 1996, and 1996 and 2000, should be close to reality because these images were taken in the same season. While considering the changes between 1987 and 1991, 2000 and 2003, there might be some errors due to the season of differences. Since all the images were from the middle or end of the growing season of reed, changes between them reflected the trend of reed land change.

**2.6.4. Statistical analysis about water level and physical properties of reed**

All statistical analyses were carried out in EXCEL and SPSS softwares, and p<0.05 was used to determine significance of all tests. Prior to any statistical analysis, Kolmogorov-Smirnov normality test was performed to test the nature of the distribution of data. Mann-Whitney U-test was used in significant difference between variables. For all the relationship analysis, linear regression analysis was carried out using the Spearman’s correlation coefficient r. Specific statistical analyses were described below.

**Differences between reed properties in Zone 1 and Zone 2**

Since Zone 1 and Zone 2 have different water levels, it was tested if reed properties differed between those areas using Mann-Whitney U-test. Reed properties included reed density, reed height and reed
diameter. Hengcao and planted reed were the two ecotypes of common reed in Baiyang Lake, and were analyzed separately. Zone 3 was not tested because it had the same water level as Zone 1. Hypotheses for the analyses were listed below.

Ho: There are no differences between stem properties (stem density, stem height and stem diameter) of hengcao in Zone 1 and Zone 2;
Ha: There are some differences between stem properties (stem density, stem height and stem diameter) of hengcao in Zone 1 and Zone 2.

Ho: There are no differences between physical properties (stem density, stem height and stem diameter) of planted reed in Zone 1 and Zone 2;
Ha: There are some differences between physical properties (stem density, stem height and stem diameter) of planted reed in Zone 1 and Zone 2.

Relationships between water depth and reed properties
Since water level of reed land in Zone 1 changed from west to east, relationships between water depth and reed properties were analyzed here using linear regression analysis. Reed properties in Zone 1 were not included because water depth was below 5 m from the soil surface and roots of reed cannot reach water table. But in Zone 2, water depth ranged from -2.5 to -0.6 m, roots of reed can reach water table, which is shown in the field. The properties of hengcao and planted reed were analyzed separately. Hypotheses for the analyses were listed below.

Ho: There are no relationships between physical properties (stem density, stem height and stem diameter) of hengcao and water depths;
Ha: There are some relationships between physical properties (stem density, stem height and stem diameter) of hengcao and water depths.
Ho: There are no relationships between physical properties (stem density, stem height and stem diameter) of planted reed and water depths;
Ha: There are some relationships between physical properties (stem density, stem height and stem diameter) of planted reed and water depths.

2.6.5. Relationships between physical properties of reed and spectral characteristics of TM image 2003
To analyze the link between spectral characteristics of TM image 2003 and the physical properties of reed, samples that were not close to water were selected. Because the pixel resolution of Band 6 is 120*120 m² in TM images, the spectral information from the samples close to water may be the mixture of reed and water. Linear regression analysis was carried out using the Spearman’s correlation coefficient r. Hypotheses for the analyses were listed below.

Ho: There are no relationships between physical properties of reed (stem density, stem height and stem diameter) and DN values of Band n;
Ha: There are no relationships between physical properties of reed (stem density, stem height and stem diameter) and DN values of Band n;
Where: n stands for the any number from 1 to 7.
3. Results

3.1. Land cover maps and land cover change

After classification, land cover maps were produced and classification accuracy was assessed. Table 4 shows the classification accuracy of Image 2003 with a total accuracy of 88.0% and a Kappa coefficient of 0.84. Table 5 shows the classification accuracy of Image 1991 with a total accuracy of 91.5% and a Kappa coefficient of 0.87. These accuracies were high enough for use. Figure 6 shows five land cover maps of Baiyang Lake in 5 different years. Figure 7 shows land cover types and their area percentage in these 5 years. The area percentages, distributions of land cover types in different years are described in more detail below.

In 1987 reed lands dominated the area with the percentage of 43.1%. Agricultural crops, open water and dry grasses were the other main land covers with the percentage of 29.2%, 16.2% and 9.3% separately. Floating vegetation, wood and bare land only took 1.3% and 0.6% and 0.3% of the total area separately.

Reed land was mainly distributed in Zone 2 of Baiyang Lake in a very large area, there were also some patches of dry grasses land, agricultural crops, open water and bare land in between. In Zone 1, agricultural crops covered most of the area in the north and south. There were also large area of reed land in the west and open water in the east, and a mixture of reed land, open water, floating vegetation and dry grasses land in the middle. In the Zone 3, agricultural crops took almost all the south and middle part. There were some open water, reed land and floating vegetation in the northern part. In the northeast part there was a great area of agricultural crops with few dry grasses land and reed land in between.

Comparison of land cover area percentage between 1987 and 1991 (figure 7) reveals various area changes. After 1987, open water increased greatly to the percent of 42.1%, and floating vegetation increased to the percent of 6.4% as well. On the other hand reed land decreased to the percent of 37.8% and agricultural crops decreased to only 12.5%. There were few changes in bare land, dry grasses and woodland in area percentage.

Comparison of the land cover maps between 1987 and 1991 (figure 6) reveals various changes of distribution. Generally open water replaced most of the reed land, agricultural crops, dry grasses land and bare land in Zone 2 and 3. Most of reed land became island, surrounded by open water. Agricultural crops only existed in the area close to the boundary and villages. Floating vegetation appeared largely in the transition area between open water and reed land. In the Zone 1, reed land developed to north, south and east, replacing about half of the agricultural crops and open water in 1987. Some floating vegetation appeared in middle part.
Table 4 Error matrix of land cover derived from TM image October 2003

BL=Bare land, AC=Agricultural crops, DG=Dry grassland, RL=Reed land, OW=Open water, W=Woodland

<table>
<thead>
<tr>
<th>Classes</th>
<th>BL</th>
<th>AC</th>
<th>DG</th>
<th>R</th>
<th>OW</th>
<th>W</th>
<th>Total</th>
<th>User’s Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>BL</td>
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<td>0</td>
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<td>0</td>
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<tr>
<td>DG</td>
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<td>0</td>
<td>0</td>
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<td>6</td>
<td>1.000</td>
</tr>
<tr>
<td>RL</td>
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<td>1</td>
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<td>0</td>
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<td>31</td>
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Classified data

<table>
<thead>
<tr>
<th></th>
<th>Producer’s accuracy</th>
<th>Overall accuracy</th>
<th>Kappa coefficient</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>0.500</td>
<td>0.8796</td>
<td>0.8385</td>
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</table>

Table 5 Error matrix of land cover derived from TM image June 1991

BL=Bare land, AC=Agricultural crops, DG=Dry grassland, RL=Reed land, OW=Open water, FV=floating vegetation, W=Woodland

<table>
<thead>
<tr>
<th>Classes</th>
<th>BL</th>
<th>AC</th>
<th>DG</th>
<th>R</th>
<th>OW</th>
<th>W</th>
<th>FV</th>
<th>Total</th>
<th>User’s Accuracy</th>
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<tbody>
<tr>
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Classified data

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<th>Overall accuracy</th>
<th>Kappa coefficient</th>
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<tr>
<td></td>
<td>1.000</td>
<td>0.9148</td>
<td>0.8745</td>
</tr>
</tbody>
</table>
Figure 6 Land cover maps of Baiyang Lake in different years
Figure 7 Land cover types and their area percentages in different years

Compared to 1991, land cover of 1996 did not change greatly in area percentage (figure 7). Reed land increased to the percent of 40.9%, and agricultural crops increased to 16.2% as well. Open water decreased to 36.5%, and floating vegetation decreased to 4.6%. Other land covers had only a small change.

Compared to 1991, land cover of 1996 did not have great change in distribution (figure 6). Reed land extended a little bit to open water and floating vegetation in the whole area. At the same time agricultural crops extended a little bit to reed land in the Zone 1, Zone 3 and northeast part of Zone 2. There were few changes in the distribution of other land cover types.
Comparison of area percentage of land cover between 1996 and 2000 reveals various changes in area. On the basis of 1996 reed land increased further to 52.6%, and agricultural crops increased to 22.4% as well. While open water further decreased to 19.3%, and floating vegetation decreased to 1.4%. Bare land and dry grasses land also increased to 1.3% and 2.7% separately. There were few changes in woodland.

Consistent with area change, distribution of land cover also changed. Reed land developed further to open water and floating vegetation in the whole area, and agricultural crops developed further to reed land in the Zone 1, Zone 3 and northeast of Zone 2. Particularly, in Zone 3, agricultural crops replaced almost all the open water and floating vegetation in the south and middle parts. The further development of reed lands and agricultural crops almost resulted in 47.0% decrease of open water in the whole, and the disappearances of open water and floating vegetation in the Zone 1 and 3 of Baiyang Lake. In addition, some dry small dry grassland appeared in the north area.

Comparison between 2000 and 2003 reveals a variety of area change. The reed land decreased to the percent of 49.7%, and open water decreased to 13.0% as well. Agricultural crops increased to 31.8%, the peak in 5 years. There was a slight increase in dry grassland and woodland.

Consistent with area change, distribution of land cover also changed. Reed land developed to open water and floating vegetation only in the Zone 2. At the same time, agricultural crops developed further to reed land in the Zone 1 and 3, which was faster than the development of reed land. The development of agricultural land resulted in only small patches of reed land left in Zone 1.

The description above demonstrated the general area changes and distribution changes of land cover between 1987 and 2003. Reed land declined from 1987 to 1991, after that, it increased greatly till to the peak (52.6%) in 2000, then decreased again. Similar to reed land, agricultural crops declined from 1987 to 1991, after that, it kept increasing till to the peak (31.8%) in 2003. Opposite to agricultural crops, open water and floating vegetation had a sharp increase to the peak in 1991, after that, it kept decreasing till to the lowest point in 2003. While other land cover types had a small area and slight changes within these years.

3.2. Reed land change and its relation to water level

3.2.1. Reed land change in different periods

Conversions from other land cover types to reed land and from reed land to others are the two opposite aspects of reed land change in Baiyang Lake. Figure 8 and 9 show the land cover changes in a spatial context. Figure 8 reveals the conversion from other cover types to reed land and figure 9 shows changes from reed land to other cover types. The extent of land cover changes in different periods is shown in figure 10.
Figure 8 Changes from other land cover types to reed land between different years
Figure 9 Changes from reed land to other land cover types between different years
Figure 10 Area of reed land change between different years

(1) From other land cover to reed land; (2) From reed land to other land cover; (3) Total Area of reed land change. BL: bare land; AC: agricultural crops; DG: dry grassland; OW: open water; W: woodland; FV: Floating vegetation.

During the period from 1987 to 2003, land cover changed greatly from other land cover to reed land. In the first period (1987-1991) and third period (1996 - 2000), more than 5,000 ha appeared where there were other land cover types before. In other 2 periods, the conversion was much smaller. During the first period, the conversions mainly took place in Zone 1 and northern part of Zone 3, and most of conversions were from Agricultural crops. During the third period, most of the conversions occurred
in north and middle part of Zone 2, and middle part of Zone 3. These conversions were mostly from open water.

Meanwhile, large areas of reed lands were converted to other land cover types. The greatest conversion occurred in the first period, when about 7000 ha of reed lands were converted, mainly to open water in the north and east parts of Zone 2. In the fourth period (2000 – 2003), the amount was also above 4000 ha and most of them were converted to agricultural crops in Zone 1 and middle part of Zone 3. But in the other 2 periods, the conversions were much smaller.

As the result of final conversions from the 2 aspects in the 4 periods, about 2000 ha of reed land increased and most of them is from open water.

3.2.2. Characteristics of reed land change from 1987 to 2003

Figure 8 to 10 reveals the overall change of reed land from 1987 to 2003. Some characteristics of the conversation from other land cover to reed land are listed as follows:

The conversion to reed land took place in a very fast speed in recent years. Except the second period the conversion rates were very high. The average conversion rate in the four periods was 1327, 553, 1322 and 1127 ha per year separately.

Open water is the most important source for the conversion. Open water, agricultural crops, dry grasses and floating vegetation were the main land cover types from which reed land created, but open water always took more than half of the area. From the first period to the fourth period, 71.5%, 51.6%, 76.5% and 66.9% of the reed land were converted from open water, which were much larger than other land cover types (figure 10-1).

The conversion to reed land is shifting from Zone 1 and Zone 3 to Zone 2. In the first period the conversion was mainly happened in the Zone 1 and 3. Since then, more and more conversion appeared in Zone 2. In the fourth period, almost all the conversion appeared in the in the Zone 2 (figure 8).

The characteristics of the conversation from reed lands to others are listed as follows:

The conversion from reed land is getting faster in recent years. The first period had the fastest conversion with the average rate of 1738 ha per year. While in the second period, the conversion rate decreased sharply to the 364 ha per year. After that, the conversion sped up to the 419 ha per year in the third period even to the 1427 ha per year in the forth period.

Reed land is more and more converted to agricultural crops. Open water and agricultural crops are the two main land cover types to which reed land converted. From the first period to the fourth period, the percent from reed to open water decreased from 76.6% to 43.7%, to 33.7%, till to 17.4%, while the percent from reed to agricultural crops increased from 5.2%, to 42.0%, to 53.9% till to 69.9% (figure 10-2).

The conversion has the trend of from Zone 2 to Zone 1 and Zone 3, and back again. In the first period, the conversion mainly appeared Zone 2. After that, the conversion happened more evenly, but in the fourth period, more conversion took place in Zone 1 and 3 (figure 9). With the total area of reed in Zone 1 and 3 decreased, more and more conversion will take place in the Zone 2.
3.2.3. Water level fluctuations

Water level fluctuated very fast between different years. From 1960 to 2003, water level in Baiyang Lake had a trend to decline, even dried up (figure 11). In the period between 1960 and 1965, mean monthly water level of Baiyang Lake fluctuated around 900 cm, then suddenly declined and dried up for 3 months in 1966. In the period between 1966 and 1981, mean monthly water level increased and fluctuated around 800 cm. During this period, Baiyang Lake dried up twice in 1972 to 1973, and 1976. In the following period after 1981, Baiyang Lake had very low water levels and even completely dried up for about 4 years until to August of 1988. In the latest period, the water level in Baiyang Lake decreased from 917 cm in September of 1988 to 631 cm in June of 1994. After a sharp increase, it kept decreasing until to 573 cm in September of 2003, the time of the fieldwork for the study.

Water levels also fluctuated within a year (figure 11). Baiyang Lake usually had a higher water level in the spring, and then started to decrease. It reached to the lowest level in middle summer, after which it began to increase to winter levels.

![Figure 11 Mean monthly water level of Baiyang Lake between 1960 and 2003 (According to Junjie, 2000)](image)

3.2.4. Rainfall fluctuations

Rainfall fluctuated greatly between different years. In most years between 1960 and 2002, annual rainfall fluctuated around 500 mm (Appendix 3). In 1964, 1977 and 1988, the rainfall was above 800 mm. While in the period between 1980 and 1987, and the period from 1997 till 2002, the annual rainfall was about 400 mm even close to 300 mm. This indicated that rainfall in Baiyang Lake does not greatly influence the water level there.

3.2.5. Relationship between area of reed land and water level

As can be seen in figure 8 and 9, there was an unbalance of reed land change between different areas of Baiyang Lake. More reed land was converted to agricultural crops in Zone 1 and Zone 3, and more open water was converted to reed land in the Zone 2. Thus, relationships between area of reed land change and water level were expected to be different in different zones of Baiyang Lake. Figure 12 demonstrates the relations from 1987 to 2003 in those 3 zones of Baiyang Lake.
Figure 12 Relationships between area of reed land and water level of Baiyang Lake: (1) in Zone 1; (2) in Zone 2; and (3) in Zone 3.
In Zone 1, there was no clear relationship between the change of reed land and the trend in water levels (figure 12-1). Zone 1 of Baiyang Lake had a small area of reed land in 1987, a larger area in 1991, 1996 and 2000, and a small area in 2003 again. Water level decreased greatly from 1988 to 2003, and was less than 560 cm in 1987. But in 1987 and 2003, area of reed land was small, and water level was also low.

In Zone 2, there was an obvious negative relationship between the area change of reed land and water level fluctuations (figure 12-2). Area of reed land increased from 7334 ha in 1991 to 12004 ha in 2003, while water level decreased. In 1987, Baiyang Lake was dried up, while reed land had an area of over 11,000 ha.

In Zone 3, the relationship between area of reed land and water level was not clear (figure 12-3). In 1987, when Baiyang Lake dried up, reed land had the smallest area. From 1991 to 2000, water level decreased year by year, while reed land increased in area. With the water level further decreased, area reed land decreased again in 2003.

In other words, Zone 2 had the most obviously relationship between area change of reed land and water level fluctuation.

3.2.6. Relationship between reed production and water level

Figure 13 demonstrates the some relationships between reed production and water level. Generally when the water level was extremely high (>900 cm), reed production was very low. Within the range between about 900 mm and 550 mm, the reed production was relatively high. But in the period from 1984 to 1988 when Baiyang Lake dried up, reed production first increased, and then sharply decreased.

![Figure 13 Relationship between reed production and water level using the historical data (from Junjie, 2000)](image)
3.3. Differences between physical properties of the reed in different areas

Figure 14 and Appendix 4 show the differences of reed properties between Zone 1 and Zone 2. For both hengcao and planted reed, stem density, stem height and stem diameter in Zone 2 were significantly greater than those in Zone 1 (Mann-Whitney U-test, p<0.05). Thus all the null hypotheses were rejected and the alternative hypotheses were accepted. Figure 14 also indicates that in Zone 1, stem density, stem height and stem diameter of planted reed were much greater than those of hengcao. In Zone 2, stem of planted reed was sparser than that of hengcao, but higher and thicker than those of hengcao.

![Figure 14 Difference between physical properties of reed in Zone 1 and Zone 2](image)

A1_H: Hengcao in Zone 1 (n=11); A1_P: Planted reed in Zone 1 (n=8); A2_H: Hengcao in Zone 2 (n=17); A2_P: Planted reed in Zone 2 (n=11).

3.4. Relationship between physical properties of reed and water depth

All the null hypotheses were rejected and alternative hypotheses were accepted (Appendix 5). Figure 15 and 16 show positive relationships between water depth and reed density. Stem density increased as the water depth increased. The relationships were significant for hengcao (LSR, $R^2 = 0.7047$, p<0.05) and planted reed (LSR, $R^2 = 0.3878$, p<0.05).

Conversely, for both hengcao and planted reed, stem height decreased as the water depth increased (figure 17 and 18). The negative relationship was significant for hengcao (LSR, $R^2 = 0.2032$, p<0.05) and planted reed (LSR, $R^2 = 0.2966$, p<0.05).

Similar to reed height, reed diameter decreased as the water depth increased (figure 19 and 20). The negative relationship was significant for hengcao (LSR, $R^2 = 0.2995$, p<0.05), and planted reed (LSR, $R^2 = 0.1242$, p<0.05).
Figure 15 The relationship between stem density of hengcao and water depth
Solid line indicates a significant relationship (P<0.05)

Figure 16 The relationship between stem density of Planted reed and water depth
Solid line indicates a significant relationship (P<0.05)

Figure 17 The relationship between stem height of hengcao and water depth
Solid line indicates a significant relationship (P<0.05)
Figure 18 The relationship between stem height of planted reed and water depth
Solid line indicates a significant relationship (P<0.05)

\[ y = -0.3573x + 2.8824 \]
\[ R^2 = 0.2995 \]

Figure 19 The relationship between stem diameter of hengcao and water depth
Solid line indicated a significant relationship (P<0.05)

\[ y = -0.766x + 6.4302 \]
\[ R^2 = 0.2995 \]

Figure 20 The relationship between stem diameter of planted reed and water depth
Solid line indicated a significant relationship (P<0.05)

\[ y = -0.5126x + 7.6199 \]
\[ R^2 = 0.1242 \]
3.5. Mapping physical properties of reed

The Linear regression analyses show that there were no clear relationships between DN values of all bands except Band 6 and reed properties. Figure 21 to 23 and Appendix 6 depict the relationships between DN values of Band 6 and reed properties. In the area with dense reed, DN values of Band 6 were low. The negative relationship was significant (LSR, $R^2=0.6874$, $p<0.05$). There were also negative relationships between DN values and reed height, and between DN values and reed diameter. But the former relationship was significant (LSR, $R^2=0.3207$, $p<0.05$), and the latter was not (LSR, $R^2=0.0147$, $p>0.05$).

![Figure 21 The relationship between DN value of Band 6 and stem density of reed](image1)

Solid line indicates a significant ($P<0.05$) and negative relationship

![Figure 22 The relationship between DN value of Band 6 and stem height of reed](image2)

Solid line indicates a significant ($P<0.05$) and negative relationship
Figure 23 The relationship between DN value of Band 6 and stem diameter of reed

Solid line indicated a negative relationship but not significant at p=0.05
4. Discussion

4.1. Assessment on the method of classification and change detection

Maximum likelihood is used for image classification in this study. Both user’s accuracy for reed land and overall accuracy in 1991 and 2003 indicate a high classification results. In this paper Kappa statistic provides a better measure of the accuracy of a classifier than the overall accuracy, since it considers inter-class agreement. A coefficient above 0.80 means an excellent performance (Congalton and Green 1999). The coefficients in 1991 and 2003 are 0.87 and 0.84 respectively. Thus, the high classification accuracy means the produced land cover maps in 1991 and 2003 were of high quality.

Although the total map accuracies for the land cover maps in 1991 and 2003 are satisfactory, there is some variation in the accuracy of mapping reed land areas over different years. Compared to October 2003, reed land was more easily discriminated from other land cover types using the image of July 1991. The explanation could be that reed has the highest biomass in July in Baiyang Lake, and thus reed has the highest reflection in Band 4 of TM image. In October it is difficult to distinguish reed from cotton because they have very similar reflection. Similar evidence was found in the research of Geospatial Technology Program (GTP 2003). They believed that during July, August, and September the spectral signature of reed is more easily distinguished from other marsh species compared to earlier months in the spring and later months in the winter. Thus, Kappa coefficient and user’s accuracy for reed land in 1991 was higher compared to that of 2003.

Post-classification comparison is a widely used method for change detection and successfully used in change detection of wetlands, forestry and grassland (Lunetta and Elvidge 1999). In this study, it provided detailed information about area size, distribution of reed land and from-to information of reed land change. Seasonal changes between images brought some difficulties in interpretation of the change detection. Comparison between land cover types of May 2000 and October 2003 showed some one-pixel-sized reed land changes in the transition area from open water to reed land. These changes may be caused by the difference of open water area between different seasons. During summer Baiyang Lake usually has lowest water level within the year, resulting in the smallest open water area. From late autumn until early spring were the seasons that Baiyang Lake had the highest water level, resulting in the largest open water area within the year. During image classification, the transition area between open water and reed land was classified either into reed land or open water depending on the percentage of open water. When open water area was small, the transition area might be classified into reed land. Thus, the difference of open water area, which resulted from seasonal variation, led to a false conclusion of reed land change in this transition area. Sepideh Arzandeh (Sepideh Arzandeh 2003) and Jensen (Jensen 1996) also met such a problem when using the post-classification comparison. They believed that season variation, together with geometric correction and resampling method, might cause error in images classification, which further negatively influenced the accuracy of change detection.
Besides, accuracy of reed land change may also be reduced due to the lack of ground reference in 1987, 1996 and 2000. The accuracy of change detection is dependent on the accuracies of the two individual classifications (Jensen 1996). But in those 3 years, there was no ground reference available for the images classification. And it was impossible to go back in time and collect the historical ground reference information. And there were also no thematic maps and aerial photographs. Thus, the unavailability of ground reference possibly led to the decrease of accuracies of image classification in those years, which maybe again lead to the decrease of accuracy of reed land change in all years.

The factors motioned above possibly led to accuracy decrease of reed land change. For the limitation of time and budget, it was difficult to collect all the ideal images and reference data. But these analyses indicate something that can improve accuracy of change detection in the future. First the differences of spectral characteristics between various land cover types are clear in some periods, but not in other periods. Selecting those periods when land cover types distinguish with each other is of significance in improving images classification and thus accuracy of change detection. Second care should be taken when detecting land cover changes using images from different periods in the year. For similar studies it is most necessary to order images that were taken around the same universary date. Third when ground reference is not available, thematic maps or aerial photographs of that year can be helpful for image classification. Other factors such as using objects characteristics (tone, texture, shape and association) and selecting images with high resolution or multi-spectrum, will also improve the accuracy of image classification (Sabins 1997). This will again improve the accuracy of change detection.

### 4.2. Reed land change and its relationship to water level

The results show that the area of reed land decreased in the whole Baiyang Lake during the first period. After period 1, the area of reed land was first increased and then decreased in Zone 1 and 3. On the contrary, it kept increasing in Zone 2. Reed land change was probably caused by the fluctuation of water levels, which increased during the first period, and showed a trend to decrease afterwards in the whole area (figure 13).

But the type and extent of the changes differed in different areas in Baiyang Lake. The possible explanation could be that Zone 2 still has a connection to the main river, while Zone 1 and 3 do not. In Zone 1, the water level decreased far (>5 m) below the soil level and there was no connection via which water can flow into the area from the Daqing River in the south. And construction of Daqing River dyke keeps the river water almost out of Zone 1. Thus reed suffered from drought and had poor quality and low production in Zone 1 (Li Aiguo 1996). This led to land use changes from reed production to agricultural crop production, and the area of the reed land decrease in Zone 1. In short no connection to the main river in Zone 1 led to the result that the relation between reed land and water level was not reflecting an ecological response to water levels. Similar changes occurred in Zone 3. However, in Zone 2, the Daqing River crossed from west to east and there were plenty of rivers, ditches and lakes connected with each other. Thus reed was still in moist condition and in a relatively good quality. Few reed lands were converted here to agricultural crops. With the water level
decrease, reed land replaced some open water and led to the increase in area. Therefore in Zone 2 reed land showed the ecological response to water level.

The relationships between reed land and water level provide insight into regulating area of reed land. From the point of view of reed harvest, an extremely high water level is not suitable in Baiyang Lake, because it will reduce reed area and thus lead to the low production. It is consistent to the research by Bodensteiner (2003), who found that water level which was 1 m higher than reed land in growing season led to the net loss of total area of reed land. Marks et al (1994) even use this as a control measure for common reed by flooding rhizomes of reed to 1 m deep during the growing season. In Baiyang Lake, an extremely low water level is also not suitable for reed harvest. Low water level, although bring to larger area of reed land, might reduce the reed quality because of the drought (Li Aiguo 1996). Besides, elevations of reed lands need to be considered in applying the relationships to regulate area of reed land. Baiyang Lake has large area of reed lands, and the elevation of reed lands generally decreased from west to east. Same water level will lead to different responses of reed in west and east. Thus, a medium water level can regulate a proper area for reed harvest. Elevations of reed land need to be considered when regulate a proper water level.

4.3. Relationships between reed production and water level

Except the relationship between area of reed land and water level, also the relationships between reed production and water level were analyzed. These relationships can be explained by area of reed land and average productivity. Results show that low production was in those years with extremely high water levels. The explanation might be the whole area was mostly flooded by the extremely high water levels and not much reed land available for reed production. Also (Schmieder 2002) indicated that flood can severely damage the shoots especially the secondly shoots and result in a great loss in reed production. When the water levels were extremely low, the reed production was very high first, and then the production reduced sharply. It might because in the first year after drying up, the reed land was still moist, and the reed was still in relatively good quality. But the area of reed land increased sharply due the low water level. Thus the production was quite high because of the large area. However, with the drought continued, reed suffered from the drought and the productivity decreased very fast, resulting in the decline of production. Mckean (2001) and Gai Ping (2002) also reported that extreme low water levels and consequently low soil moisture might lead to poor quality and biomass of reed. With intermediate water levels, there is not much reed land available but the reed is of good quality with high biomass, thus has a relatively high production. From the analysis above, considering both reed production and reed quality, a medium water level might be the best choice for reed harvest.

Because reed production was the secondary statistic, and some data in recent years was not accessible, detailed analysis was not carried out in the relationships between reed production and water level.

4.4. Relationships between physical properties of reed and water depth

In a spatial context, effect of water depth on reed properties was also analyzed. Results showed that both hengcao and planted reed in Zone 2 were significantly denser, higher and thicker than those in Zone 1. The differences of reed properties between zone 1 and zone 2 probably resulted from the differences of water depth in Zone 1 and Zone 2. In zone 1, there was no water connection to the river.
The main water source was ground water, which was found more than 5 meters below the soil surface during the time of the fieldwork. The reed root can normally reach about 2 m deep into the earth in dry condition (Rodwell 1995), and in Baiyang Lake the reed root was found about 2.5 m below the soil surface. Thus, the reed root in Zone 1 could not reach the water table. Thus there was little water source available for the living of reed and might result in the poor physical properties. But in Zone 2 reed had relatively sufficient water supply from the connected rivers and lakes, and had a relatively good physical properties. Therefore the different accessibility to water source, which resulted from different water depth, caused the different physical properties of reed.

The results in figure 15 to 20 show that reed density was significantly and positively related to water depth, and reed density and stem diameter were significantly negatively related to water depth in both hengcao and planted reed. There are some possible reasons for the relationships. The first is that reed land in Zone 2 was connected directly to the surface of river system. During the time of fieldwork, water table below the reed land ranged from –2.5 m to -0.6 m from west to east. In this range of water depth, reed roots can reach to the water table, which was found in the sector close to river and lakes. In fact, average water depth from April to September (growing period for reed) water depth was about 0.5 m higher than that during the time of fieldwork (figure 11). Thus reed in this area had sufficient access to water, which provides the possibility that the properties of reed change with the fluctuation of water level. The second possible reason is that different water depth influenced different soil moisture and temperature, which further affected reed properties (McKean 2001). Soil moisture is closely related to bud sprout of reed. During the period from April to August, most of the buds can sprout and grow up in the condition of sufficient water (Jiarong 2002). In the water depth from -2.5 to -0.6 m, the soil with a higher water depth had more accessibility to water and had a higher stem density. After bud sprout, stem development was positively related to nutrient status of the soil and light (Meyerson, Saltonstall et al. 2000). In the areas with lower water level, due to the lower density of reed stems, the competition for light and soil nutrient is lower (McKean 2001). Thus reed stems grow faster, and get thicker and higher in the end. It might also because where the temperature is higher due to the relative dry soil, and higher temperature can improve the ability to absorb nutrient from soil (Jiarong 2002). Therefore, reed stems here are higher and thicker.

The relationships between physical properties and water depth give some indications for the management of water depth in reed land. Reed quality and reed production are the main factors that influence values of reed. Stem height and diameter are normally the indicators for reed quality. Making mats are the main use of reed harvest in Baiyang Lake. According to the local people, normally the height equal to or above 3.5 meters is needed for mats with good quality, but not specific requirement in diameter. By controlling the water depth lower than one proper water depth (in the equation shown in figure 18, which is about -1.7m in September for planted reed), reed stems can reach the height 3.5 m. But once reaching the height of 3.5 m, reed production is the anther main factor that affects the total values of reed. More reed stems, more reed production for reed weaving. A relative high reed density, however, require a relative high water depth. Therefore controlling water depth in optimal level will benefit both reed quality and reed production and make the greatest values. If only consider planted reed and use for mats making, the depth might be –1.7 m in September or about –1.2 m during the growing period of reed (the average water depth in growing period this year is 0.5 m higher than that in September, figure 11). But in reality, more factors need to be considered.
Not only different ecotypes of reed and various use values of reed, but also the elevation of reed land in the whole Baiyang Lake and other environmental factors need to be considered for reed harvest.

Besides, the two ecotypes of reed in Baiyang Lake showed some similar and different responses to water depth. In Zone 2, for both hengcao and planted reed, they showed similar response to water depth change. But compared with each other, the relationship in hengcao was stronger than that in planted reed. Water level change explained 70.5% of the variation of reed density for hengcao, but only explained 38.8% for planted reed. The different responses to water level are also shown when comparing reed properties between Zone 1 and Zone 2. Hengcao was much sparer than that of planted reed in Zone 1, but denser in zone 2. In zone 1 hengcao was almost half lower and smaller than those of planted reed (figure 14). But in Zone 2 they almost had the same height and diameter. All these indicate that hengcao likes relatively low-lying wet area, but planted reed has a relative higher suitability to dry condition.

These similar and different responses to water depth between hengcao and planted reed, to some extent, explain the different distribution and use of reed in Baiyang Lake. Planted reed almost distributes in Zone 1, Zone 3, and west and middle parts of Zone 2. Theses zones have a relatively high elevation, which ensure planted reed with a high stem to meet the requirement for mat production. While hengcao, distribute in the whole area of Baiyang Lake, but largely in middle and east parts of Zone 2. Those zones are relative low in elevation, which make reed have relatively high density, and high production for the construction. These different distributions, together with the different responses to water depth, require water in a proper level. In this desirable water level, both of them have the greatest quality and quantity.

However, the relationships between reed properties and water level are contradictory to the results obtained by Bodensteiner and Gabriel (2003), who believed that stem height of reed was positively correlated to water depth, and stem density was not significantly affected by the water depth. The different responses to water depth may due to different study areas. In the study areas where Bodensteiner and Gabriel carried out their researches, the roots of the reed planted remain submerged during the entire growing season. The rooting zone of the reed is permanently flooded there. While in Baiyang Lake, the water table drops much further below the soil surface. Different water depth situation in different study areas resulted in the opposite results. In this sense, this study broadens the relationships between reed properties and water depth.

### 4.5. Can reed properties be mapped using remote sensing techniques

Remote sensing is widely used as a tool to map vegetation characteristics (Bacour, Jacquemoud et al. 2002). In this study, spectral characteristics of TM image in 2003 were used to identify the different reed physical properties. In DN value of all bands of TM image 2003, only that of Band 6 (Thermal Infrared Band) showed a significantly negative relationship to reed density and reed height, and a weak negative relationship to reed diameter. The relationships might be caused by the moisture of reed land. In general, from bare land to vegetation area, to open water, DN values of Thermal-Infrared band decreased. It is because Thermal Infrared Band is sensitive to the temperature of the ground objects. The ground objects with lower temperature such as open water emit lower radiation, which is detected by the sensor of satellite and result in lower DN values of Thermal Infrared Band (J. F.
Mustard 1999). Within the reed land, the area with denser and higher stems has a lower temperature due to higher moisture of soil or the higher evaporation of reed stems, which can result in a lower DN values Thermal Infrared Band. This is the possible explanation for the relationships.

Although there are some relationships between spectral characteristic of Band 6 and reed properties, they are not applied to map reed properties in the whole area of Baiyang Lake. This is mainly because of the reason of pixel resolution. Band 6 has a pixel resolution of 120 m. If the patch of reed land is less than 120*120 m^2, the spectral characteristics of Band 6 may be the mixed one of reed land and other land cover types. In Baiyang Lake, there are only a few patches of reed lands are larger than that size. And most of the reed lands are isolated by rivers and ditches. The small patches size of reed land limits the application of the relationships. Besides, even the patch size is larger than that of one pixel, the DN value in each pixel only indicates the whole condition of reed properties in the pixel. It can not reflect the differences between reed properties in one pixel. In most area of Baiyang Lake, hengcao and planted reed live in a mixture way, and there are some differences of physical properties between them. Thus the low pixel resolution of Band 6 limits mapping physical properties of reed.

Therefore, spectral characteristics of Band 6 of TM image can only reflect the general physical properties of large patches of reed lands. It may be used to reflect the living condition of large and homogeneous reed lands. But using Thermal-Infrared band of ETM+ image (pixel resolution is 60 m) or Aster image (pixel resolution is 90 m), the possibility of mapping physical properties of reed will be increased. With the development of remote sensing techniques and improvement of the pixel resolution of Thermal-Infrared band, Thermal-Infrared band has great potential to map physical properties of reed.

4.6. Hydrology management in Baiyang Lake for the sustainable use of reed

In ecological terms, use is considered sustainable if harvest has no long-term detrimental effect on the reproduction and regeneration of populations being harvested in comparison to equivalent non-harvested natural populations (Hall and Bawa, 1993). Harvest of reeds and nature conservation are usually the two aspects of sustainable reed land use (Marks K. M. 1992). From the analysis above, harvesting reed is analyzed and a medium water level or relative high water depth is essential to increase the reed production and reed quality. But in fact, in Baiyang Lake, considering biodiversity conservation is also needed, which again relates to water level or water depth.

Reed land is still used as habitat for bird conservation in Baiyang Lake. Bird diversity in reed land might relate to the diversity of plant species in that area (Hawke and Jose 1996). Literature study reveals that diversity of plant species enhances food availability of many invertebrates, which in turn favors species for birds (Lenssen 1998). In this study the highest diversity of plant species in the reed land was found in the relatively low-lying wet area in the east of Zone 2 (Appendix 7). More birds were also found in this area and the nature reserve was established here. From the point of view of biodiversity conservation, a relatively high water depth is required to keep the relative higher diversity of plant species in the east of Zone 2.

Reed harvest is economically important in the area. But recent development showed an increase in tourism as well. Because Baiyang Lake has the landscape characteristic with the reed lands and more than 100 lakes and thousands of rivers and ditches mixed. The landscape is unique in China (Junjie
To meet the requirement of tourism, reed should be in good quality, and there must be a large area of open water, which again requires relatively high water depth.

In other words, from the point of sustainable use reed land in Baiyang Lake, a medium water level (or a relatively high water depth) is necessary. The water level in Baiyang Lake decreased rapidly in recent years, mainly because of low water input upstream. The water level in September 2003 was only 5.75 m, which is close to the condition of totally drying up. Besides, local people indicated that water pollution got more seriously because of the low water input. In such a condition, the original functions and values decreased or even disappeared. Water quality decreased, the original main product such as Gordon euryale and water caltrop almost disappear, and the production of reed, lotus and fish decreased greatly. In addition, boats, the main means of transportation in Baiyang Lake, can not work properly because of low water level. Overall seen, the current state of Baiyang Lake is not good. In this way it loses most of its function as “kidney of north China”.

Thus, hydrology management in Baiyang Lake is necessary and important for the sustainable use of reed land, of the whole Baiyang Lake in general. Among them, an optimal water level is crucial and needs to be calculated in more detail. The desirable water level is the level where reed will have the high production and high quality. Also, this water level will benefit the conservation and tourism, and even benefit to the whole functioning and values of the whole ecosystems.

In this study, some relationships between water levels and physical properties of reed were analyzed, and a medium water level (about 1.2 m below soil surface for the harvest of planted reed) is suggested. But the data in this study are not sufficient to identify a precise water level for reed harvest. To calculate an optimal water level, more researches such as terrain of reed lands and other functions and values of Baiyang Lake, are needed. Hydrological modelling could help in more detailed calculations. Optimal water levels should be obtained by arranging sufficient water release from upstream. Thus the negotiation between local government and hydrology administrate of upstream is required. Besides, to improve the water quality, measures should be taken in treatment of the wastewater from the local people and factories. In a word, an integrated planning and management is in great need for the sustainable development of Baiyang Lake.
5. Conclusions and recommendations

5.1. Conclusions

Land cover maps produced from satellite images showed that distributions of reed land in different years (1987, 1991, 1996, 2000 and 2003). In 1987, reed lands mostly distributed in Zone 2, few reed lands distributed in the middle part of Zone 1 and the northern part of Zone 3. But in 1991 and 1996, reed land in Zone 2 shrank, but in Zone 1 more reed appeared in the middle, northern and southern parts, and in Zone 3 more reed appeared in middle. In 2000, reed land in Zone 1 decreased slightly in the southern part, in Zone 2 new reed land expanded to open water, and in Zone 3 reed land expanded greatly in the northern part. In 2003, only small patches of reed lands left in Zone 1, reed continued to expand in Zone 2, and several large patches of reed lands left in the northern part.

2. Regarding to research question 2: How did the reed area and distribution of reed change over the period from 1987 to 2003?
During the period from 1987 to 2003, great reed land changes took place in Baiyang Lake. Area of reed land decreased from 13246 ha in 1987 to 11608 ha in 1991, then increased to 12553 ha in 1996, to the highest point of 16163 ha in 2000, and decreased to 15260 ha in 2003 again.
These changes differed in different zones and different period. Overall, reed land in Zone 1 expanded to the southern and northern part in the first period (1987 to 1991), after a slight fluctuation from 1991 to 2000, a large area of reed lands were converted to agricultural crops in the forth period (2000 to 2003). In Zone 2, after a sharp decrease in area from 1987 to 1991, reed lands expanded to open water gradually from 1991 to 2003. In zone 3, reed land expanded from the north to the south gradually during the period from 1987 to 2000. But reed land shrank greatly from 2000 to 2003.

3. Regarding to research question 3: Is there a relation between reed areas and water levels in previous years?
Relationships between reed area and water level were different in different areas. In Zone 1 and Zone 3, there were no clear relationships between them. But in Zone 2, there was a clear negative relationship between them. From 1991 to 2003, with the trend of water level decreased, the area of reed land increased. In the year of 1987, when it dried up, there was a vast reed land over the whole Baiyang Lake.

4. Regarding to research question 4: Is there a relationship between reed production and water level in previous years?
The analysis between the statistical reed production and water level indicates that there is a relation between reed production and water levels. With high water levels there is not much reed land available for reed production. With extreme low water levels reed suffers from drought and has a low
production. With intermediate water levels, there is not much reed land available and the reed is of good quality with high biomass.

5. Regarding to research question 5: Are there any differences between reed properties (stem density, stem height, and stem diameter) in Zone 1 and Zone 2?
For both hengcao and planted reed, there were significant differences between stem height, stem density and stem diameter of the common reed in Zone 1 and Zone 2. The differences possibly resulted from the differences of water level in those zones.

6. Regarding to research question 6: Are there any relationships between reed properties (stem density, stem height, and stem diameter) and different water depths?
For both hengcao and planted reed, there were significantly relationships between reed properties and water depth of reed lands. Stem density was significantly and positively related to water depth of reed land, but both stem height and stem diameter was significantly and negatively related to water depth.

7. Regarding to research question 7: Are there any relations between reed properties (stem density, stem height, and stem diameter) and spectral characteristics of the TM image 2003?
The Linear regression analyses show that there were no clear relationships between spectral characteristics and reed properties in all bands except Band 6. In Band 6 reed density and reed height negatively and significantly related to DN values. The relationship between reed diameter and DN values of Band 6 was negative but not significant at 0.05. Because of the low resolution of Band 6 and heterogeneity of reed land, the relationships can not be applied to map reed properties in the whole Baiyang Lake.

8. Regarding to research question 8: How can this study contribute to sustainable management of Baiyang Lake?
A proper water level is very important not only for reed harvest, but also for the biodiversity conservation in reed land and tourism. From the view points of area of reed land, reed properties and reed production, some relationships to water level or water depth were given. A medium water level is required for the sustainable management of Baiyang Lake. But the data presented in this paper is not sufficient enough to recommend a precise water level.

5.2. Recommendations

1. A proper water level is very important for reed harvest. A high water level will lead to the low production because of small area, and a low water level will also lead to the low production and poor quality of reed due to dry condition of reed land. A proper water level is also critical for the functions and values of the whole ecosystem of Baiyang Lake. But what is the optimal water level in Baiyang Lake? Hydrological modelling might help in more detailed calculations.
2. Except water level, water quality is also very important factor for the sustainable reed land use, and for the whole ecosystem of Baiyang Lake. It is another issue for the future study.
3. Thermal band has the potential to distinguish moist conditions of different reed land and moist conditions again relate to reed properties. But current resolution is limited. The thermal bands with high resolution have more potential to map physical properties of reed land and other vegetation.
6. References


Appendices

Appendix 1 Data collection sheet (1)

No. ___ Name of recorders:______________ Date:__(m)/__(d)/2003

1. Position:
   E: 50S __ __ __ __ __ __; N: UTM __ __ __ __ __ __.

2. Description:

<table>
<thead>
<tr>
<th></th>
<th>Species name (ab.)</th>
<th>Coverage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper layer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Middle layer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower layer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bare soil</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Open water</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Remark:
Appendix 2 Data collection sheet (2)

No. ___ Name of recorders: ___________ Date: ___(m)/___(d)/2003

1. Location of plot center:
E: 50S __ __ __ __ __ __ __; N: UTM __ __ __ __ __ __ __.

2. Water depth: _______cm.

3. Plant species:

<table>
<thead>
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<th>Species name (ab.)</th>
<th>Coverage</th>
<th>ID</th>
<th>Species name (ab.)</th>
<th>Coverage</th>
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<td></td>
</tr>
<tr>
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<td></td>
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<td></td>
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<td>5</td>
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<tr>
<td>6</td>
<td></td>
<td></td>
<td>14</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td></td>
<td></td>
<td>15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td></td>
<td></td>
<td>16</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Remark:

4. Density of reed: _____/m² (Living stems)
   Density of reed: _____/m² (Dead stems)

5. Stem height of reed

<table>
<thead>
<tr>
<th>ID</th>
<th>Height (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

6. Stem diameter of reed

<table>
<thead>
<tr>
<th>ID</th>
<th>Height (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Appendix 3 Annual and monthly water level of Baiyang Lake between 1960 and 2003
Appendix 4 Differences between stem properties of reed in Zone 1 and Zone 2

1. Differences between stem density of hengcao in Zone 1 and Zone 2.

**Mann-Whitney Test**

<table>
<thead>
<tr>
<th>CODE</th>
<th>Density</th>
<th>N</th>
<th>Mean Rank</th>
<th>Sum of Ranks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area1</td>
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<td>7.77</td>
<td>85.50</td>
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</tr>
<tr>
<td>Area2</td>
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<td>18.85</td>
<td>320.50</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>28</td>
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<td></td>
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</tr>
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</table>

**Test Statistics**

<table>
<thead>
<tr>
<th>Density</th>
<th>Mann-Whitney U</th>
<th>Wilcoxon W</th>
<th>Z</th>
<th>Asymp. Sig. (2-tailed)</th>
<th>Exact Sig. [2*(1-tailed Sig.)]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>19.500</td>
<td>85.500</td>
<td>-3.482</td>
<td>.000</td>
<td>.000 a</td>
</tr>
</tbody>
</table>

a. Not corrected for ties.

b. Grouping Variable: CODE

2. Differences between stem density of planted reed in Zone 1 and Zone 2.

**Mann-Whitney Test**

<table>
<thead>
<tr>
<th>CODE</th>
<th>Density</th>
<th>N</th>
<th>Mean Rank</th>
<th>Sum of Ranks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area1</td>
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<td>6.88</td>
<td>55.00</td>
<td></td>
</tr>
<tr>
<td>Area2</td>
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<td>12.27</td>
<td>135.00</td>
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</tr>
<tr>
<td>Total</td>
<td>19</td>
<td></td>
<td></td>
<td></td>
</tr>
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</table>

**Test Statistics**

<table>
<thead>
<tr>
<th>Density</th>
<th>Mann-Whitney U</th>
<th>Wilcoxon W</th>
<th>Z</th>
<th>Asymp. Sig. (2-tailed)</th>
<th>Exact Sig. [2*(1-tailed Sig.)]</th>
</tr>
</thead>
<tbody>
<tr>
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<td>.041 a</td>
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a. Not corrected for ties.

b. Grouping Variable: CODE

3. Differences between stem height of hengcao in Zone 1 and Zone 2.

**Mann-Whitney Test**
4. Differences between stem height of planted reed in Zone 1 and Zone 2.

**Mann-Whitney Test**

<table>
<thead>
<tr>
<th>CODE</th>
<th>N</th>
<th>Mean Rank</th>
<th>Sum of Ranks</th>
</tr>
</thead>
<tbody>
<tr>
<td>HEIGHT</td>
<td>1.00</td>
<td>8</td>
<td>6.13</td>
</tr>
<tr>
<td></td>
<td>2.00</td>
<td>11</td>
<td>12.82</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>19</td>
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**Test Statistics**

<table>
<thead>
<tr>
<th></th>
<th>HEIGHT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mann-Whitney U</td>
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</tr>
<tr>
<td>Wilcoxon W</td>
<td>49.000</td>
</tr>
<tr>
<td>Z</td>
<td>-2.560</td>
</tr>
<tr>
<td>Asymp. Sig. (2-tailed)</td>
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<tr>
<td>Exact Sig. [2*(1-tailed Sig.)]</td>
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- b. Grouping Variable: CODE

5. Differences between stem diameter of hengcao in Zone 1 and Zone 2.

**Mann-Whitney Test**
6. Differences between stem diameter of planted reed in Zone 1 and Zone 2.

**Mann-Whitney Test**

<table>
<thead>
<tr>
<th>CODE</th>
<th>N</th>
<th>Mean Rank</th>
<th>Sum of Ranks</th>
</tr>
</thead>
<tbody>
<tr>
<td>DIAMETER Area1</td>
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<td>7.23</td>
<td>79.50</td>
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<td>Area2</td>
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**Test Statistics**

<table>
<thead>
<tr>
<th></th>
<th>DIAMETER</th>
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<tbody>
<tr>
<td>Mann-Whitney U</td>
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<td>Wilcoxon W</td>
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<td>-3.767</td>
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a. Not corrected for ties.
b. Grouping Variable: CODE
Appendix 5 Relationships between stem properties of reed and water depth

1. Relationships between stem density of hengcao and water depth

Regression

<table>
<thead>
<tr>
<th>Model</th>
<th>Variables Entered</th>
<th>Variables Removed</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>water_depth</td>
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<td>Enter</td>
</tr>
</tbody>
</table>

- a. All requested variables entered.
- b. Dependent Variable: DENSITY

Model Summary

<table>
<thead>
<tr>
<th>Model</th>
<th>R</th>
<th>R Square</th>
<th>Adjusted R Square</th>
<th>Std. Error of the Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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<td>.705</td>
<td>.693</td>
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- a. Predictors: (Constant), water_depth

ANOVA

<table>
<thead>
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<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
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</thead>
<tbody>
<tr>
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<td>2050.367</td>
<td>59.655</td>
<td>.000a</td>
</tr>
<tr>
<td>Residual</td>
<td>859.262</td>
<td>25</td>
<td>34.370</td>
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<tr>
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<td>26</td>
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- a. Predictors: (Constant), water_depth
- b. Dependent Variable: DENSITY

Coefficients

<table>
<thead>
<tr>
<th>Model</th>
<th>Unstandardized Coefficients</th>
<th>Standardized Coefficients</th>
<th>t</th>
<th>Sig.</th>
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<tbody>
<tr>
<td></td>
<td>B</td>
<td>Std. Error</td>
<td>Beta</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(Constant)</td>
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<tr>
<td>1</td>
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<tr>
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<td>WDa</td>
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- a. Dependent Variable: DENSITY

2. Relationships between stem density of planted reed and water depth

Regression

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<tr>
<th>Model</th>
<th>Variables Entered</th>
<th>Variables Removed</th>
<th>Method</th>
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<tr>
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- a. All requested variables entered.
- b. Dependent Variable: DENSITY
Model Summary

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<th>Std. Error of the Estimate</th>
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<tbody>
<tr>
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a. Predictors: (Constant), WD

ANOVA<sup>b</sup>

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<th>Mean Square</th>
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a. Predictors: (Constant), WD
b. Dependent Variable: DENSITY

Coefficients<sup>a</sup>

<table>
<thead>
<tr>
<th>Model</th>
<th>Unstandardized Coefficients</th>
<th>Standardized Coefficients</th>
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3. Relationships between stem height of hengcao and water depth

**Regression**

Variables Entered/Removed<sup>d</sup>

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<tr>
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<th>Variables Entered</th>
<th>Variables Removed</th>
<th>Method</th>
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a. All requested variables entered.
b. Dependent Variable: HEIGHT

Model Summary

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<th>Model</th>
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<th>Adjusted R Square</th>
<th>Std. Error of the Estimate</th>
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</thead>
<tbody>
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<td>.170</td>
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</table>

a. Predictors: (Constant), water_depth
### ANOVA\(^b\)

<table>
<thead>
<tr>
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<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Regression</td>
<td>.313</td>
<td>1</td>
<td>.313</td>
<td>6.339</td>
<td>.019(^a)</td>
</tr>
<tr>
<td>1 Residual</td>
<td>1.233</td>
<td>25</td>
<td>.049</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 Total</td>
<td>1.546</td>
<td>26</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a. Predictors: (Constant), water_depth

b. Dependent Variable: HEIGHT

### Coefficients\(^a\)

<table>
<thead>
<tr>
<th>Model</th>
<th>Unstandardized Coefficients</th>
<th>Standardized Coefficients</th>
<th>t</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (Constant)</td>
<td>2.999</td>
<td>.111</td>
<td>27.052</td>
<td>.000</td>
</tr>
<tr>
<td></td>
<td>water_depth</td>
<td>-.180</td>
<td>-.450</td>
<td>-.2518</td>
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</tbody>
</table>

a. Dependent Variable: HEIGHT

4. Relationships between stem height of planted reed and water depth

**Regression**

**Variables Entered/Removed\(^d\)**

<table>
<thead>
<tr>
<th>Model</th>
<th>Variables Entered</th>
<th>Variables Removed</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>WD(^a)</td>
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<td>Enter</td>
</tr>
</tbody>
</table>

a. All requested variables entered.

b. Dependent Variable: HEIGHT

**Model Summary**

<table>
<thead>
<tr>
<th>Model</th>
<th>R</th>
<th>R Square</th>
<th>Adjusted R Square</th>
<th>Std. Error of the Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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<td>.297</td>
<td>.274</td>
<td>.34175</td>
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</table>

a. Predictors: (Constant), WD

### ANOVA\(^b\)

<table>
<thead>
<tr>
<th>Model</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
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<tbody>
<tr>
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<td>1.527</td>
<td>1</td>
<td>1.527</td>
<td>13.074</td>
<td>.001(^a)</td>
</tr>
<tr>
<td>1 Residual</td>
<td>3.620</td>
<td>31</td>
<td>.117</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 Total</td>
<td>5.147</td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

a. Predictors: (Constant), WD

b. Dependent Variable: HEIGHT
5. Relationships between stem diameter of hengcao and water depth

**Regression**

**Variables Entered/Removed**

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<thead>
<tr>
<th>Model</th>
<th>Variables Entered</th>
<th>Variables Removed</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>water_depth</td>
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</tbody>
</table>

a. All requested variables entered.
b. Dependent Variable: DIAMETER

**Model Summary**

<table>
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<th>Model</th>
<th>R</th>
<th>R Square</th>
<th>Adjusted R Square</th>
<th>Std. Error of the Estimate</th>
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</thead>
<tbody>
<tr>
<td>1</td>
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<td>.300</td>
<td>.272</td>
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a. Predictors: (Constant), water_depth

**ANOVA**

<table>
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<th>Model</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
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<td>1</td>
<td>5.654</td>
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<td></td>
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</table>

a. Predictors: (Constant), water_depth
b. Dependent Variable: DIAMETER

**Coefficients**

<table>
<thead>
<tr>
<th>Model</th>
<th>Unstandardized Coefficients</th>
<th>Standardized Coefficients</th>
<th>t</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B</td>
<td>Std. Error</td>
<td>Beta</td>
<td></td>
</tr>
<tr>
<td>1</td>
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<td>-.547</td>
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</tbody>
</table>

a. Dependent Variable: DIAMETER

6. Relationships between stem diameter of planted reed and water depth

**Regression**
### Variables Entered/Removed

<table>
<thead>
<tr>
<th>Model</th>
<th>Variables Entered</th>
<th>Variables Removed</th>
<th>Method</th>
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</thead>
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<tr>
<td>1</td>
<td>WD</td>
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<td>Enter</td>
</tr>
</tbody>
</table>

- a. All requested variables entered.
- b. Dependent Variable: DIAMETER

### Model Summary

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<tr>
<th>Model</th>
<th>R</th>
<th>R Square</th>
<th>Adjusted R Square</th>
<th>Std. Error of the Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>.352&lt;sup&gt;a&lt;/sup&gt;</td>
<td>.124</td>
<td>.096</td>
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</table>

- a. Predictors: (Constant), WD

### ANOVA<sup>b</sup>

<table>
<thead>
<tr>
<th>Model</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
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</thead>
<tbody>
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<td>1</td>
<td>3.143</td>
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</tr>
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<td>Residual</td>
<td>22.151</td>
<td>31</td>
<td>.715</td>
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</tr>
<tr>
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<td>Total</td>
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- a. Predictors: (Constant), WD
- b. Dependent Variable: DIAMETER

### Coefficients<sup>a</sup>

<table>
<thead>
<tr>
<th>Model</th>
<th>Unstandardized Coefficients</th>
<th>Standardized Coefficients</th>
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<th>Sig.</th>
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<tr>
<td></td>
<td>B</td>
<td>Std. Error</td>
<td>Beta</td>
<td></td>
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<tr>
<td>1</td>
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- a. Dependent Variable: DIAMETER
Appendix 6 Relationships between spectral characteristics of TM image 2003 and physical properties of reed

1. The relationship between DN value of Band 6 of reed density

   **Variables Entered/Removed**

<table>
<thead>
<tr>
<th>Model</th>
<th>Variables Entered</th>
<th>Variables Removed</th>
<th>Method</th>
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<tr>
<td>1</td>
<td>density</td>
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   a. All requested variables entered.
   b. Dependent Variable: BAND6

   **Model Summary**

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<th>Model</th>
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<th>R Square</th>
<th>Adjusted R Square</th>
<th>Std. Error of the Estimate</th>
</tr>
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<td>.687</td>
<td>.672</td>
<td>1.18</td>
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   a. Predictors: (Constant), density

   **ANOVA**

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<th>Model</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
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</thead>
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<tr>
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<td>Regression</td>
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<td>64.074</td>
<td>46.171</td>
<td>.000a</td>
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<tr>
<td></td>
<td>Residual</td>
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<td>.29.143</td>
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   a. Predictors: (Constant), density
   b. Dependent Variable: BAND6

   **Coefficients**

<table>
<thead>
<tr>
<th>Model</th>
<th>Unstandardized Coefficients</th>
<th>Standardized Coefficients</th>
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<th>Sig.</th>
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<tbody>
<tr>
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<td></td>
</tr>
<tr>
<td></td>
<td>density</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>Std. Error</td>
<td>Beta</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>119.157</td>
<td>.749</td>
<td>-.829</td>
<td>-6.795</td>
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</tbody>
</table>

   a. Dependent Variable: BAND6

2. The relationship between DN value of Band 6 of reed height

   **Variables Entered/Removed**

<table>
<thead>
<tr>
<th>Model</th>
<th>Variables Entered</th>
<th>Variables Removed</th>
<th>Method</th>
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</thead>
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<td>1</td>
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<td>Enter</td>
</tr>
</tbody>
</table>

   a. All requested variables entered.
   b. Dependent Variable: BAND6
The relationship between DN value of Band 6 of reed diameter

### Model Summary

<table>
<thead>
<tr>
<th>Model</th>
<th>R</th>
<th>R Square</th>
<th>Adjusted R Square</th>
<th>Std. Error of the Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>.566a</td>
<td>.321</td>
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<td>1.74</td>
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</table>

a. Predictors: (Constant), HEIGHT

### ANOVA

<table>
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<tr>
<th>Model</th>
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<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
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</thead>
<tbody>
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<td>9.914</td>
<td>.005a</td>
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<td></td>
<td>Residual</td>
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<td>3.015</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>22</td>
<td>93.217</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a. Predictors: (Constant), HEIGHT
b. Dependent Variable: BAND6

### Coefficients

<table>
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<tr>
<th>Model</th>
<th>Unstandardized Coefficients</th>
<th>Standardized Coefficients</th>
<th>t</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
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<td>B</td>
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<td>Beta</td>
<td></td>
</tr>
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<td>-3.149</td>
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</table>

a. Dependent Variable: BAND6

3. The relationship between DN value of Band 6 of reed diameter

### Variables Entered/Removed

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<th>Variables Removed</th>
<th>Method</th>
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</table>

a. All requested variables entered.
b. Dependent Variable: BAND6

### Model Summary

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<thead>
<tr>
<th>Model</th>
<th>R</th>
<th>R Square</th>
<th>Adjusted R Square</th>
<th>Std. Error of the Estimate</th>
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</table>

a. Predictors: (Constant), DIAMETER
Appendix 7 Average number of plant species in different water depth

![Graph showing average number of plant species in different water depths]

Appendix 8 Average density of dead stems of reed in different water depth

![Graph showing average density of dead stems in different water depths]