Carex Dynamics as an Environmental Indicator in the Poyang Lake Wetland Area: Remote Sensing Mapping and GIS Analysis

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Abstract

It is of considerable importance to analyze the changes in *Carex* distribution and environmental elements in order to protect and exploit the wetland resources of the Poyang Lake wetland area, one of the most important wetlands in the world. Employing multitemporal remote sensing images acquired on October 31st, 2005 and December 10th, 1999, the authors determined the dynamic distribution of *Carex* by combining spectral angle mapping technologies. Then, for the first time, ArcView GIS-based statistical analysis was performed on the *Carex* dynamics. Finally, the relationship between the *Carex* dynamics and delta change, and the landscape fragmentation index of *Carex* were further analyzed. It was found that: (1) the extent of *Carex* in the Gan River delta, particularly in the north distributary of the river, was directly correlated to lake sedimentation and regional drought in the same year; (2) the distribution of migratory birds is influenced by factors additional to the distribution of *Carex*; and (3) the wetland landscape ecology of the Poyang Lake wetland area is facing threats from human disturbance and needs further attention if it is to retain its status as an important bird habitat.

Keywords

Remote sensing and GIS; *Carex*; Dynamics, Poyang Lake wetland, Environmental indication

I. INTRODUCTION

Located in the north of Jiangxi Province, the Poyang Lake wetland area is one of the 6 most important wetlands in the world and accounts for 97.2% of the total wetland area of Jiangxi Province (Figure 1). This wetland plays an important role including flood control, providing habitation for migratory birds, purifying toxicants, and regulating the climate. Poyang Lake wetland is formally protected as a world natural heritage site (http://news.xinhuanet.com/house/2004-11/04/content_2175744.htm).

The seasonal water level of Poyang Lake is an important

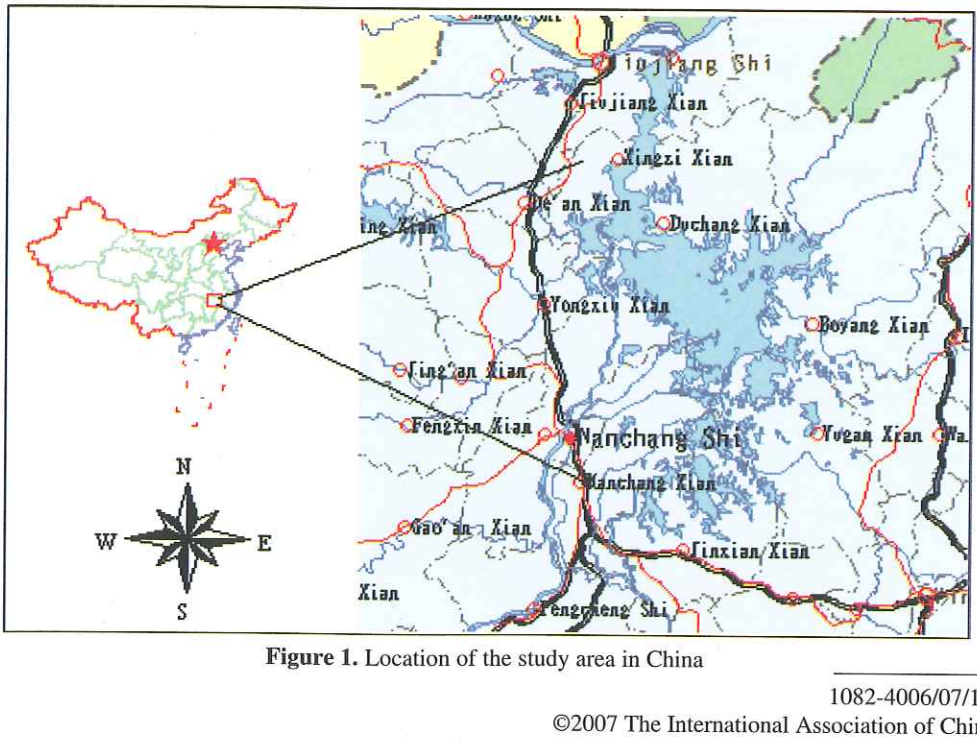

Figure 1. Location of the study area in China

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determinant of *Carex* growth and distribution. Similarly, the water level of the lake is also important for the conservation of migratory birds and safeguarding the urban water supply of the lake area. However, the wetland biological resources of Poyang Lake have been severely affected in recent years due to both natural and human elements, resulting in a decline of the wetland system's ecological functions and self-restoration ability. This decline is associated with a decrease in the area of the water body due to sedimentation, severe local water pollution, and a general reduction in biological quality(Zhang, 2004; Zhu, et al., 2004). In 2006, Poyang Lake witnessed severe low water levels resulting in a series of ecological consequences, including the disruption of shipping, threats to the life water supply, and the deterioration of various habitats, due to the premature emergence of *Carex*. Large cost and inaccessibility make it difficult to monitor the *Carex* dynamics of China's largest freshwater lacustrine system. Fortunately, remote sensing technology has the potential to monitor changes in the *Carex* dynamics and to analyze the habitat of migratory birds over large areas at a low cost (Nepstad, et al., 1999). Remotely sensed data have been extensively used to map land cover (including wetland areas) for the purpose of ecological conservation, e.g., identifying areas demanding protection and the monitoring of important habitats(Steininger, et al., 2001; Turner, et al., 2003).

Remotely sensed data has previously been used for acquiring information on the environment and resources of Poyang Lake wetland, including the specific characteristics of healthy vegetation(Zhou, et al., 2002), and multitemporal analysis. The leaf, caudex, radicle, and grass seed of *Carex* are the food of wild geese and ducks (migratory birds) during the winter season in the Poyang Lake wetland area. However, research on *Carex* dynamics and its connection with lake water levels and delta changes in Poyang Lake is few, and 3s (RS, GIS and GPS) technology analysis of migratory birds environment is lacking, too. The purpose of this study was (1) to map the dynamic distribution of *Carex* based on an advanced SAM approach and to analyze its dynamic relationship with lake water level, delta change of the Gan River, and migratory bird distribution using 3s technology; (2) to understand the fragmentation index dynamics of the *Carex* landscape under different water levels and during different seasons; and (3) to advance the study of wetland evolution in the Poyang Lake area.

II. DATA AND METHODS

A. Data

Landsat TM and ETM+ images with a spatial resolution of 30 × 30 m in bands 1–5 and 7 were used in this study. For the purpose of this study, the Poyang Lake wetland is defined as the floodplain area or the Poyang Lake cofferdam. One Landsat image, taken in July 1989, was used for the automatic retrieval of flooding area and a further two in October 2005 and December 1999 were used for the extraction of lake beach *Carex* vegetation information within the Poyang Lake cofferdam and for the dynamic analysis of *Carex* vegetation. These 3 satellite image scenes were obtained on July 15th, 1989 (flooding season), December 10th, 1999, and October 31st, 2005 (dry season), respectively. Before subsetting images, and after the dark subtraction method of atmospheric correction had been applied to the atmospheric scattering corrections of the image data (the digital number to subtract from each Pband is the band minimum), radiometric calibration was performed to transform the digital number (DN) values into image reflectance using published post-launch gains and offsets (on the TM image of 1999) (see http://landsat7.usgs.gov/cpf/cpf.php) or Envi 4.2 calibration utility (on the TM image of 2005).

B. Study area

The study area was confined to the floodplain region. The focus of the study was the *Carex* community. *Carex* is the most common visible vegetation, and the *Carex* community is the main constituent community of the grassland vegetation of Poyang Lake; this vegetation is often distributed on the lower 13–14 m reaches and wash fringes of the lake in circular–shaped patches. *Carex* is a perennial herbaceous plant with a rhizomorphous caudex that sprouts after the autumn flood season and overwinters as scorched ground parts. Individual *Carex* plants can grow to heights of approximately 40–60cm. Of the species coexisting with *Carex*, *Kalimeris indica* predominates. Species such as *Artemisia dubia*, *Polygonum hydropiper*, and *Phragmites communis* are present in smaller numbers.

The July flood season images were used to create a mask of two classes—water and land. The flood plain of Poyang Lake during the flood period was used for automatic mapping of the lake beach vegetation distribution area in the low water season, limiting the *Carex* mapping area to within the lake beach wetland and lake water area. The extracted flood plain area in the image for July was used as a mask to obtain the lake beach wetland and water area from the images for October and December, i.e., our study area. As the water body and land have different reflectance, it is possible to set a threshold to distinguish water body from land using reflectance values. Based on the statistical analysis of the reflectance of water body and land regions on band 4, a threshold value of 0.12 was applied to distinguish water and non-water areas on the image of 15 July, 1989; band 4 (near infrared band) was selected as this provided the best differentiation between water and land. Image pixels with reflectance values of less than 0.12 were classified as water (including both lake and reservoir water), whereas the remainder were classified as land. It can be seen from Figure 2 that the reflectance of the lake water is less than 0.12.

C. Mapping *Carex* dynamics

Based on in-situ investigations conducted on October 31, 2005 and December 15, 2004, there were 2 sites (29.2117N, 116.0355E; 28.8877N, 116.3219E) with dense green *Carex* growth that were positioned to extract the image endmember spectra of *Carex*

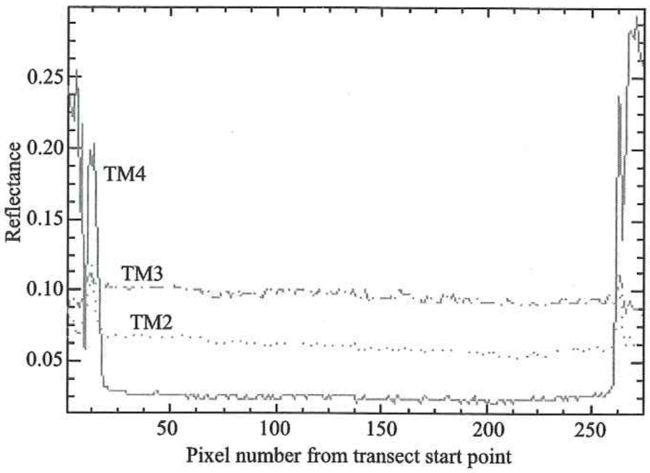

Figure 2. Reflectance transect of ETM+ band 4 across Poyang lake

to be used for the SAM classification analysis of *Carex* in 2 temporal scenes of Landsat TM and ETM+ images(Figure 3), respectively. Therefore, it is possible to determine the spatial distribution and seasonal succession of *Carex* vegetation within the Poyang Lake cofferdam; information is necessary for the sustainable development of this type of seasonal wetland ecosystem. Initially, the standard *Carex* spectra was extracted from 2 calibrated TM images obtained in 2005 and 1999, and the dense green *Carex* vegetation was classified based on the abovementioned SAM method.

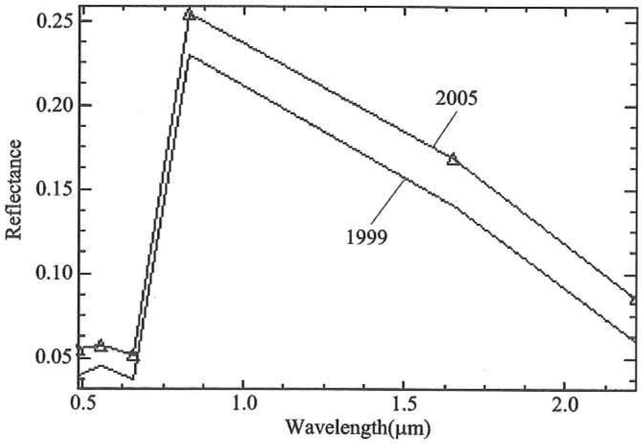

Figure 3. Two *Carex* endmember spectra extracted from the images of 1999 and 2005

D. Spectral angle mapping (SAM)

SAM is one of the most commonly used methods in spectrometry, i.e., the comparison of spectral angles between different land covers. The difference of spectral angles between the spectra of natural materials, such as lake water, reservoir water, and other land types, and those of grassland endmembers, is obvious.

SAM techniques incorporate linearly scaled reflectance patterns in order to avoid the misclassification of land use/land covers that are linearly scaled versions of a particular reflectance pattern.

The angle that defines a spectral signature or class does not change, and the vectors forming the angle from the origin delineate and contain all possible positions for the spectra. Because the spectral angle classifier utilizes the shape of the pattern for clustering and classification of multispectral image data(An, et al., 2005; Luo, et al., 2002; Sohn, et al., 2002), the analyst's ability to relate field information to spectral characteristics and spectral shape patterns for different land cover/land use types are important for acquiring accurate mapping results.

In our study, spectral angle-based statistical analysis was better able to quantify *Carex* vegetation than other wetland vegetation types. The image endmember spectrum of *Carex* was located by in-situ investigation and extracted from the TM images of 2005, while the image endmember spectrum of *Carex* on the TM image of 1999 was approximately extracted from the location on the image of Dec 15, 2004. This is more convenient and precise than the traditional supervised and unsupervised methods of classification under automation.

III. RESULTS AND DISCUSSION

A. *Carex* mapping results

The precision of the dense *Carex* mapping was validated by a field investigation. Of the 11 field sites investigated, there were 10 sites supporting *Carex* growth; the exception being 1 site supporting predominantly *Artemisia selengensis*. However, even at this site there was *Carex* growing under the boscage of *A. selengensis*. A high precision of 91% for *Carex* mapping was achieved.

B. *Carex* dynamics and delta change

The comparison of *Carex* distribution dynamics under different lake water levels assists in gaining an understanding of the relationship by the spatial revealment of shoal between various bird habitats and the *Carex* growth environment in the study area. Figure 5 and Table 1 display the relationship as obtained with normal spatial view. Figure 5 is the SAM-extracted *Carex* distributions of Dec 1999 and Oct 2005 overlaying on the TM image of 1999. The areas of *Carex* were analyzed with ArcView 3.2 GIS(Table 1). The distribution dynamics of shoals and *Carex* indicates that the lake water level is the decisive factor determining *Carex* area, and that seasonal succession during low water plays an important role. Due to the different imaging acquirement dates, the *Carex* distribution probably underwent the different process of succession from *Carex* emergence to senescence, and also exhibited a shorter growth period than the meadow plants growing in land. The *Carex* distribution on Oct 31, 2005 is nearer to the center of the lake body and

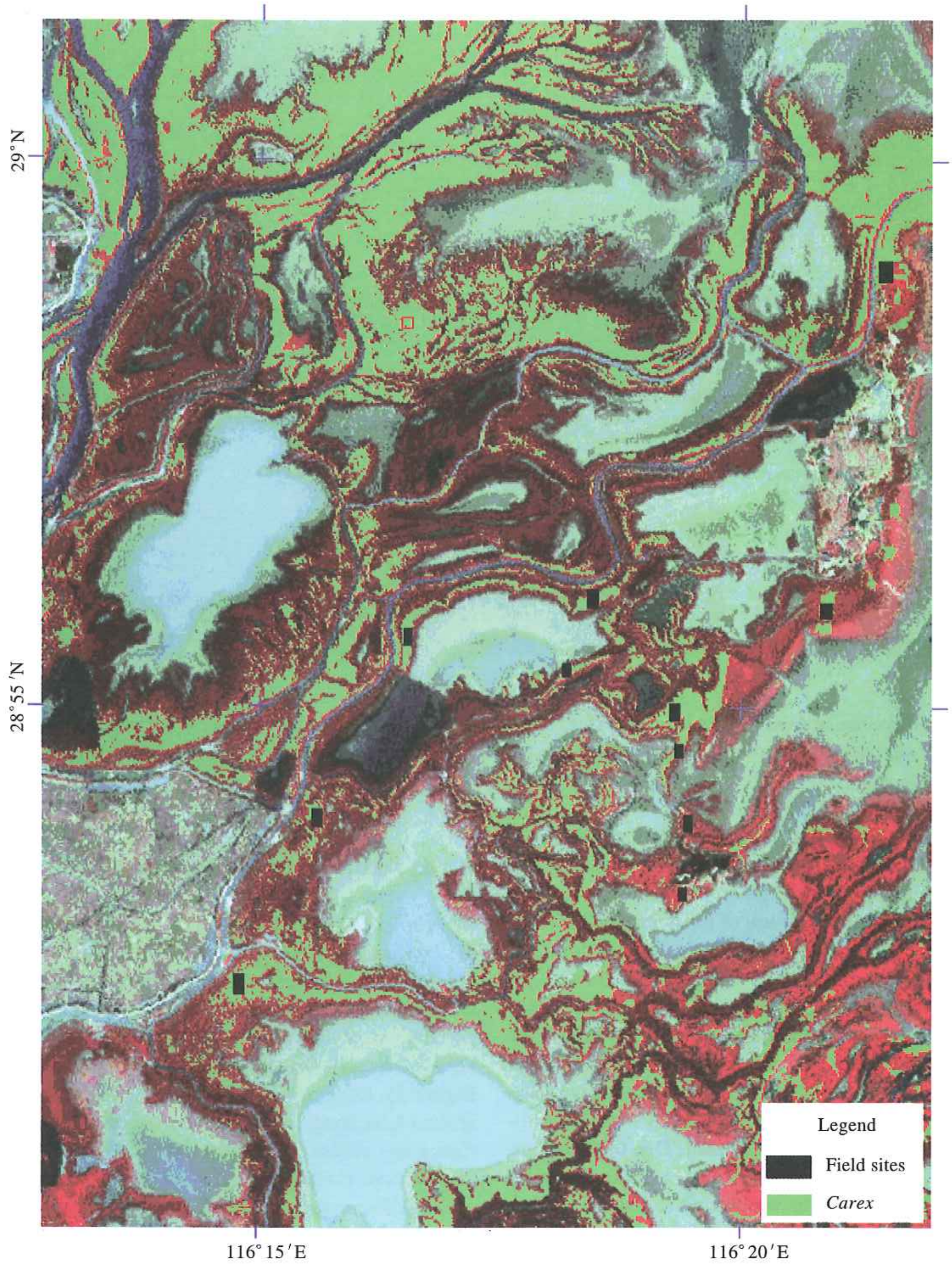

Figure 4. Sites of classification result validation in the study area

Table 1. *Carex* area in 1999 and 2005 and their overlapped area

Category	Lake water level at Xingzi hydrological station(m)	Area(sq.km)	Area(ha)
Dec. 10, 1999	10.74	148.8	14868.8
Oct. 31, 2005	12.52	149.9	14985.3
Overlapped area		61.1	6101.7

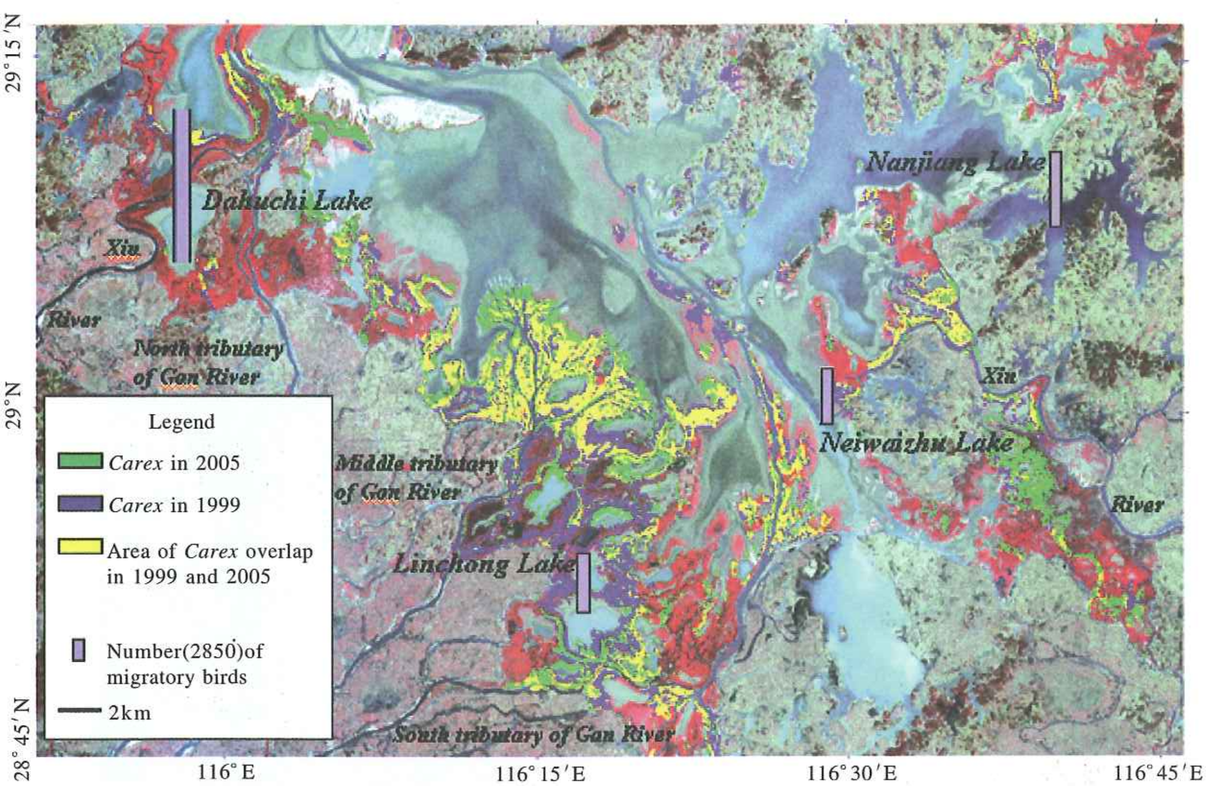

Figure 5. *Carex* distribution from the TM images of Dec. 1999 and Oct. 2005, showing the habitats supporting the 4 highest annual migratory bird populations in the study area (R, G, B = TM 4, 3, 2 of the TM image of Dec. 1999)

riverway. The *Carex* distribution characteristics and image tones of shoals on Oct 31, 2005 indicate that the Gan River delta of Poyang Lake is extending north and northeast, since the *Carex* was situated at the mouth of the delta even under a higher lake water level (data from the hydrological station at Xingzi) in 2005. This is probably the result of a severe drought that extended from September to the early November of 2005 (http://www.shuigong.com/news/related/20051117/news12505.shtml) resulting in a rapid drop in the Poyang Lake water level and the vigorous growth of seasonal wetland vegetation. After November, the wetland area would usually undergo a period of vegetation senescence. Due to the severe drought of 2005, the growing area of *Carex* in the estuarine delta regions of the Gan river was found to extend further northwards more on image of Oct 31st, 2005 than the image of the same month in 1999. Although the *Carex* distributions for the 2 days presented in Figure 5 and Figure 6 were similar, it suggested that if the same determination were to be performed today, the area of *Carex* would be considerably greater after November, 2005. Despite the relatively higher water level, the continued deposition of silt has resulted in an increased shoal area; and this in turn has been conducive to a further expansion of *Carex*. The lake shoal distributions in Figure 5 and Figure 6 clearly indicate more shoal land in 2005 than 1999 due to continuous sedimentation and drought. In this regard, it needs further study that which of sedimentation and drought process more dominates the *Carex* dynamic.

C. *Carex* distribution and migratory birds

The *Carex* community is one of the most important ones of the Poyang Lake wetland vegetation, which provides good environmental conditions for migratory birds to locate food and habitat sites. However, in the 4 lakes with the largest populations of migratory birds, i.e., Dahuchi Lake, Linchong Lake, Neiwaizhu Lake and Nanjiang Lake (from left to right in Figure 5), large areas of *Carex* distribution are found only around Linchong Lake. The distribution and abundance of *Carex* are probably not the only factors determining bird distribution; it is possible that other grassland communities, such as *Miscanthus sacchariflorus* and *P. communis*, play an important role in providing food and habitat for migratory birds. Meanwhile, from the perspective of migratory bird conservation, it is noteworthy that the 4 most important lakes for migratory birds are situated at the main estuaries in the Poyang Lake drainage.

D. *Carex* landscape ecology

The distributions of dense *Carex* in Dec 1999 and Oct 2005 were mapped based on the spectral angles of image pixels with a corresponding reference *Carex* endmember. The total area of *Carex* was approximately 150 km^2. The following formula was used to calculate the landscape fragmentation index of *Carex*:

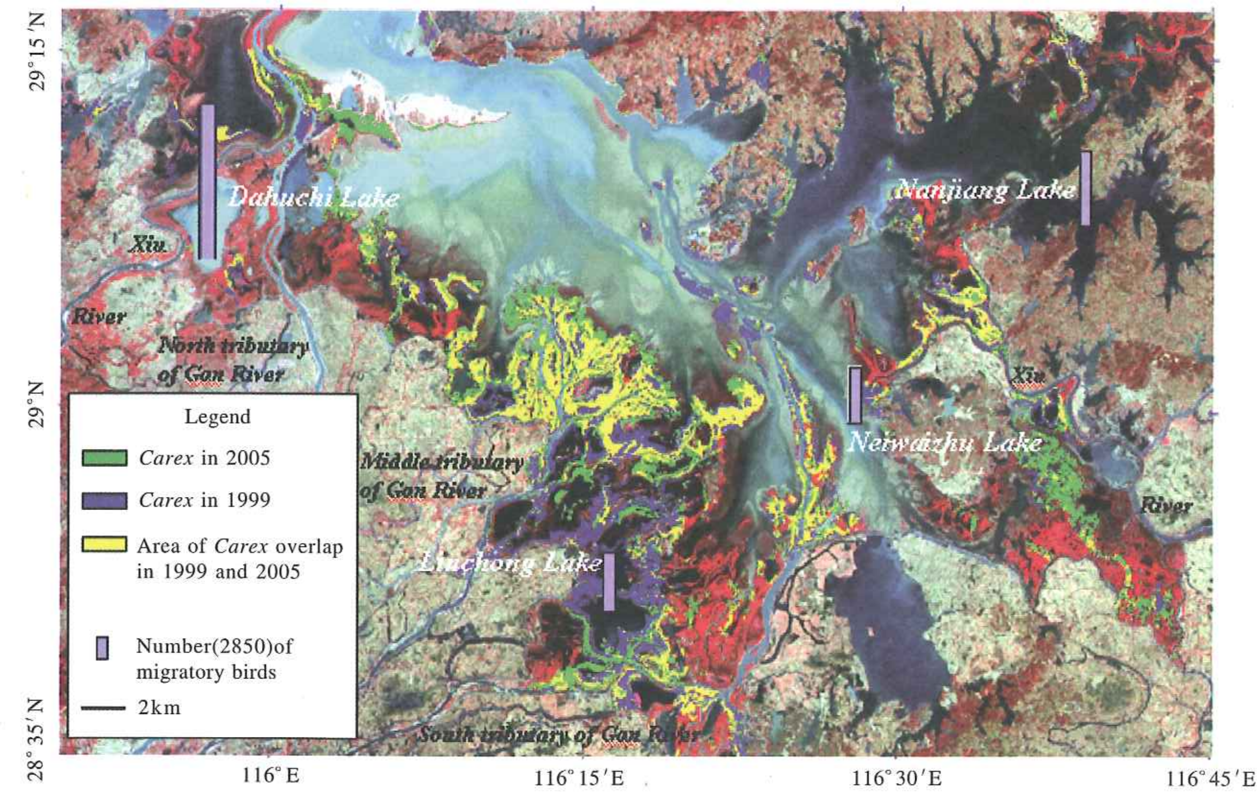

Figure 6. *Carex* distribution from the TM images of Dec 1999 and Oct 2005, showing the habitats supporting the 4 highest annual migratory bird populations in the study area (R, G, B = TM 4, 3, 2 of the TM image of Oct 2005)

$$C = \sum N_i / A$$

where C is the landscape fragmentation index of *Carex*, $\sum N_i$ represents the total number of *Carex* landscape-type polygons, and A is the total area of *Carex* landscape. The fragmentation index of *Carex* landscape in the Poyang Lake wetland area is 0.345 and 0.372 in 1999 and 2005, respectively (0 represents a landscape that has received no damage; 1 represents one that has been completely destroyed). Accordingly, the values present in Table 2 indicate that the landscape in Poyang Lake had been influenced to a greater extent by human activities in 2005 than in 1999, following six years' evolution. Therefore, protection of the Poyang Lake wetland needs to be further enhanced in order that it retains its status as an internationally important wetland site.

Table 2. A comparison of the fragmentation index of *Carex* landscape in 1999 and 2005

	Number of polygons	Area(*ha*)	Landscape fragmentation index
Dec. 10, 1999	5537	14868.8	0.345
Oct. 31, 2005	5169	14985.3	0.372

IV. CONCLUSION

Remote sensing has been proved an indispensable mapping tool for wetland grassland research in the Poyang Lake area. Employing an automatic and rapid mapping method for the discrimination of water and land, mapping of *Carex* vegetation within the Poyang Lake plain area during the low water season was undertaken using multispectral Landsat TM and ETM+ data. The dense *Carex* distributions were extracted by the SAM approach based on the comparison of the reflection between a *Carex* endmember and image pixels. The spatial distribution of *Carex* (within the plain area in December 1999 and October 2005 by ETM+ and TM images, respectively) was mapped separately and by overlaying. The SAM method used for determining *Carex* distribution can also be used for the auto-mapping of other wetland vegetation types in the Poyang Lake area, such as *M. sacchariflorus* and *P. communis,* in order to gain a better understanding of migratory bird habitats. This research demonstrates that multitemporal images with their near-infrared reflection of water bodies and a spectral library are valid choices for automatic and rapid wetland grassland classification. The *Carex* distribution determined by remote sensing mapping and GIS can be used as an indicator of lake water levels and lake area drought grade in the Poyang Lake plain. The *Carex* dynamics are of utility to the study of delta evolution and the analysis of migratory bird habitat. The more temporal TM scenes and corresponding grassland distribution mapping related to water levels can be used to build a grassland area water level warning system, which may be used to simulate and predict the grassland area and regional drought grade during the low water season.

Further study on the spectral library-based automatic extraction of other wetland vegetation types in the Poyang Lake area using 3s technology should also concentrated upon the habitat environment of migratory birds. In addition, the relationship between other vegetation communities and large amount of migratory habitat need to be further investigated.

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