MONITORING DYNAMICS OF GRASSLAND VEGETATION IN POYANG LAKE NATIONAL NATURE RESERVE，USING MODIS IMAGERY

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Commission VI, ThS-19

KEY WORDS: Satellite remote sensing, Normalized Difference Vegetation Index (NDVI), Spatio-temporal modeling, Ecosystem

ABSTRACT:

The particular flood recessional ecosystem in Poyang Lake provides young and high quality grasses in late autumn and wintertime, and attracts millions of migratory birds to over winter. Grasslands along the lakes within Poyang Lake National Nature Reserve (NNR) have a remarkable phenology. So far, little attention has been paid to this dynamics of phenology. This thesis aimed to describe and investigate the seasonal patterns of the recessional grassland vegetation and how are these related to environmental variables (elevation, water level and air temperature). Normalized Difference Vegetation Indices (NDVI) derived from time-series MODIS was applied to investigate the phenological patterns of grassland vegetation. Huisman-Olff-Fresco model II (HOF model II) was employed to detect the response of the grassland vegetation to environment variables. The results revealed a strong negative relationship between the cover percentage of *Carex* and elevation and a positive relationship between the length of *Carex* and elevation, with R^2 was 0.317 and 0.381 respectively. Time series NDVI showed clear seasonal phenological patterns of *Carex*. The phenology dynamics was attributed to the fluctuation of water level and air temperature between years. It revealed that NDVI of *Carex* has a negative relationship with water level and a positive relationship with cumulative air temperature respectively.

1. INTRODUCTION

The particular flood recessional ecosystem in Poyang Lake provides young and high quality grasses in late autumn and wintertime, and attracts millions of migratory birds to over winter. As an important national and international wetland ecosystem, it has significant ecological function in biological diversity protection.

The grasslands along the lakes in Poyang Lake National Nature Reserve (NNR) have a remarkable phenology (Wu and Ji,2002; Si, 2006; Zeng, 2006). Their species composition and pattern of greening change with elevation. Grasslands at lower elevation are dominated by short grasses and sedges (*Carex*), while grasslands at higher elevation have *Miscanthus sacchriflorus* and *Cynodon daxtylon.* At higher elevations, vegetation emerging in spring continues to grow over summer and senescence in autumn. Vegetation at lower elevations which is green in autumn, winter and spring submerges for a shorter or longer period in summer. In autumn, when the water recedes, vegetation emerges again at the lake edge (Si, 2006). This difference in species composition and phenology has been attributed to differences in flooding.

The phenology of the grasslands is also affected by temperature. Highest and lowest monthly temperature of 29.1℃ and 4.5℃ occur in July and January respectively in Poyang Lake NNR (Wu and Ji, 2002). In late autumn, vegetation at higher elevation dies off. Vegetation at low elevation remains green but their growth may be reduced or stopped because of the low temperature.

However, the grasslands in Poyang Lake NNR have shank and thus habitats for wild migrate birds are in danger, as a consequence of lower and lower water levels in Poyang Lake. This change in water level has a certain impact on the date of up greening and development of recessional grasslands. Thus monitoring the phenology dynamics of this recessional grassland vegetation has specific meaning for habitat protection of migratory birds. So far, researches have been conducted which focus on monitoring and mapping the grasslands in Poyang Lake (Si, 2006; Zeng, 2006). However, little attention has been paid to this dynamics of phenology. Time series remote sensing offers the possibility to monitor wetland vegetation (Salomonson *et al*., 1989; Zhang *et al*., 2003; Barbosa *et al*., 2006) and map phenological patterns of them (Davidson and Csillag, 2003; Zeng, 2006). Normalized Difference Vegetation Indices (NDVI) has been used for vegetation phenology at global, regional and local scale (Maselli *et al*., 1998; Chen *et al*., 2001; Choo *et al*., 2002; Schmidt and Karnieli, 2002; Jin and Sader, 2005; Barbosa *et al*., 2006; Beck *et al*., 2006; Si, 2006).

This thesis aimed to describe and investigate the seasonal patterns of the recessional grassland vegetation using Moderate Resolution Imaging Spectroradiometer (MODIS) and how are these related to environmental variables (elevation, water level and air temperature).

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2. RESEARCH MATERIALS AND METHODS

2.1 Study Area

The research focused on Dahuchi Lake, which is the core area in Poyang Lake NNR. It lies to the south of the Poyang Lake NNR with an area of 30 km^2 (Wu and Ji, 2002). The elevation range of this area is from 12 to18 meters, with only 5 or 6 meters difference between the minimum and maximum. Although the terrain appears almost flat, vertical distribution pattern of vegetation communities was developed due to water fluctuation.

The water levels in Poyang Lake NNR are typically high in summer due to the monsoon rains, and low in winter. In rainy season, the water level of Dahuchi Lake rises and lake is filled by flooding water from the Yangtze River and sometimes would be merged together with the large Poyang Lake. In dry season, the water levels decrease in these sub lakes and vast areas of shallow water and flooded muddy banks are exposed.

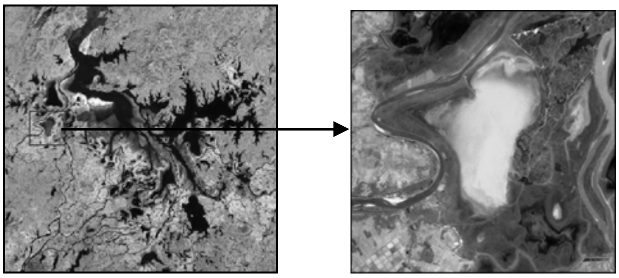


Figure 1 Study area: Dahuchi Lake (TM image on 15th October, 2002). Location of Dahuchi Lake in Poyang Lake (left) Dahuchi Lake (right)

2.2 Data Used

MODIS land surface reflectance product was selected because of its finer spatial and temporal resolution (Xiao *et al*., 2005). This MOD09CQK product has high quality since has been atmospheric and geometric corrected. It was used for calculating NDVI to investigate the phenological patterns of grassland vegetation within and between years.

The digital elevation model (DEM) of Dahuchi Lake was obtained to derive elevation information. The spatial resolution is 20 m and vertical accuracy is around decimeter. The water level data and mean daily air temperature data measured in Nanchang Metrological Station (28° 22′ N, 115° 33) in 2001, 2003, 2004, 2005 and 2006 were used as environmental variables for regression analysis.

Topographic map of the Poyang Lake NNR was used to get general idea of the study area and help accessing to sample plots in the field. Botanical data from literature and expert knowledge from stuff who has worked in the Poyang Lake NNR for more than 10 years were used to identify the grasses species during filed survey and data analyzing.

2.3 Field Survey

Field survey was executed on 13^{th} to 16^{th} September 2006 during the summer-blooming growth season from September to November (Dou *et al*., 1997), when the water depth of Dahuchi Lake was around 1.2 meters. Several pre-sample lines were designed based on TM image of 2005 October 15^{th}, which were vertical to zonal belts of the grassland could be visual interpreted on the image. This strategy insured the sample plots that taken along these lines can include vegetation at all different elevation, which was considered to play a key role in modelling (Guisan and Zimmermann, 2000).

In total, 71 sample plots were observed. The elevation of these sample plots run from 12.9m to 15.9m. At each site, plot of 20 by 20 meters was established. Species and their cover were described and estimated in this plot. Within each site four sub plots of 1 m^2 each were established, evenly located at the direction of north, south, east and west from centre of the plot. In these sub-plots, data on cover percentage, names of dominant species, length of the grass vegetation measured from ground surface and other observation were collected. The final cover percentage and length of the sample plot was calculated by the average of the four sub plots.

2.4 NDVI

NDVI was calculated for the each date for the MOD09GQK datasets (Equation (1)) for 2001, 2003, 2004, 2005 and 2006 to get vegetation greenness. Mean NDVI values of *Carex* in each month were calculated for *Carex* for 5 years, based on the percentage of *Carex* cover. 70% was used as the threshold for the calculation, assuming that when *Carex* covers more than 70% in the sample plot, it appears to be the overwhelming dominant vegetation species in this sample plot.

$$NDVI_{mean} = \frac{\sum NDVI_i}{n} \qquad (1)$$

where $NDVI_{mean}$= mean NDVI value in each month
$NDVI_i$ = individual NDVI value of in each sample plot with *Carex* cover more than 70% (i=1, 2, 3…n)
n = total number of days in each month.

2.5 Seasonal Pattern of Water Level and Cumulative Air Temperature

The water level records of Dahuchi Lake were based on the Wusong height datum, which is the system that used by the government for Yangtze in China. It was converted to the National Vertical Datum 1985 which is the official and most widely used height system in China, for the sake of calculation with digital elevation model in Dahuchi Lake. The elevation of levelling origin of this height system is 72.260 m (Kong and Mei, 2002; Ning et al., 2004). Mean water levels for each month in these years were also calculated for further monthly statistical analysis.

$$H_{1985} = H_{wusong} - 1.836 \qquad (2)$$

where H_{1985} = height in National Vertical Datum 1985
H_{wusong}= height in Wusong height datum

Cumulative temperature is an efficient way to describe temperature condition for vegetation growth. Fidanza *et al*. used it for prediction of crop emergence (Fidanza *et al*., 1996). Bartholomew and Williams (2005) used cumulative temperature to assess whether it can be a useful indicator of forage cool-season grass development.

Carex is a kind of sedge, which prefers to grow under cool environment and inhabit in mesotrophic fens or frequently waterlogged conditions. In Poyang Lake NNR, they are activate under temperature 8-20℃ (Si, 2006) producing young leaves which utilized by migratory birds. Schutz's study showed that the seed of *Carex* may remain non-dormant under 10-20℃ regime during burial when water level fluctuates frequently. This enables them to germinate whenever they are exposed to air again during the growing season, once inundation has ceased (Schutz, 1997). Thus, 10℃ was used as the standard temperature threshold to calculated cumulative temperature to derive inner- and inter-annual air temperature conditions for the growth of the recessional grasslands.

2.6 Regression Analysis

Three dominant vegetation species were suggested by earlier researches in Poyang Lake NNR (Si, 2006; Zeng, 2006). The variation in the abundance of species in space and time were supposed to be related to environmental factors (Dou *et al*., 1997; Cui *et al*., 2000). However, very few studies have examined these relationships through statistical analysis in Poyang Lake NNR. Simple mathematical models then were required to describe these observed relationships.

Huisman-Olff-Fresco model II (HOF model II) was employed to detect the response of the grassland vegetation to these environment variables. HOF model is a hierarchical set of five models for species response analysis, which is particularly suited for description of responses in time or over major environmental gradients (Huisman *et al*., 1993; Guisan and Zimmermann, 2000).

2.6.1 Regression for length of *Carex* and Elevation: In early spring, as air temperature increasing, *Carex* green up and start to grow. At different elevation, the way that *Carex* grow is different. At lower elevation, *Carex* are flooded in June or early July (depending on hydrological conditions of the year), with average length around 17cm (Dou *et al*., 1997). During rainy season, *Carex* along the edge of the lake would be flooded as water level rising. By the time they are totally submerged, *Carex* would stop growing. At higher elevation, *Carex*, which are submerged by flooding later than those at lower elevation, would continue to grow and their length would be longer. For the year that water level is low during summer, *Carex* at higher elevation even would not be submerged and keep growing through summer time.

Usually, mature *Carex* (*Carex cinerascens*, *Carex argi* and *Carex unisexualis*) has length from 30 to 70 cm (DEELECTIS FLORAE REIPUBLICAE POPULARIS SINICAE AGENDEE ACADEMIAE SINICAE EDITA, 2000). Field observation found the maximum length in Dahuchi Lake was around 110 cm and no more than 120 cm, hence 120 cm was used as the upper threshold in this analysis. Thus the M was equal to 2.079 as the upper bound in HOF model II after $\log_{10}$ transformed.

2.6.2 Regression for length of *Carex* and Exposed Days: The number of exposed days to air for each sample plot is determined by two factors. One is the elevation of the sample plot. The other one is water levels along time gradient. Firstly, the difference between the height of water level and elevation was calculated by using daily water level minus the value of elevation of each sample plot. The formula was list below:

$$\alpha = H_{1985} - ELE \quad (3)$$

Where H_{1985} = height of daily water level of sample plots measured in National Vertical Datum 1985
ELE = elevation of sample plots;
α = value of difference between daily water level and elevation of sample plots.

When water level was higher than the elevation of the sample plots, labelled α as 0; when water level was lower than the elevation of the sample plots, labelled α as 1. Then sum function was conducted to calculate the total number of days at each sample plot in 2006 from January to September.

$$N = \sum \alpha_i \quad (4)$$

Where α_i = difference between daily water level and elevation of each sample plot on each date (i =1, 2, 3,…, 365 or 366)
N = total number of exposed days to air of each sample plot

2.6.3 Regression for NDVI and Time Series Seasonal Water Fluctuation: Water levels trigger up greening of *Carex* in autumn. If water level in September or October ceased earlier, *Carex* would green up at the edge of the lake earlier. Consequently, the earlier the Carex started to grow again, the higher the NDVI value would be obtained from satellite images. Thus, if the water level was high in September or October, the mean NDVI value of *Carex* would be low. HOF model II was employed to detect how water level in September or October determined the NDVI value of *Carex*. The upper bound M in the model was set as 1 since the NDVI ranged from -1 to 1.

2.6.4 Regression for NDVI and Time Series Cumulative Air Temperature: In Dahuchi Lake, *Carex* green up as early as in February if the air temperature was warm enough for their growth. In some years, when winter was cold and air temperature was low in early spring, *Carex* would green up later and grow slowly. Thus the NDVI values on satellite images would appear differently in these months between years.

The mean monthly NDVI values in spring (February and March) during which vegetation would green up were calculated for each year. Cumulative temperatures above a threshold of 10℃ at the end of February and March were used. HOF model II was applied to detect how the cumulative temperature affected the up greening of *Carex* in spring.

3. RESULTS AND DISCUSSIONS

3.1 Spatial Composition of Grassland Vegetation

Young recessional vegetation was located at the edge of the lake or spring out in the wet land with an average length no more than 15 cm. The ground was wet muddy ground mixed with open water. There were two species found in these areas. In most of the cases, young *Carex* dominate with a proportion more than 95% of the vegetation. Along elevation gradients, a little bit far away from the edge of the lake, *Carex* cover dominated more than 70%. The lengths of the plant measured from ground surface were from 20 to 40 cm. A great lot of dead *Carex* with length around 40 cm were found laying over the muddy ground surface. It revealed that in spring *Carex* developed in these areas and died off during submerged when the water level rose in summer. At higher elevation, *Carex* and *Miscanthus* grew mixed with each other. At higher elevation far away from the edge of the lake, *Miscanthus* was the dominant species which take up more than 70% land cover. Its height varies from under 10cm to more than 300 cm along the gradients from lower to higher elevation.

3.2 Relation between *Carex* and Environmental Variables

3.2.1 Relation between Elevation and *Carex* Cover: *Carex* prefers to inhabit in mesotrophic fens or frequently waterlogged conditions. In Dahuchi Lake, they usually emerged at the edge of the lake bank at lower elevation. At higher elevation, few *Carex* grew mixed with *Miscanthus* and *Cynodon*. At elevation around 15 m, *Carex* was hardly found. The regression model was list in Equation (5). The R^2 was 0.317. The significant level was 99%. It indicated that as the elevation increase, the cover percentage of *Carex* decreased, while *Miscanthus* increased. It also revealed that *Carex* dominated elevation at around 13 to 13.5 m, while *Miscanthus* appeared at higher elevation around 14 m. Within the range of elevation from 13 to 13.5 m, most of sample plots covered by *Carex* more than 50%. Beyond 14 m, *Carex* covered less than 30% in the plots and almost none was found at 16 m.

$$y = 100 \cdot \frac{1}{1 + e^{-29.198511 + 2.0817276\ x}} \qquad (5)$$

3.2.2 Relation between Length of *Carex* and Elevation: A zonal pattern of grassland had developed since the water level declined gradually in autumn. In the field, the length of *Carex* varied from 8 cm to more than 110 cm. At the edge of the lake, the length of *Carex* was around 10cm, while at higher elevation the length of *Carex* was much longer. In addition, the longer the *Carex*, the colour of it was darker. In the west and north part of the lake, most of *Carex* had length more than 40 cm. They were old and appeared yellow at the top of the plant, which indicated that they had been senescence. The Figure 2 showed a positive relationship between length of *Carex* and elevation using HOF model II. The R^2 is 0.381. The significant level was 99%. It revealed that *Carex* were longer at higher elevation than those at lower elevation.

$$y = 2.079 \cdot \frac{1}{1 + e^{26.569545\ -\ 2.0743234\ x}} \qquad (6)$$

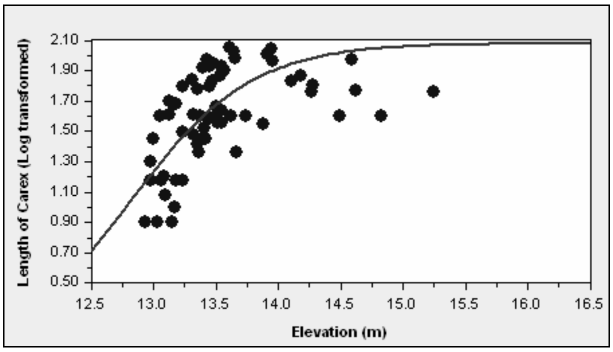


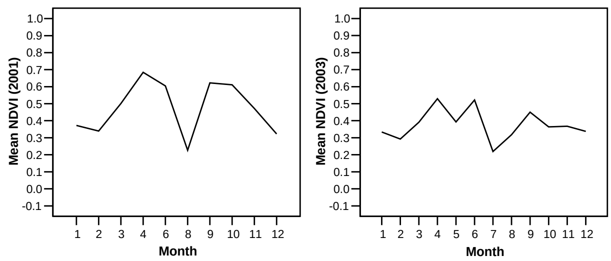
Figure 2 Relation between length of *Carex* and elevation

3.2.3 Relation between Length of *Carex* and Exposed Days: *Carex* emerged when they exposed again to air since the flood receded in autumn. As water level falling, new belts of *Carex* developed down-shore. Meanwhile, the *Carex* which emerged earlier up-shore had been growing taller and older. This continued as the water level fell, resulting in a zonal pattern of short young *Carex* down-shore and taller and older *Carex* up-shore. Thus, the longer the period that *Carex* exposed to air, the taller they were. The Equation (7) showed a positive relationship between the length of *Carex* and the number of exposed days. It revealed that *Carex* grew taller when the period of inundation was shorter. The R^2 is 0.341. The significant level was 99%.

$$y = 2.079 \cdot \frac{1}{1 + e^{-0.076247538\ -\ 0.01014463\ x}} \qquad (7)$$

3.3 Time Series Seasonal NDVI Pattern of *Carex*

Seasonal phenological NDVI patterns of *Carex* were obtained in Figure 3. In most of years, NDVI values increased sharply from February in early spring and yield a peak in April or May with a value around 0.6. In 2001, it was extremely high around 0.7. NDVI decreased gradually during summer time and reached its lowest point in July or August at around 0.2, with small fluctuation sometimes. As early as in late August or September, NDVI of *Carex* increased again through autumn and then decreased in winter time. However, in different years, the maximum and minimum NDVI values of *Carex* appeared in different month at different values.



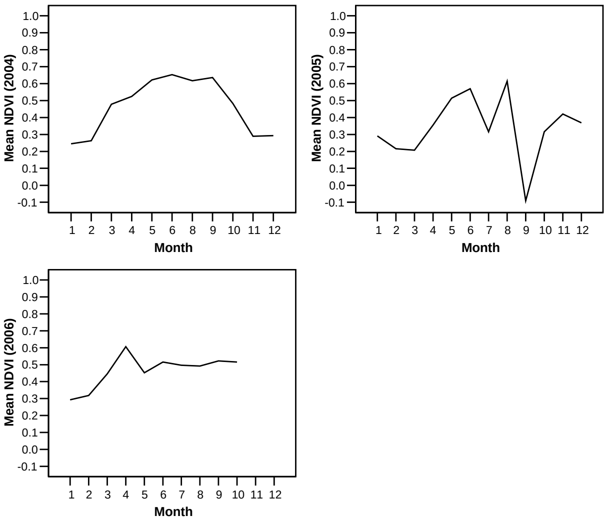


Figure 3 Time series seasonal NDVI patterns of *Carex*

3.4 Relation between NDVI of *Carex* and Water Level

From the time series seasonal NDVI patterns of *Carex* and water level, it revealed a negative relationship between them. Also, the date of NDVI increased again after rainy season was different between years. It was attributed to the variation in the date that water level declined. The HOF regression model II (Equation (8)) showed a negative relationship between NDVI values of *Carex* and water levels in September and October through regression analysis. The R^2 was 0.579. The significant level was 95%. It revealed that if water level had declined as earlier as in September or October, the NDVI value of *Carex* was higher. Thus, it elicited that in autumn the date of up greening of *Carex* was negative related to the date of water level declined.

$$y = \frac{1}{1 + e^{-12.608919 + 0.90020346\,x}} \tag{8}$$

Above it was suggested that water level influences up greening of *Carex* in autumn. However, in 2004 and 2006, although there was a similar fluctuation pattern with the maximum value of water level around 15.0 m, the NDVI in 2004 was quite higher than in 2006 since up greening. We attributed this to the variation in the date of water level increased. It is possible because *Carex* had been tall enough when water level increased and was not totally submerged during rainy season. And NDVI values of the pixel somewhat influenced by mixed open water might be another reason. However, this situation confirmed that the seasonal dynamics of water level has certain impact on the seasonal phenology of *Carex*.

3.5 Relation between NDVI of *Carex* and Cumulative Air Temperature

In early spring in February and March when the air temperature was warm enough (above 10℃) for green up, *Carex* started to grow. Consequently, the NDVI value increased. Regression analysis using HOF model II revealed a positive relationship between cumulative temperature and NDVI value of *Carex* through. It indicated that when cumulative temperature was higher in spring, the NDVI value of *Carex* was also relative higher. The HOF regression model was in Equation (9). The R^2 was 0.648. The significant level was 95%.

$$y = \frac{1}{1 + e^{1.2748687 - 0.0022939087\,x}} \tag{9}$$

4. CONCLUSIONS

The recessional grasslands in Dahuchi Lake have a spatial pattern of species composition. And it changes along elevation gradient. Grasslands at lower elevation are dominated by short grasses and sedges (*Carex*), while grasslands at higher elevation have *Miscanthus sacchriflorus* and *Cynodon daxtylon*. This research showed that the cover by *Carex* increased towards lower elevations. We also demonstrated that the length of *Carex* declined towards lower elevation. This is attributed to the fact that *Carex* plants at lower elevation are younger, as they have experienced a shorter period since emergence. Regression analysis by HOF model II proved that the length of *Carex* increased as they were earlier exposed again to air since water declined.

Carex which is the dominant species at lower elevation has remarkable seasonal phenology. The time series NDVI showed the seasonal patterns of *Carex*. Usually, it is green in autumn, winter and spring. During rainy season in summer *Carex* is submerged by flooding for a shorter or longer period and when the water recedes in autumn, it emerges again at the lake edge. It revealed that the date of up greening of *Carex* in spring and autumn was different between years.

The time series NDVI revealed that the date of emergence in autumn differed between years. This year to year deference of up greening of *Carex* in autumn had a strong negative relationship with water level. When water level receded earlier in autumn, higher NDVI was yield since *Carex* emerged earlier. In contrast, if water level was still high in September and October, the NDVI was lower.

The time series NDVI also revealed that the date of up greening in spring differed between years. Our research indicated that this year to year variation was positive related to variation between years in cumulative temperature. When cumulative air temperature in February or March was higher, the NDVI of *Carex* increased sharply earlier. In contrast, when cumulative air temperature was extremely low in some years, the time of NDVI increased delayed to April.

MODIS imagery has relative lower spatial, but higher temporal resolution, compared with TM. MODIS providing daily imagery is ideal for monitoring phenology of the grasslands vegetation. Some researches have already showed MODIS could detect vegetation phenology well using vegetation indices at regional scale. Our research revealed that, at local scale, NDVI derived from MODIS successfully performed to monitor the dynamics of recessional grassland vegetation (*Carex*).

REFERENCES

Barbosa, H. A., A. R. Huete, and W. E. Baethgen. 2006. A 20-year study of NDVI variability over the Northeast Region of Brazil. *Journal of Arid Environments*, 67(2), pp. 288-307.

Bartholomew, P. W., and R. D. Williams. 2005. Cool-Season Grass Development Response to Accumulated Temperature under a Range of Temperature Regimes. *Crop Science Society of American*, 45, pp. 529-534.

Beck, P. S. A., C. Atzberger, K. A. Hogda, B. Johansen, and A. K. Skidmore. 2006. Improved monitoring of vegetation dynamics at very high latitudes: A new method using MODIS NDVI. *Remote Sensing of Environment*, 100(3), pp. 321-334.

Chen, X., C. Xu, and Z. Tan. 2001. An analysis of relationships among plant community phenology and seasonal metrics of Normalized Difference Vegetation Index in the northern part of the monsoon region of China. *International Journal of Biometeorology*, 45(4), pp. 170-177.

Choo, Y.-S., C.-B. Lee, and R. Albert. 2002. Effects of nitrogen nutrition on the pattern of ions and organic solutes in five sedges (*Carex* spp.). *Flora - Morphology, Distribution, Functional Ecology of Plants*, 197(1), pp. 56-66.

Cui, X., Y. Zhong, and J. Chen. 2000. Influence of a catastrophic flood on densities and biomasses of three plant species in Poyang Lake, China. *Journal of Freshwater Ecology*, 15(44), pp. 537-541.

Davidson, A., and F. Csillag. 2003. A comparison of three approaches for predicting C4 species cover of northern mixed grass prairie. *Remote Sensing of Environment*, 86(1), pp. 70-82.

DEELECTIS FLORAE REIPUBLICAE POPULARIS SINICAE AGENDEE ACADEMIAE SINICAE EDITA. 2000. *FLORA REIPUBLICAE POPULARIS SINICAE*. Science Press, Beijing.

Dou, H., S. Zhang, Y. Liu, and H. Zhu. 1997. Poyang Lake typical wetland bio-section monitoring, resource exploration and habitat protection. In: *Three gorges, wetland along the Yangtze River and pickled land in estuary*, Science Press, Beijing, pp. 132-133

Fidanza, M. A., P. H. Dernoeden, and M. Zhang. 1996. Degree-days for predicting smooth crabgrass emergence in cool-season turfgrasses. *Crop Science*, 36, pp. 990-996.

Guisan, A., and N. E. Zimmermann. 2000. Predictive habitat distribution models in ecology. *Ecological Modelling*, 135(2-3), pp. 147-186.

Huisman, J., H. Olff, and L. F. M. Fresco. 1993. A Hierarchical Set of Models for Species Response Analysis. *Journal of Vegetation Science*, 4(1), pp. 37-46.

Jin, S., and S. A. Sader. 2005. MODIS time-series imagery for forest disturbance detection and quantification of patch size effects. *Remote Sensing of Environment*, 99(4), pp. 462-470.

Kong, X., and S. Mei. 2002. *Control Surveying*. Wuhan University Press, Wuhan.

Maselli, F., M. A. Gilabert, and C. Conese. 1998. Integration of High and Low Resolution NDVI Data for Monitoring Vegetation in Mediterranean Environments. *Remote Sensing of Environment*, 63(3), pp. 208-218.

Ning, J., J. Chen, D. Li, J. Liu, and Z. Zhang. 2004. *Introduction to Geomatics*, *First edition*. Wuhan University Press,Wuhan.

Salomonson, V. V., W. L. Barnes, P. W. Maymon, H. E. Montgomery, and H. Ostrow. 1989. MODIS: advanced facility instrument for studies of the Earth as a system. *Geoscience and Remote Sensing*, *IEEE Transactions* on 27(2): pp. 145-153.

Schmidt, H., and A. Karnieli. 2002. Analysis of the temporal and spatial vegetation patterns in a semi-arid environment observed by NOAA AVHRR imagery and spectral ground measurements. *International Journal of Remote Sensing*, 23(19), pp. 3971-3990.

Schutz, W. 1997. Primary dormancy and annual dormancy cycles in seeds of six temperate wetland sedges. *Aquatic Botany*, 59(1-2), pp. 75-85.

Si, Y. 2006. Mapping flood recessional grasslands grazed by overwintering geese : an application of multi-temporal remote sensing. ITC, Enschede, The Netherland.

Wu, Y., and W. Ji. 2002. *Study on Jiangxi Poyang Lake National Natrue Reserve.* Science Press, Beijing

Xiao, X., S. Boles, J. Liu, Z. Dafang, S. Frolking, C. Li, W. Salas, and B. M. III. 2005. Mapping paddy rice agriculture in southern China using multi-temporal MODIS images. *Remote Sensing of Environment,* 95(4), pp. 480-492.

Zeng, Y. 2006. Monitoring grassland in Poyang natural reserve, China. ITC, Enschede, The Netherland.

Zhang, X., M. A. Friedl, C. B. Schaaf, A. H. Strahler, J. C. F. Hodges, F. Gao, B. C. Reed, and A. Huete. 2003. Monitoring vegetation phenology using MODIS. *Remote Sensing of Environment*, 84(3), pp. 471-475.

ACKNOWLEDGEMENTS

I would like to give my special thanks to Mr. Zhou Feilong and other staff of Poyang Lake National Nature Reserve. Without their cooperation and willingness to share data I could not achieve this. Thanks to Zhuo Luo for assisting me during fieldwork. I wish to express my deep gratitude to Dr. Jan De Leeuw, for guiding me through this research. I want to express my gratitude to Dr. David Rossiter for your personal help and your friendship. Your scientific and critical attitude for research impressed me so much. Prof. A. de Gier, thank you so much for your comments and lecture about statistics. I owe special thanks to Mr. G. Reinink and Mr. V. Venus for acquiring and processing RS images. My special thanks to Dr. Wu Guofeng and Dr. Wang Tiejun for your numerous useful data, advices, comments and insights in this subject. Special thanks go to Sisi, Fei Teng, Zeng Yuandi, Zhou Yuhong and Shi Jusong for your help and encouragement.