Prediction of the distribution of C_3 and C_4 plant species from a GIS-based model:

-A case study in Poyang Lake, China-

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To my dear parents

Abstract

Every year, the wetlands along the middle and lower Yangtze River attract tens of thousands of water birds to overwinter and to forage on the leaves and rhizomes of grasses and sedges. Annual water fluctuation caused by monsoonal rains and topographic position determine the patterns of the grasslands in Poyang Lake, so that grasslands at lower elevations are inundated longer than those at higher elevations .Consequently, the grasslands present a pattern of "shorter grasses lower down, higher grasses higher up".

Overwintering geese prefer C_3 grasses to C_4 plant species.C_3 grasses thrive in an environment with decreased light, increased soil moisture, lower temperature and higher CO_2 conditions and typically have higher concentrations of photosynthetic enzymes. We hypothesize that C_3 grasses dominate at lower elevations in Poyang Lake and we would like to investigate the distribution of C_3 and C_4 species in the grassland in Poyang Lake National Nature Reserve, and to model and predict how the ratio of C_3/C_4 changes along with elevation based on DEM model.

Three models were built to quantify these relations. The vegetation height vs. elevation model identified a highly significant relation between vegetation height and elevation ($R^2 = 0.542$). The vegetation height vs. inundated duration model showed a highly significant relation between vegetation height and inundated duration ($R^2 = 0.743$). The C_3/C_4 ratio vs. inundated duration model suggested that the percentage of C_3 plant species in a plot is significantly related to the inundated duration ($R^2 = 0.738$). Isotope analysis showed that white fronted geese forage on C_3 plant species. Finally, we were able to generate C_3/C_4 distribution map for Dahuchi, Poyang Lake.

Key words: C_3/C_4 plant species, distribution, stable carbon isotope analysis, DEM model, white fronted geese

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Wish all friends above and the ones not listed here good luck and best wishes!

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1. Introduction

1.1 Background

Recent winter bird surveys revealed the importance of wetlands along the middle and lower Yangtze River for overwintering geese (Barter, Chen et al. 2004), especially White fronted geese (*Anser albifrons albifron*), one of the most important overwintering groups of water birds in China, the total numbers of which has decreased dramatically all over the country in recent years. Here they forage on the leaves and rhizomes of grasses and sedges (Meine and Archibald 1996; Zhang and Lu 1999). Geese prefer easily digestible plant tissue low in fiber and high in nitrogen and/or carbohydrate content (Owens 1997; Vickery, Sutherland et al. 1997; De Leeuw, Si et al. 2006).

Extensive grasslands occur on creek banks and along the fringes of lakes formed by the rivers which drain in Poyang Lake. Here grasses occur along an elevation gradient ranging from 16 to 14 m above sea level (Guo 2005). Fluctuation in water level has a strong impact on the species composition and phenology of this grassland vegetation (Chen, Su et al. 2007), the species composition of these grasslands changes along this elevation gradient. Water levels may reach or exceed 16 m for shorter or longer periods in summer. In winter by contrast water levels in the above mentioned delta lakes drop to 13 m or below. As a consequence depending on the elevation of their substrate, grasslands will be flooded for shorter or longer duration.

Topographic position thus determines the duration of flooding. Grasslands on top of the creek banks at 16 m will be flooded for short periods. The tall grasses growing here withstand this flooding without problem as their length allows protruding their canopy above the waters. Grasses and sedges at the lower edge by contrast will be flooded for longer period. The flooding also impacts these species more severely because they do not have the possibility to extend their canopies above the water because of their short stature.

The combination of hydrology and vegetation height results in a strong contrast in vegetation phenology along the elevation gradient. Grasses at high elevation, green up in spring, remain emergent and green and productive through summer; the canopy of these grasslands will only submerge during extremely high water levels, which are infrequent. The tissue of these grasses will be, as a consequence, exposed to the high temperatures which prevail in summer time.

The grasses at the other (lower) end of the elevation gradient will be flooded more frequently and for longer duration, particularly, in summer when water levels are very high as a result of the monsoon. As a consequence, they typically green up in spring, but are submerged during summer (De Leeuw, Si et al. 2006). Next they green up again once more in autumn when waters recede and vegetation emerges. As a result the tissue of these grasses will be photosynthetically active at lower temperatures in spring and autumn.

Worldwide vegetation shows a well established gradient in photosynthetic pathway of plant species. C_4 plant species which are more productive at higher temperature dominate the vegetation in the tropics and sub tropics, while cool season species (C_3) dominate the vegetation in the temperate zone (David and Larry 1980; Ehleringer, Cerling et al. 1997; Winslow, Hunt et al. 2003). These pathways are so called because in C_3 species the CO_2 is first incorporated into a 3-carbon compound while or in C_4 photosynthesis it is incorporated into a 4-carbon compound (Foody and Dash 2007). C_3 grasses thrive in an environment with decreased light (Tieszen 1970), increased soil moisture (Barnes, Tieszen et al. 1983), lower temperature (Schuster and Monson 1990) and higher CO_2 conditions (Ehleringer and Moonson 1993) compared to C_4 species (Davidson and Csillag 2001).

Compared to C_4 species, C_3 species typically have higher concentrations of photosynthetic enzymes (Barbehenn, B. et al. 1992). There is also a difference in food quality between C_3 and C_4 grasses. C_3 species contain higher levels of non-structural carbohydrates, protein and lower levels of fibre, silica and are less though than C_4 species. C_3 species therefore produce better diet quality for animals.

We hypothesize that a similar gradient in photosynthetic exists along the elevation gradient of Poyang Lake, with C_4 species dominating at high elevation and C_3 species prevail at lower elevation. Thus, in Poyang Lake we expect C_3 species to dominate in areas flooded during the hot season, which restricts the period of active photosynthesis to the cooler periods before and after the floods. Such environments in which vegetation is productive before and after, but not during the summer monsoon, are very common in China and the Indian sub-continent, where riverine wetlands are flooded during the hot season (Zhao, Yan et al. 2007; Guo, Hu et al. 2008; Li, Li et al. 2008; Rai 2008; Sharma and Rawat 2009). The phenological pattern of grasses growing at low elevation coincides with the definition and preferable climatic condition of C_3 plant species and the same situation between grasses growing at lower elevation while C_4 plant species dominate at higher elevation.

Various methods have been used to map and predict C_3/C_4 species distribution. Foody and Dash used time series MERIS images to estimate and map the C_3-C_4 composition of grasslands based on difference in vegetation phenology (Foody and Dash 2007); Vegetation indices derived from two-date remote sensing data were applied to monitor the spatial variability in C_3/C_4 composition (Davidson and Csillag 2001); Ecological modeling with geographical information analysis and remote sensing was employed to determine and stimulate the effects of sea-level rise to development of C_3/C_4 plants in estuarine salt marshes (Simas, Nunes et al. 2001). Three approaches using temporal trajectory indices (TTIs) of sensor-derived NDVI were compared (Goodin and Henebry 1997; Tieszen, Reed et al. 1997; Davidson and Csillag 2003). However, GIS based models have been rarely adopted for discriminating and mapping C_3/C_4 species distribution.

We suggest that the photosynthetic pathway of plant species changes along above described topographic gradient in Poyang Lake. In this research, we develop a model to predict the submergence of vegetation, validate this model while using DEM model and explore whether the ratio of C_3/C_4 species is related to the duration of submergence as predicted by the model and DEM model. We finally apply this relation to predict C_3/C_4 species ratio from the duration of submergence.

1.2 General research objectives

The general objective of this research is to investigate the distribution of C_3 and C_4 species in the grassland in Poyang Lake National Nature Reserve (NNR), and to model and predict how the ratio of C_3/C_4 changes along with elevation.

1.3 Specific objectives and research questions

The specific objectives (numbered) and research questions (lettered) are as follows:

1) To investigate and model the relationship between vegetation height and elevation;
   a) What is the relation between vegetation height and elevation?
   b) Which model best describes this relation?

2) To investigate the distribution of C_3 and C_4 species and their relation with elevation in the grasslands of Poyang Lake;
   a) What is the relation between the C_3/C_4 ratio and elevation?
   b) Is there a zonal distribution pattern of C_3/C_4 species in the grassland of Poyang Lake NNR?

3) To predict canopy submergence based on water level, vegetation height and bottom elevation derived from DEM data.
   a) What is the spatial variation in predicted duration?
   b) How accurately does this prediction model predict submergence for the year 2004?

4) To investigate the relationship between the ratio of C_3/C_4 grasses and duration of grass canopy submergence;
   a) What is the relation between the C_3/C_4 ratio and the duration of canopy submergence?
   b) Which model best describes this relation?

5) To investigate invert the best model identified under 3 b and to assess how accurately this model predicts the distribution of C_3/C_4 species.
   a) What is the accuracy of the predicted C_3/C_4 ratio?

1.4 Research assumptions

1) Peak water levels occur in summertime when temperatures are highest;
2) Elevation related variation in submergence determines that low elevation vegetation has

its main period of photosynthetic activity at lower temperatures in spring and autumn while canopies at higher elevation have their productivity throughout the hot summer period;

3) These seasonal differences in productivity and the temperatures to which vegetation is exposed causes predominance of C_3 species at lower elevation and dominance of C_4 species at higher elevation;
4) Prolonged submergence during summer allows C_3 species to dominate in the wetlands along the Yangtze, notwithstanding the fact that C_4 species would be expected to dominate the vegetation when considering climatic conditions alone.
5) The suitability of the grasslands along the Yangtze for wintering geese depends on the summer monsoonal flooding which creates the specific niche for C_3 plant species.

1.5 Research hypotheses

1) Vegetation height at lower elevation is shorter than the one at higher elevation;
2) The duration of submergence of vegetation canopies decreases with elevation increasedly;
3) Spatial variation in duration of submergence can reliably be predicted from substrate elevation;
4) The distribution of C_3/C_4 species ratio and submergence pattern of the vegetation can be predicted,

1.6 Research approach

The general framework of this research method is demonstrated in Figure 1-1. The methods used in the framework will be described in the methods chapter.

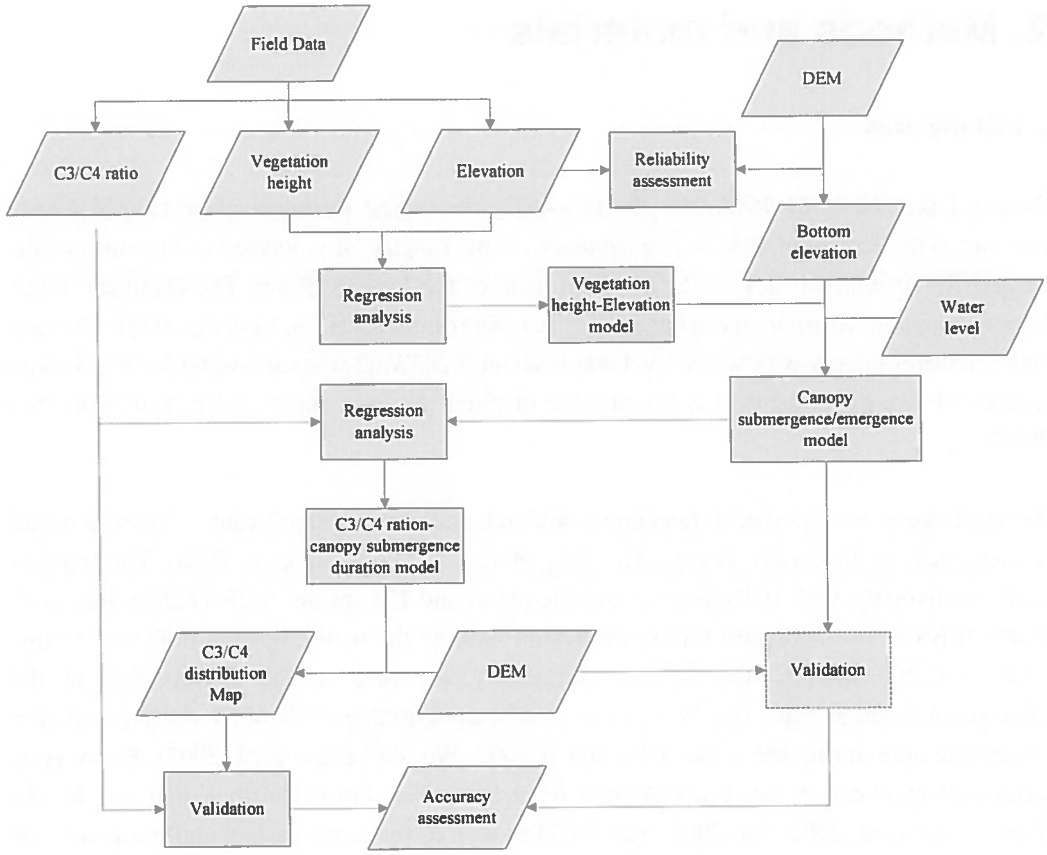

Figure 1-1 Research flowchart

2. Methods and materials

2.1 Study area

Poyang Lake (28°4′–29°46′N, 115°49′–116°46′E), the largest freshwater lake (21224.4 km^2) in China (Hu, Feng et al. 2007), is a tributary of the Yangtze. It is located in the north of the Jiangxi Province and it lies on the southern bank of the Yangtze River. The Ganjiang, Fuhe, Raohe, Xinjiang, Xiushui, and Xihe are its six main tributaries (Luo, Li et al. 2008). The lake area fluctuates greatly with water level and is about 3,283 km2 when the water level at Hukou reaches 21.7m. Mean depth is 8.4m, and the maximal depth is about 25.1m (Liu 2006; Yan 2007).

Poyang Lake is an important international wetland, and delivers significant environmental services such as floodwater storage (Hu, Feng et al. 2007; Guo, Hu et al. 2008). The lake has a rich biodiversity, with 102 species of aquatic plants and 122 species of fish (Chen, Bao et al. 2006). It is one of the biggest bird conservation areas in the world, hosting millions of birds from over 300 species. The lake is particularly important to the conservation of the endangered Siberian crane (Li, W. Ji. et al. 2005), as more than 95% of its world population congregate here during the winter (Wu and Ji 2002; Wu, de Leeuw et al. 2007). Every year, significant numbers of rare birds migrate from Mongolia, Japan, North Korea and Russia (Kanai, Ueta et al. 2002; Liu 2006; Yan 2007) as well as the north-eastern and north-western parts of China to Poyang Lake for foraging on the flood recessional grasslands during autumn and winter.

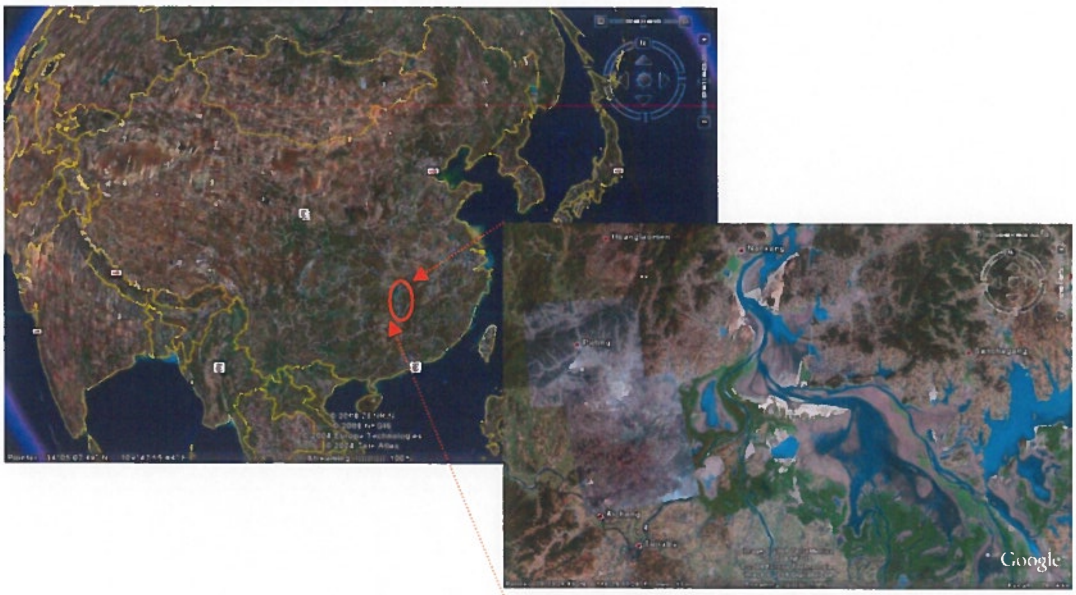

Figure 2-1 Location of Poyang Lake on Google Earth images

The climate and hydrology conditions in Poyang Lake are crucial for the unique landscape pattern of the grassland there, also play a significant role for migratory birds to overwinter there. From meteorological data collected from the bureau of Poyang Lake, we could have detailed information about temperature, precipitation and water level, see Figure 2-2.

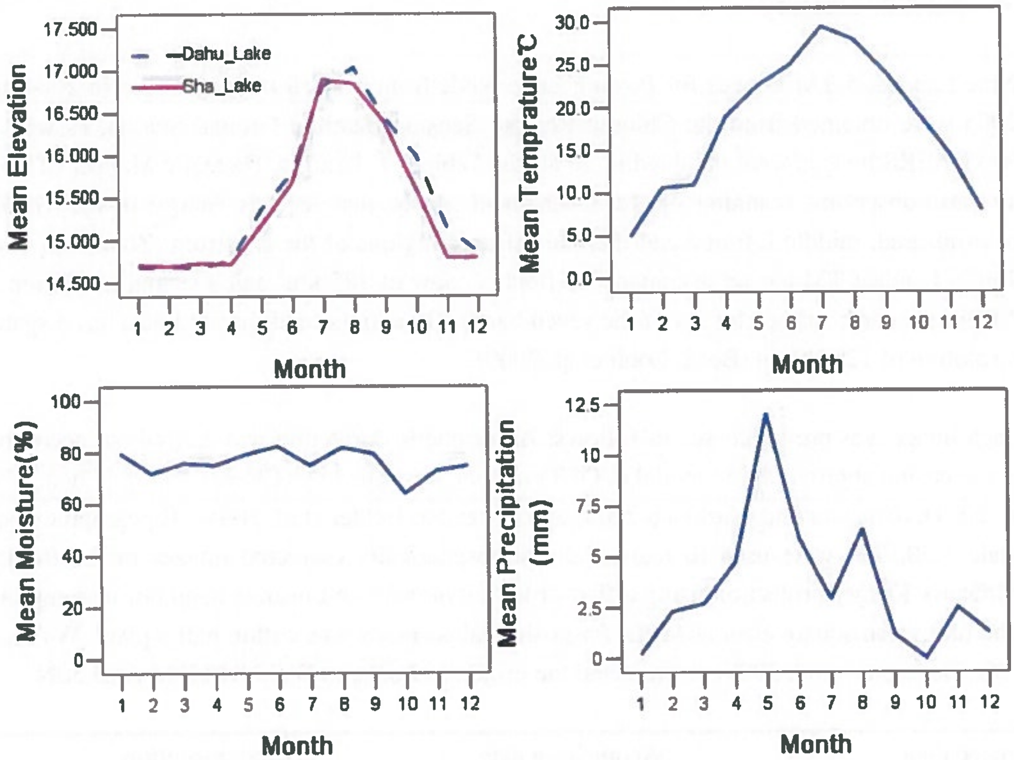

Figure 2-2 Graphs showing environmental conditions in Poyang Lake in 2004. Top left: mean monthly water level (m); Top right: Mean monthly temperature (°C); Low left: mean monthly moisture (%); Low right: mean monthly precipitation (mm) (Si 2006)

In rainy season, from June to August, precipitation increases, the water level of Dahu Lake and Sha Lake rises, water from Yangtze River and also from the six branches fill inside these two lakes. Due to this fluctuation mechanism, lower grasslands which are close to lakesides are totally submerged. When dry season comes, from September to April in the next year, precipitation and the water level reduce and the lower grasslands emerge and green up.

The terrain of the area where the grasslands occur in Poyang Lake is almost flat; the elevation range of this area is from 12m to 18m, with a difference between 5 or 6 meters. So, elevation doesn't contribute greatly to the special vertical zonal vegetation distribution of grasslands on lakesides, which is mainly developed as a result of water fluctuation. The grass species there could be categorized into 28 families. The most commonly observed genera are *Carex*, *Miscanthus* and *Cynodon*. *Carex* species are normally distributed near the lake at the lower elevation between 12 and 14m. *Miscanthus* and *Cynodon* communities are distributed relatively farther from the lake and at higher elevation between 14 and 16m (Cai, Ma et al. 1997; Zeng 2006).

2.2 Data available

➢ Satellite imagery

Nine Landsat 5 TM images for Poyang Lake NNR from 1 April to 31 October in 2004 and 2005 were obtained from the Chinese Remote Sensing Satellite Ground Station, as well as two CBERS images were obtained in 2004, see Table 2-1. Landsat Thematic Mapper (TM) is an earth-observing scanning optical-mechanical sensor that records energy in the visible, near-infrared, middle-infrared and thermal-infrared regions of the spectrum (Zhou, Lin et al. 2002). Landsat TM has an instantaneous field of view of 185 km^2 and a spatial resolution of 30*30m at earth surface for six of the seven bands. Band 6 thermal-infrared data has a spatial resolution of 120*120m (Beck, Lobit et al. 2000).

Each image was pre-processed as follows: Atmospheric correction was carried out according to the cosine approximation model (COST) method described by (Chavez 1996), (Chen, Li et al. 2004), (Chander and Markham 2003) and (Chander, Helder et al. 2004). Topographic maps, scale 1:50, 000 were used to register the atmospherically corrected images to the Beijing 54/Gauss-Kruger projection using a first-order polynomial and nearest-neighbor re-sampling. The root mean square error (RMSE) for positional accuracy was within half a pixel. Wu et al. (Wu, De Leeuw et al. 2008) re-projected the projected image to WGS 84/UTM zone 50N.

Image data	Acquisition date	Spatial resolution
CBERS image	2004-1-27	20 meters
Landsat 5 TM	2004-5-5	30 meters
Landsat 5 TM	2004-6-22	30 meters
Landsat 5 TM	2004-7-24	30 meters
Landsat 5 TM	2004-8-9	30 meters
Landsat 5 TM	2004-9-26	30 meters
Landsat 5 TM	2004-10-12	30 meters
Landsat 5 TM	2004-10-28	30 meters
CBERS image	2004-11-08	20 meters
Landsat 5 TM	2004-11-29	30 meters
Landsat 5 TM	2004-12-15	30 meters

Table 2-1 Landsat 5 TM and CBERS image data information for Poyang Lake NNR

➢ Digital Elevation Model

We used the digital elevation model (DEM) which was based on interpolation of sonar measurements made from a ship in 1998 during extremely high water levels, with 0.1m vertical accuracy and 20m spatial resolution. It covers the whole Poyang Lake NNR, including part of the big Poyang Lake (Yan 2007).

➢ Water level data

Daily water level data from 2000 to 2007 was acquired from the Bureau of Poyang Lake NNR. We used these data to build canopy submergence/emergence model.

- Meteorological data

Temperature, moisture, precipitation data were acquired from the Bureau of Poyang Lake NNR. These data could facilitate us to have a better understanding of the weather conditions there, and how they can have influence on the vegetation distribution in the grasslands communities there.

- Topographic map

The scale of topographic map of Poyang Lake NNR is 1:10000, made in 1997 (Si 2006). We used it to assist us for field data collection and sampling sites design.

- Photosynthetic pathway of plant species

Information on the photosynthetic pathway of plant species was acquired in two steps. First, a list was obtained from staff who has been working in Poyang Lake NNR for more than 10 years, and could also from botanical literature (Zeng 2006). Next, we searched the web for information on the photosynthetic pathway (C_3 or C_4) information for these species. We partly obtained this information from the grass genera of the world (Watson and Dallwitz 1992). We also established C_3/C_4 status of other species with support of the institute of botany of the Chinese Academy of Science, which would be depicted in later section.

2.3 Field Survey

Field data was collected at Dahuchi, Poyang Lake to check the reliability of DEM model using a differential GPS (substrate elevation survey) from 27th Oct, 2008 to 29th Oct, 2008 and to acquire information of vegetation (so called vegetation survey) from 17th Nov, 2008 to 21st Nov, 2008.

2.3.1 Substrate elevation survey

The Differential GPS equipment (Trimble 5700) and a portable GPS (Unistrong, GPSmap 60CS) were borrowed from the geography laboratory of School of Resource and Environmental Science (SRES) in Wuhan University. Known from the staff in Poyang Lake NNR, we used the control point at the northwest corner of Dahuchi as our standard. The whole procedure of surveying followed the standard procedure (Meriden 2008):

(1). Base station setup:
We chose a high flat roof near the control point at the northwest corner of Dahuchi. One fixed height tripod was used for the base station with locking pins; another one was used for holding the antenna. A battery was supplying the controller, which were collected with the

base station and the antenna.

(2). Rover setup:
A bipod was used to fix the rover, and another controller was fixed to the waist of the bipod with locking pins.

(3). Initialization
Turn on the both controllers, the base station and the rover. Double click the Trimble icon on the desktop, and create a new task for both base station and the rover. For the parameters setup, select "transverse Mercator projection" for projection type, type 117 E for central meridian. Confirm data communication between the base station and the rover.

(4) Elevation survey
Take the rover fixed on a bipod to a survey point, wait the satellite signal to be settled, start survey.

We followed the procedure and surveyed 45 sample points at different elevation gradients based on the principle that the sample points should be located in every elevation gradient as much as possible and recorded them in Excel sheet. The data collected are listed in Annex 2. We imported them into ArcMap by clicking "add data" to generate an event file first and exported them to create a point file (Caltech 2008). The sample points are displayed in Figure 2-3 as green dots.

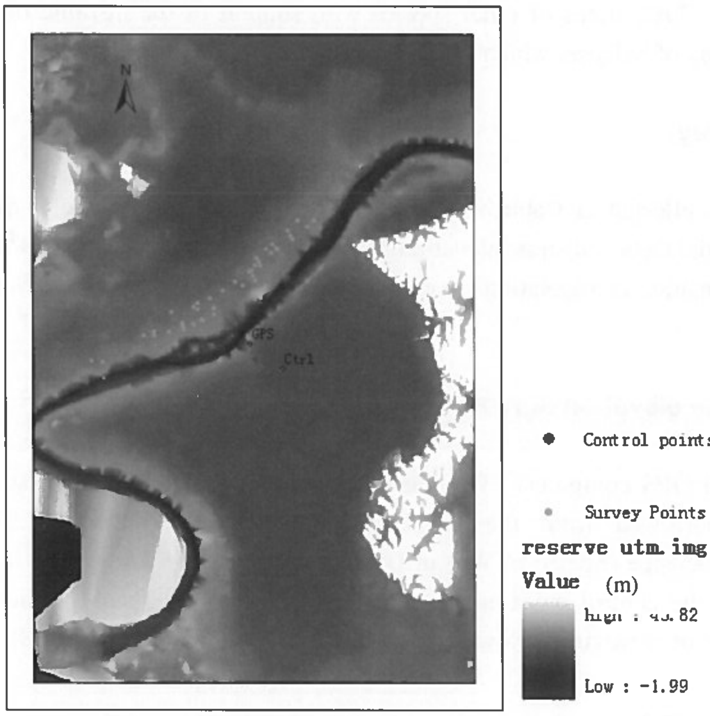

Figure 2-3 raw Sample points and control points (the unit is meter).

As seen from Figure 2-3, there is great discrepancy: the sample points are located on the southeast side of Xiu River, but according to survey results, they are located on the northwest side of Xiu River. That's because the sample points are not calibrated using RTK theory by the control point. However, Poyang Lake NNR doesn't have the coordinates information for that control point (the point in Figure 2-3, labeled as "GPS"), they only have the coordinates for the water level pole (the point in Figure 2-3, labeled as "Ctrl"), which was submerged and not accessible during the survey time. In order to solve the problem, we recorded control point's horizontal coordinates (x, y) just by the portable GPS on hand, and all the sample points' horizontal coordinates (x, y) are calibrated by this point. After calibration, they are displayed as Figure 2-4.

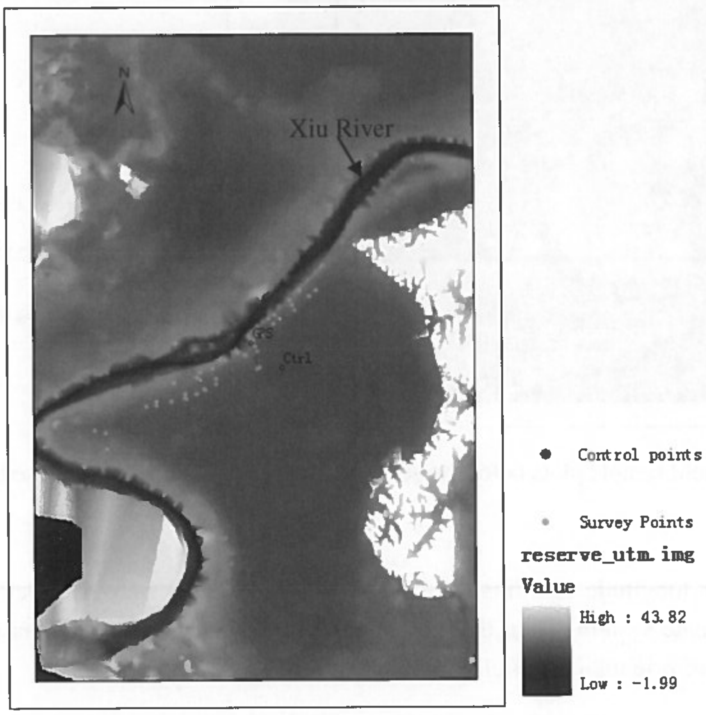

Figure 2-4 sample points after calibration and control points (the unit is meter).

2.3.2 Vegetation survey

A line intersect sampling method (Bate, Torgersen et al. 2004; Woldendorp, Keenan et al. 2004; Esseen, Jansson et al. 2006; Zeng 2006; Fearnside, Barbosa et al. 2007; Yan 2007) was used for vegetation survey. We selected 22 transects spaced at 1km distance from each other and perpendicular to the riverside, to ensure that the elevation gradient and vegetation zonation would be optimally represented in each individual transect. 85 plots (20*20m) were selected along every transect at distances stratified according to elevation while using the 0.5 m contour lines (using Spatial Analyst toolbox in ArcMap), see Figure 2-5.

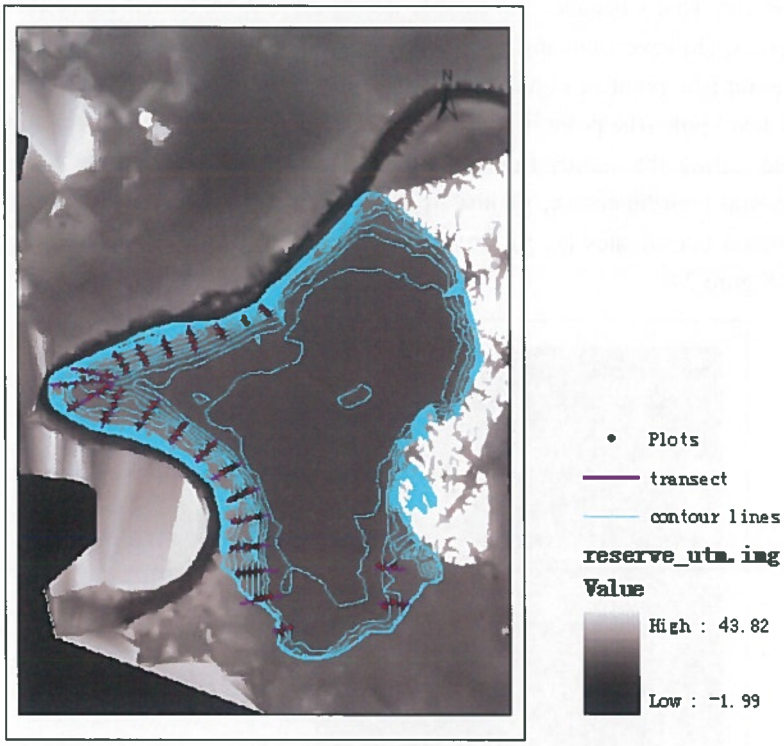

Figure 2-5 pre-field sample plots before vegetation survey (the unit is meter, Based on DEM of the reserve, 1998)

The latitude and longitude coordinates of pre-field sample plots were recorded and converted into XY coordinate system. Then these XY coordinates were input into potable GPS device for the purpose of orientation in field (Yan 2007).

At every plot we first of all recorded geographic location using a portable GPS (Unistrong, GPSmap 60CS) and compiled a list of all plant species. Specimens of unknown plant species encountered in the field were collected and fixed on a separate sheet with information where it had been collected, in a field plant species specimen holder. Next we visually estimated the percentage cover of all species with cover > 5%. The average height of these species was estimated based on records of species height of various individuals within a plot. In addition, we recorded signs of grazing by geese in each plot while considering presence of geese, dropping density and defoliated tissue. We estimated the dropping density visually and collected the fresh droppings in transport plastic bags for further stable isotope analysis. Detailed description of the vegetation field survey can be found on the field work sheet, see Annex 1.

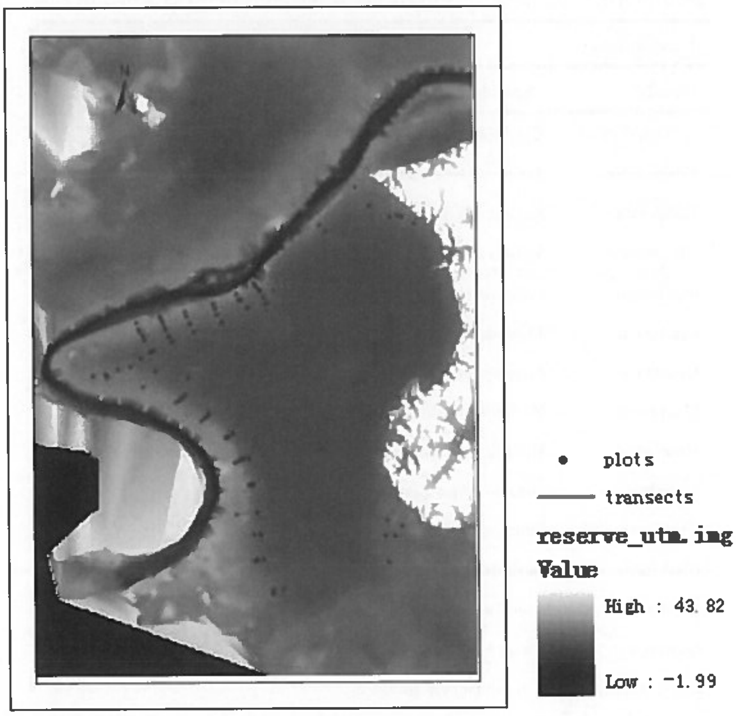

Figure 2-6 Locations of the survey plots *in situ* (the unit is meter).

After vegetation survey, we consulted Prof. Shengxiang Liu (HuaZhong Normal University) to identify those unknown plant species, preserved inside the specimen holder. Their family and species names are listed in Table 2-2. After that, the specimen holder was kept in a dry and open-to-air condition, and every two days we changed the sheets of the specimen holder to prevent the plant material from rotting, and took the plant species to a lab to do isotope analysis, which will be depicted later.

Table 2-2 Full taxonomic description of the dominant plant species in our study area

Plant species	
Family	**Specie Latin Name**
Asclepiadaceae	*Cynanchum glaucescens(Decne.) Hand. -Mazz.*
Compositae	*Artemisia lavandulaefolia DC*
Compositae	*Kalimeris incisa (Fisch.) DC.*
Cyperaceae	*Scirpus triqueter L*
cyperaceae	*Carex argyi (HEAR 2009)*
Gramineae	*Themeda japonica (Willd.) Tanaka*
Gramineae	*Eragrostis ferruginea (Thunb) Beauv*
Gramineae	*Miscanthus sinensis Anderss*
Gramineae	*Miscanthus sacchariflorus (Maxim). Benth. Ef. Hook. F*
Gramineae	*Arundo donax Linn.*
Gramineae	*Phragmites communis Trin*
Gramineae	*phalaris arundinacea. L*
Gramineae	*Cynodon dactylon (Grass 2009)*
Gramineae	*Zoysia japonica Steud*
Polygonaceae	*Polygonum perfoliatum L.*
Polygonaceae	*Polygonum criopolitanum Hance*
Polygonaceae	*Polygonum hydropiper Linn*
Gramineae	*Setaria viridis (Linn.) Beauv.*
Polygonaceae	*Polygonum flaccidum(Meissn.)Steward*
Polygonaceae	*Polygonum barbatum L*
Polygonaceae	*Polygonum minus Huds*
Rosaceae	*Potentilla tanacetifolia*
Rubiaceae	*Paederia scandens*

2.4 Stable ^{13}C isotope analysis

Stable ^{13}C isotope analysis is a technique used to identify C_3/C_4 plant species and their distributions pattern along with different variables such as soil moisture, temperature, latitude (Muzuka 1999; Cayet and Lichtfouse 2001; Cheng, Luo et al. 2006; Cheng, An et al. 2007). We analyzed samples of 23 plant species and 10 geese droppings in the stable isotope laboratory of Institute of Geographic Sciences and Natural Resource Research, CAS, with the assistance of Prof. Jingrong Yang. The analysis was carried out with a Thermo Finnigan MAT DELTAplus XP isotope-ratio mass spectrometers (IRMS), which is configured through the CONFLO III device for automated continuous-flow analysis of organic samples (C and N, or S isotopes) using the Flash EA 1112 elemental analyzer. The samples were treated according to the precise instructions (SILEER 2008):

We collected tissues of 23 plant species, stored this in labeled plastic bags identifying species name and location and brought this to the laboratory, where the material was dried overnight in an oven at 78.3°C. Similarly, a sample of 10 droppings of white fronted goose was collected and stored in plastic beakers, and subsequently dried similarly in the laboratory.

Next, the material of each plant species and the geese droppings was grinded for 2 minutes in a ball mill and the powder returned to the labeled plastic bags and beakers. The container and the two steel balls of the ball mills were washed before grinding the next specimen.

The last step before the analysis was to weigh the sample materials in 4*6mm tinfoil hats. Before each measurement, the tinfoil hat should be put on the analytical balance first till it's zeroed. We put enough sample powder inside the tinfoil, and shaped the tinfoil as a small ball or cube. During this process, the powder was not allowed to leak out, so we weighed the ball or cube on the analytical balance and recorded the results.

After all the above steps were finished correctly, the samples could be analyzed; Results are reported in terms of $\delta^{13}C$ (%) relative to the PDB standard (Smith and Brown 1973) where $\delta^{13}C$= [(R Sample/R Standard)-1] *1000; R= $^{13}C/^{12}C$. Normally, C_3 plants possessed a lower mean $\delta^{13}C$ value around -21~-30‰ than C4 which possessed a mean δ13C value around -10~-15 ‰ (David and Larry 1980). The results of the Stable ^{13}C isotopic analysis are listed in annex 3.

2.5 Vegetation height vs. elevation model (Model I)

During the vegetation field survey, for each sampling plot, we recorded heights of all plant species to obtain a final vegetation height: average vegetation height; minimum vegetation height; maximum vegetation height:

To calculate average vegetation height at one sampling plot, we used formula as follows:
Average vegetation height = sum (percentage * vegetation height). Here percentage represents the percentage of one plant species in total plant species coverage, while vegetation height denotes the vegetation height of that particular plant species in centimeter, respectively.

To calculate minimum or maximum vegetation height, we just selected the height of the shortest or highest plant species.

As described above, plant species growing at different elevation gradients show characteristic height. So, to check out the linkage between vegetation height and elevation, we did regression analysis and also P-test. Finally, we compared the results of the three regressions and accepted the most satisfactory one to be our model one: vegetation height vs. elevation model. The whole procedure of building this model is shown in Figure 2-7.

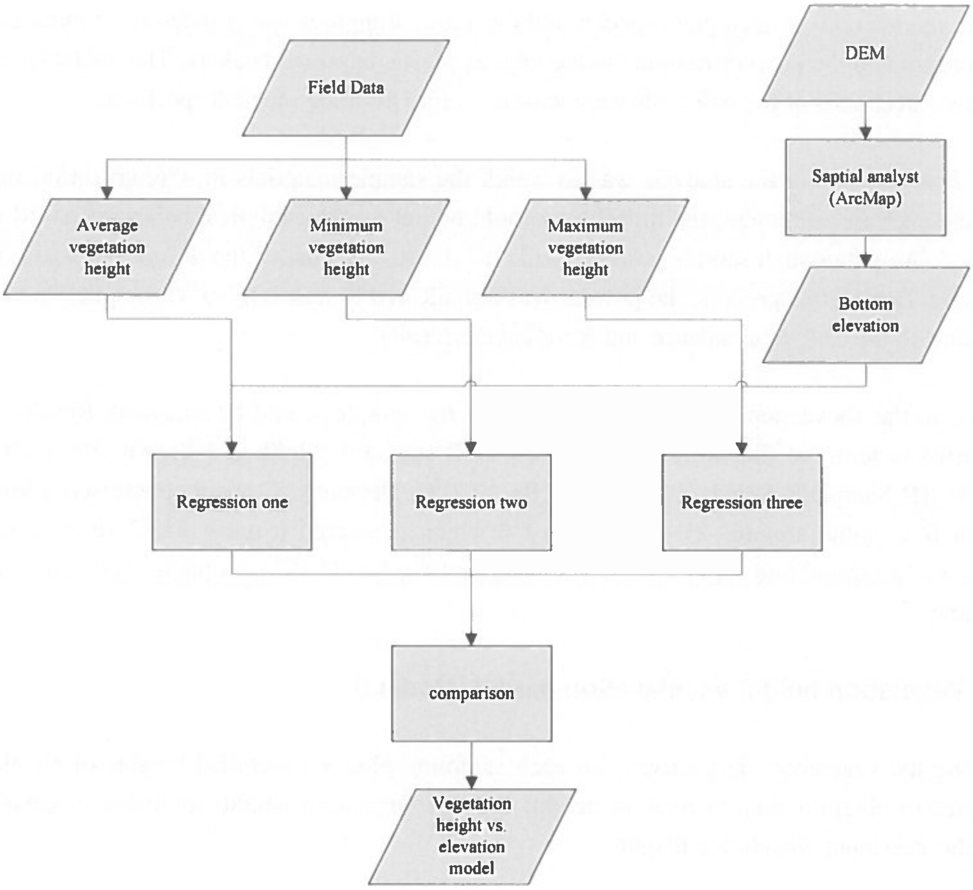

Figure 2-7 the procedure of building model one: vegetation height vs. elevation model

2.6 Canopy submergence/emergence model (Model II)

Elevation derived from DEM, water level as well as result from vegetation height-elevation model was used to build canopy submergence/emergence model. The rationale behind canopy submergence/emergence model is easily understandable and can be expressed as the following two conditional statements:

1) Canopy submergent if: SE + VH – WL >0
2) Canopy emergent if: SE + VH – WL <0

Where SE = substrate elevation derived from the DEM, VH = vegetation height calculated from Vegetation height vs. elevation model and WH = water level.

The solution to build this model involves reclassifying and map algebra. First, using arithmetic map algebra function ("+") in Erdas (Spatial Modeler→Model maker→New Model→Function definition), we created an elevation plus vegetation height map by integrating DEM model and vegetation height map. The elevation information is stored in each cell of the DEM model, and vegetation height map could be generated by using arithmetic map algebra function ("+") based on the vegetation height vs. elevation model.

The daily water level data was saved in Excel table, which can be drawn as Figure 2-8, so we have to create binary maps by reclassifying the DEM according to the water level for each day where a pixel with a 1 means it is in water and a pixel with zero means it is above water, and then sum these 366 binary maps together to generate our final inundated map model.

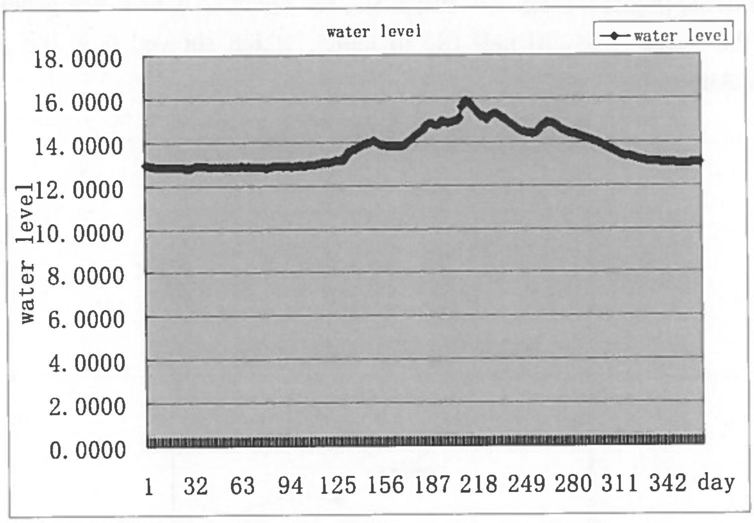

Figure 2-8 daily water level data of 2004

Here is a basic example for the model: For instance, we have a DEM with only 4 pixels and have 4 days of water level data. And the pixels have the following elevation attributes:

Pixel 1 (P1) = 10 P2 = 12
P3 = 8 P4 = 15

Water levels for each day are:

Day1 = 7 Day2 = 10
Day3 = 14 Day4 = 9

after re-classification DEM for each day it would be:

Day1: P1 = 0 P2 = 0
P3 = 0 P4 = 0

Day2: P1 = 1 P2 = 0
P3 = 1 P4 = 0

Day3: P1 = 1 P2 = 1
P3 = 1 P4 = 0

Day4: P1 = 0 P2 = 0
P3 = 1 P4 = 0

Now use map algebra to add the 4 re-classed raster together to get the days of inundation for each pixel:

Inundation map: P1 = 2 (days where this pixel was inundated with water)
P2 = 1 P3 = 3 P4 = 0

The values in this resulting raster would represent the number of days a pixel was inundated with water.

In Erdas 8.7, we could use the Model maker module to build new models, which would allow us create a binary map for each day. However, if we just created binary mps for a whole year and summed them together, it would be very time-consuming. Besides, there isn't such a function module imbedded in Erdas 8.7, so, we had to do some programming work to create macros to speed up the process. We tackled the problem as follows:

Step one: Build one model for day 1 in Erdas 8.7, see Figure 2-9, and then generate script for it: du1.mdl. We opened the du1.mdl file in tablet, which showed how the principle was structured, see Annex 4.

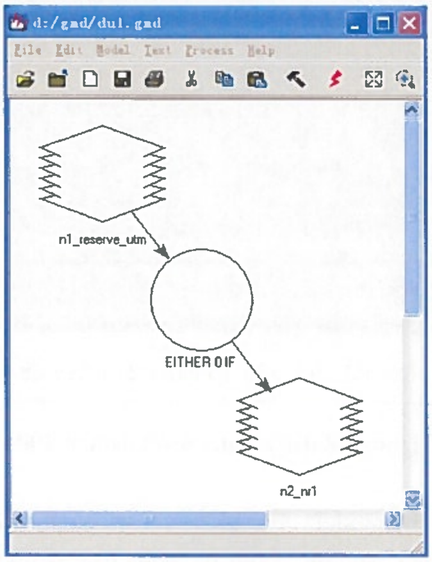

Figure 2-9 Created model for the first binary map

Step two: As the input file is constant, the variation for each model is daily water level value and the output binary map; we programmed a short code using Microsoft Visual C++ to automatically generate the other 365 script files, the C++ code is listed in Annex 5.

Step three: Run Batch command within Model Librarian in Erdas 8.7 to generate all the 366 binary maps.

Step four: Sum all the 366 binary maps to formalize the final inundated duration map model within Model maker in Erdas 8.7.

2.7 C_3/C_4 ratio vs. canopy submergence duration model (Model III)

Grasslands at lower elevation gradients are flooded during summer time. And grasses there green up in autumn. So, we expect C_3/C_4 ratio varies along with the elevation gradients, and its value decreases when elevation gradient increases, and its value might have a relation with canopy submergence duration.

^{13}C stable carbon isotopic analysis of plant species along with percentages measured during the field survey, could give us the C_3/C_4 ratio of vegetation, in the form of per centum of C_3

plant species out of all plant species at each sampling plot. At the other hand, Model II established an inundated duration map which would provide the inundated days for each sampling plots.

To test our hypothesis above, regression analysis and also P-test are used in our research. Hopefully, if $P<0.05$ and R^2 is acceptable, we could apply this model to DEM to generate C_3/C_4 distribution map, see figure 2-10.

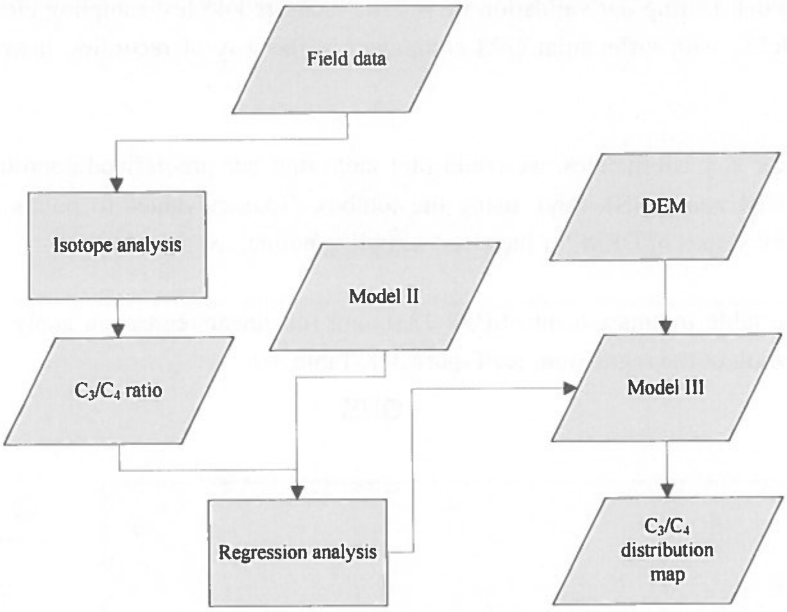

Figure 2-10 the procedure of building model III: C3/C4 ratio vs. canopy submergence duration model

3. Results

3.1 Reliability assessment

The foundation stone of our research is the DEM model. The quality of this DEM model will definitely influence research results; therefore, it's necessary to do reliability assessment of the DEM model. During our validation survey, we measured 45 test sampling plots using the method of RTK, with differential GPS equipment in the way of recording their x, y and z coordinates.

Knowing their x, y coordinates, we could plot them into our pre-defined coordinate system (WGS 84/UTM zone 50N). And, using the toolbox "Extract values to points", we could extract the cell values of DEM for these test sampling points, see annex 6.

We input the table in annex 6 into SPSS 13.0, and run linear regression analysis function. Here is the result of the regression, see Figure 3-1, Table 3-1.

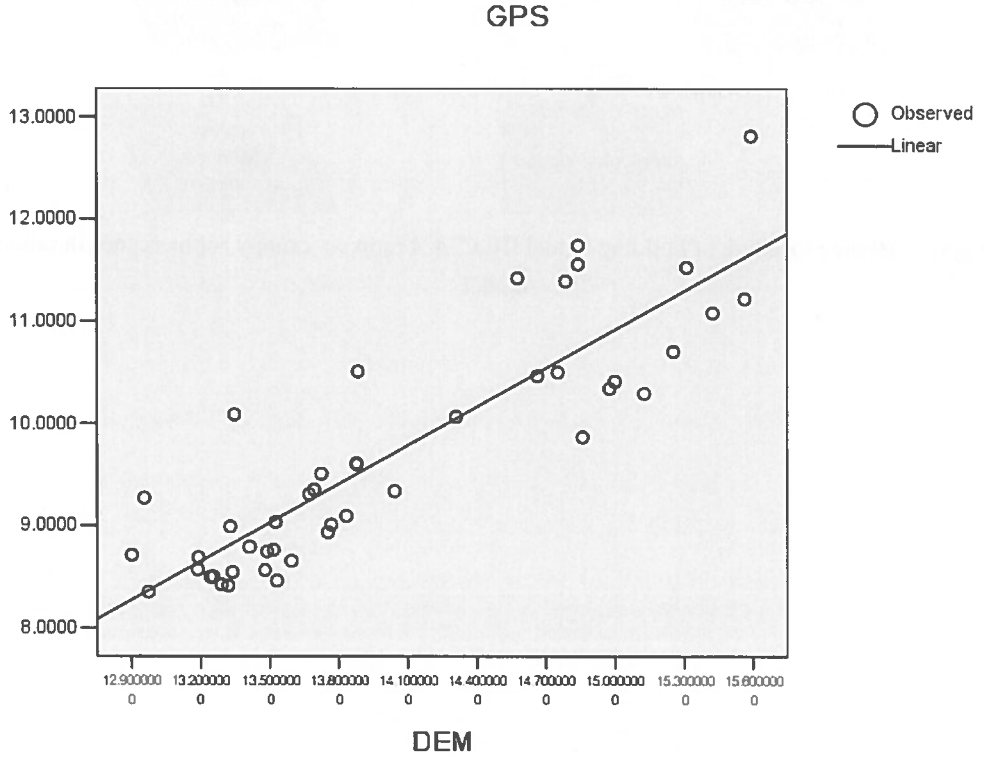

Figure 3-1 Relation between Elevation values derived from the DEM model (labeled as DEM, x axis) and GPS measured elevation values (labeled as GPS, y axis)

Table 3-1 Statistical diagnostics of the regression of elevation measured in the field against elevation according to the DEM

Coefficients

	Unstandardized Coefficients		Standardized Coefficients		
	B	Std. Error	Beta	t	Sig.
DEM	1.258	.104	.880	12.120	.000
(Constant)	-7.953	1.457		-5.457	.000

ANOVA

	Sum of Squares	df	Mean Square	F	Sig.
Regression	44.309	1	44.309	146.893	.000
Residual	12.970	43	.302		
Total	57.279	44			

The independent variable is DEM.

Table 3-1 reveals a significant linear relation between elevation according to the DEM and elevation measured in the field. The intercept of the regression of -7.95 was significantly different from zero (t-test, t = 5.456, d.f. = 44, P < .0005) which implies that the DEM overestimated elevation systematically by 7.9 m. The slope of 1.25 was significantly different from the expected slope of 1 (t test, t = 2.404, d.f. = 44, P = 0.01<0.05) which implies that any gradients computed with the DEM underestimated the gradient according to GPS measurements.

Despite the discrepancy between GPS and DEM elevations, we chose not to correct the DEM based on the field GPS. The systematic difference is most likely because of different projections used for differential GPS and DEM model. The DEM was interpolated based on sonar measurements of. Beijing 54/Gauss-Kruger projection, and then it was re-projected to WGS 84/UTM zone 50N. However, the projection system of differential GPS measurements was WGS 84/UTM zone 50N. So, we have reason to doubt that the re-projection might be the cause for this systematic difference and we would like to just use the original DEM model for our research.

3.2 Results for Model I

Our hypothesis is that shorter plant species (especially the *Carex* communities) dominates the lower elevation gradient of the grasslands around Dahuchi, while the higher plant species (especially the *Miscanthus* communities) dominates the higher elevation gradient. So, in our research, we would like to investigate the relation between the height of plant species and the bottom elevation of which the plant species grows at the same place; and we would like to use minimum vegetation height, average vegetation height as well as maximum vegetation height to denote the vegetation height of each plot using the method we mentioned in Chapter 2, analyze the relation between the height of plant species and the bottom elevation of which the plant species grows at the same place.

The datasheet containing vegetation height of three different categories (average, minimum, maximum) and bottom elevation data for each sampling plots is listed in annex 7. We input them into SPSS 13.1 and run regression analysis for the three categories. Here is the result for them.

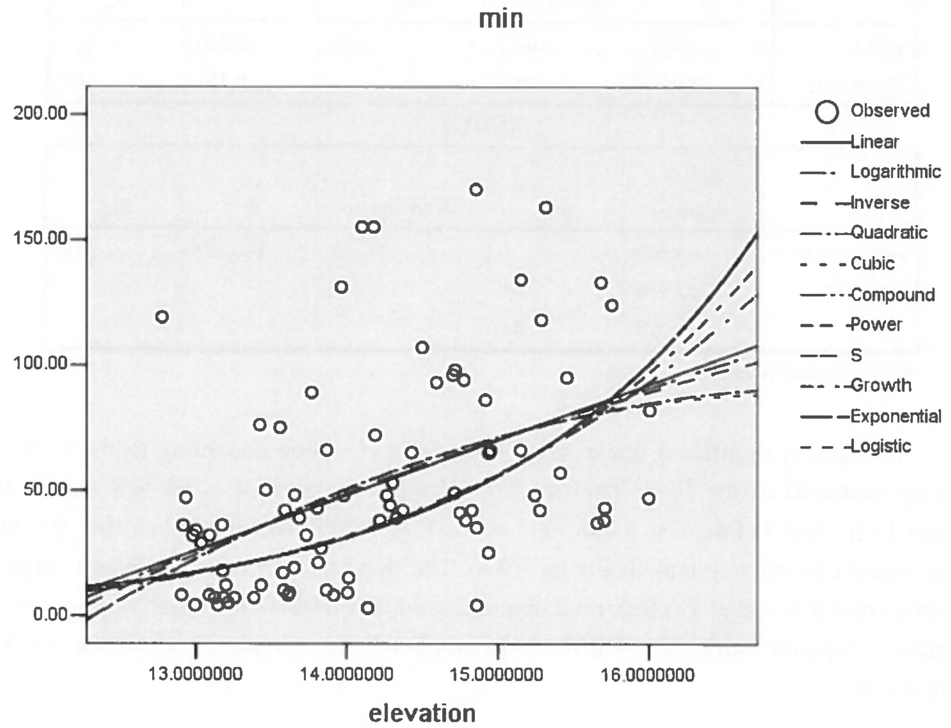

Figure 3-2 relation between bottom elevation (labeled as elevation) and minimum vegetation height (labeled as min)

Model Summary and Parameter Estimates

Dependent Variable: min

Equation	Model Summary					Parameter Estimates			
	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	.208	21.739	1	83	.000	-260.751	22.063		
Logarithmic	.209	21.907	1	83	.000	-784.584	315.735		
Inverse	.210	22.001	1	83	.000	370.451	-4497.490		
Quadratic	.211	10.989	2	82	.000	-983.513	123.479	-3.544	
Cubic	.212	11.019	2	82	.000	-769.439	75.633	.000	-.087
Compound	.248	27.397	1	83	.000	.009	1.796		
Power	.250	27.668	1	83	.000	7.83E-009	8.381		
S	.251	27.848	1	83	.000	12.002	-119.478		
Growth	.248	27.397	1	83	.000	-4.755	.585		
Exponential	.248	27.397	1	83	.000	.009	.585		
Logistic	.248	27.397	1	83	.000	116.146	.557		

The independent variable is elevation.

Table 3-2 Statistics description of the regression models between bottom elevation (labeled as elevation) and minimum vegetation height (labeled as min)

We selected linear regression among these regression models: min = 22.063*elevation -260.751, $p< 0.05$ (Sig. = .000), R square equals 0.208. Here, min means minimum vegetation height, elevation means bottom elevation, see Figure 3-2, Table 3-2.

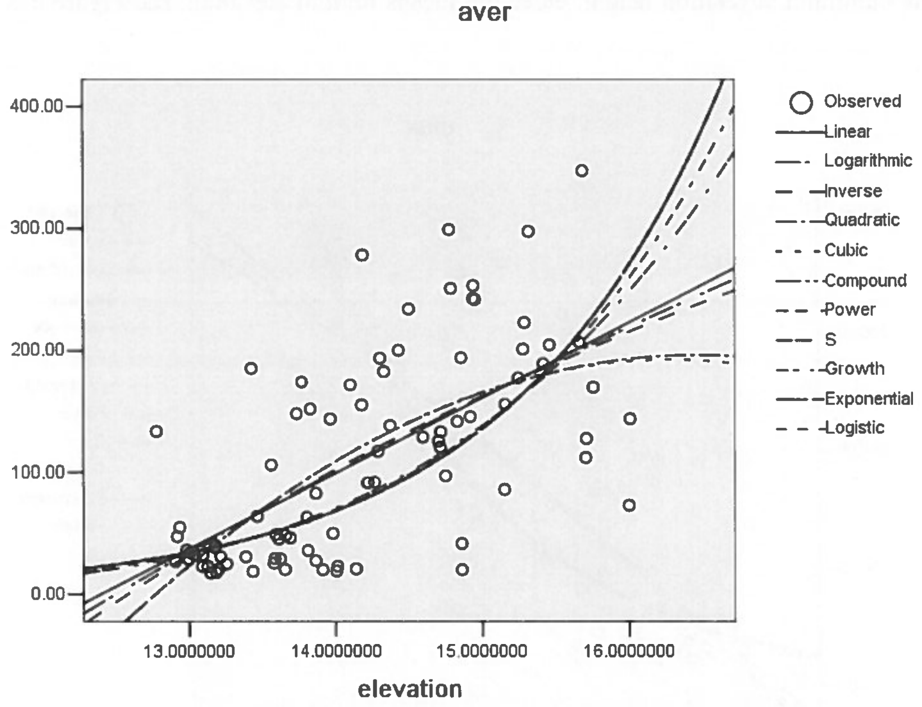

Figure 3-3 relation between bottom elevation (labeled as elevation) and average vegetation height (labeled as aver)

Model Summary and Parameter Estimates

Dependent Variable: aver

Equation	Model Summary					Parameter Estimates			
	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	.413	58.330	1	83	.000	-767.879	61.934		
Logarithmic	.417	59.300	1	83	.000	-2242.472	887.862		
Inverse	.420	60.011	1	83	.000	1007.137	-12669.696		
Quadratic	.428	30.728	2	82	.000	-3684.585	471.196	-14.303	
Cubic	.430	30.884	2	82	.000	-2783.346	274.180	.000	-.345
Compound	.436	64.085	1	83	.000	.005	1.988		
Power	.440	65.303	1	83	.000	3.50E-010	9.858		
S	.444	66.239	1	83	.000	14.311	-140.739		
Growth	.436	64.085	1	83	.000	-5.398	.687		
Exponential	.436	64.085	1	83	.000	.005	.687		
Logistic	.436	64.085	1	83	.000	220.869	.503		

The independent variable is elevation.

Table 3-3 Statistics description of the regression models between bottom elevation (labeled as elevation) and average vegetation height (labeled as aver)

As we can see from the above table, all the regressions have similar R square values around 0.45. For this reason, we selected the simple linear regression among these regression models: aver = 61.934*elevation -767.879, p< 0.05 (Sig. = .000), R square equals to 0.413. Here, aver means minimum vegetation height, elevation means bottom elevation, see Figure 3-3, Table 3-3.

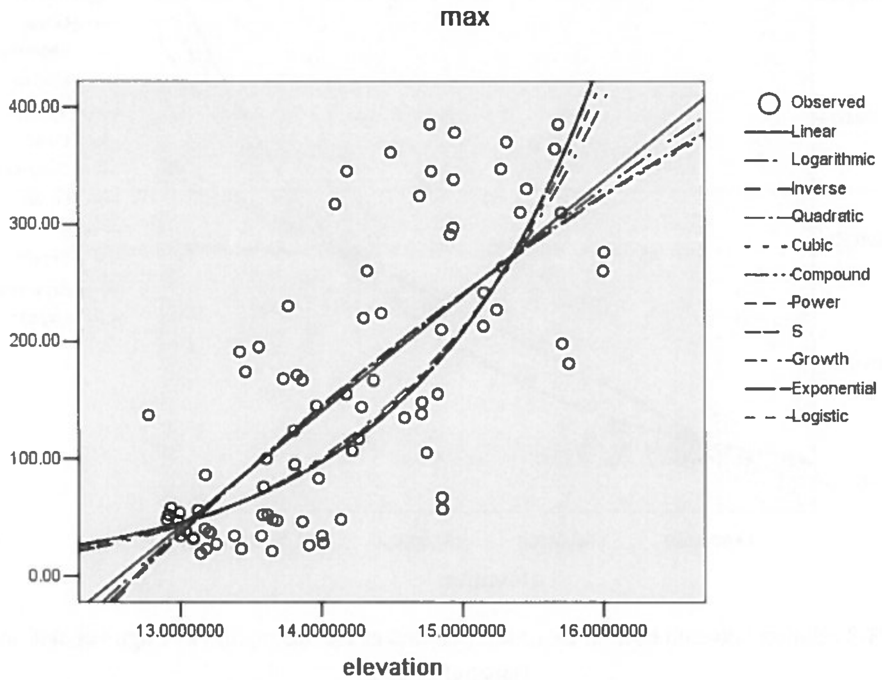

Figure 3-4 relation between bottom elevation (labeled as elevation) and maximum vegetation height (labeled as maximum)

Model Summary and Parameter Estimates

Dependent Variable: max

Equation	Model Summary					Parameter Estimates			
	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	.542	98.154	1	83	.000	-1236.330	98.338		
Logarithmic	.543	98.497	1	83	.000	-3562.676	1404.078		
Inverse	.542	98.360	1	83	.000	1570.944	-19960.365		
Quadratic	.543	48.757	2	82	.000	-2438.746	267.057	-5.896	
Cubic	.543	48.806	2	82	.000	-2104.339	189.747	.000	-.148
Compound	.531	93.896	1	83	.000	.002	2.139		
Power	.534	95.255	1	83	.000	3.34E-011	10.882		
S	.537	96.172	1	83	.000	15.694	-155.093		
Growth	.531	93.896	1	83	.000	-6.064	.760		

Exponential	.531	93.896	1	83	.000	.002	.760		
Logistic	.531	93.896	1	83	.000	430.095	.468		

The independent variable is elevation.

Table 3-4 Statistics description of the regression models between bottom elevation (labeled as elevation) and maximum vegetation height (labeled as max)

As we can see from the above table, all the regressions have similar R square values around 0.54. For this reason, we selected linear regression from among these regression models: max = 98.338*elevation -1236.330, $p < 0.05$ (Sig. = .000), R square equals to 0.542. Here, max means minimum vegetation height, elevation means bottom elevation, see Figure 3-4, Table 3-4.

After building the regression models for these three categories, we compared and assessed the results of these regression models, see Table 3-5.

	Average VH (cm)	Minimum VH (cm)	Maximum VH (cm)
Formula	61.9*E -767.9	22.1*E -260.8	98.3*E-1236.3
R^2	0.413	0.208	0.542
T-test	P < 0.001	P < 0.001	P < 0.001

Table 3-5 Results of linear regression models for Average VH, Minimum VH, Maximum VH, VH denotes vegetation height, E denotes elevation.

From Table 3-5, we could know that although linear regression models for average vegetation height, minimum vegetation height and maximum vegetation height all satisfy T-test, maximum vegetation height model has the highest R square value (R^2=0. 542). Therefore, we chose it to represent our model one: vegetation height vs. elevation model: VH = 98.3*E-1236.3, R^2=0.542, VH denotes vegetation height, E denotes elevation, and the unit for VH is cm.

3.3 Results for Model II

3.3.1 Inundated duration model

Water fluctuation has a great impact on the growing pattern of the grasslands along Dahuchi. In summer, the lower gradient of the grasslands is inundated as the monsoon comes bring lots of rainfall during this season which lifts up the water level to an extent. Contrarily, in winter, it's always cold and dry in this region so that the water level goes down. Hereby, we are curious to investigate whether the growing pattern of the grasslands such as vegetation height is correlated with the inundated duration, and this is also why we would like to build our second model: canopy submergence/ emergence model.

We used the arithmetic map algebra function method mentioned in Chapter 2 to help us to build Model II. We used the result from Model I: VH = 98.3*E-1236.3 (cm), VH denotes vegetation height; E denotes elevation, to calculate our vegetation height map, see Figure 3-5.

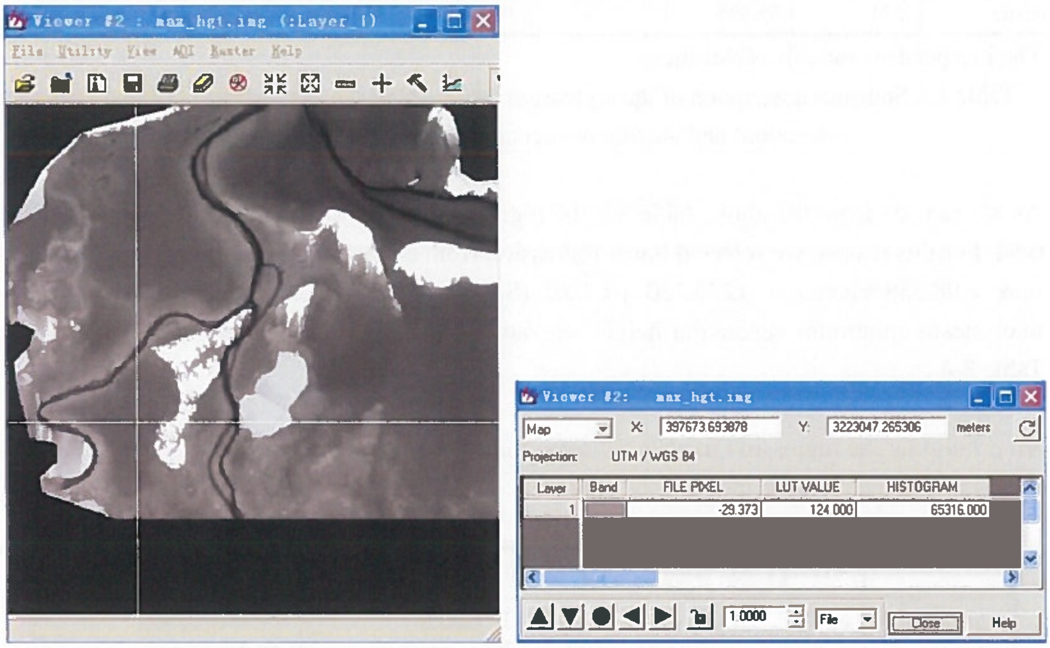

Figure 3-5 Vegetation height map of our study area (the unit is meter).

After building vegetation height map, we integrated it with DEM model to formalize our elevation plus vegetation height map using map addition in Erdas. Here, we have to uniform the unit for both vegetation height map and DEM model, the unit of vegetation height is centimeter, while the unit of DEM model is meter, therefore, the function should be listed as: DEM + vegetation height Map/100. And the result can be displayed as Figure 3-6.

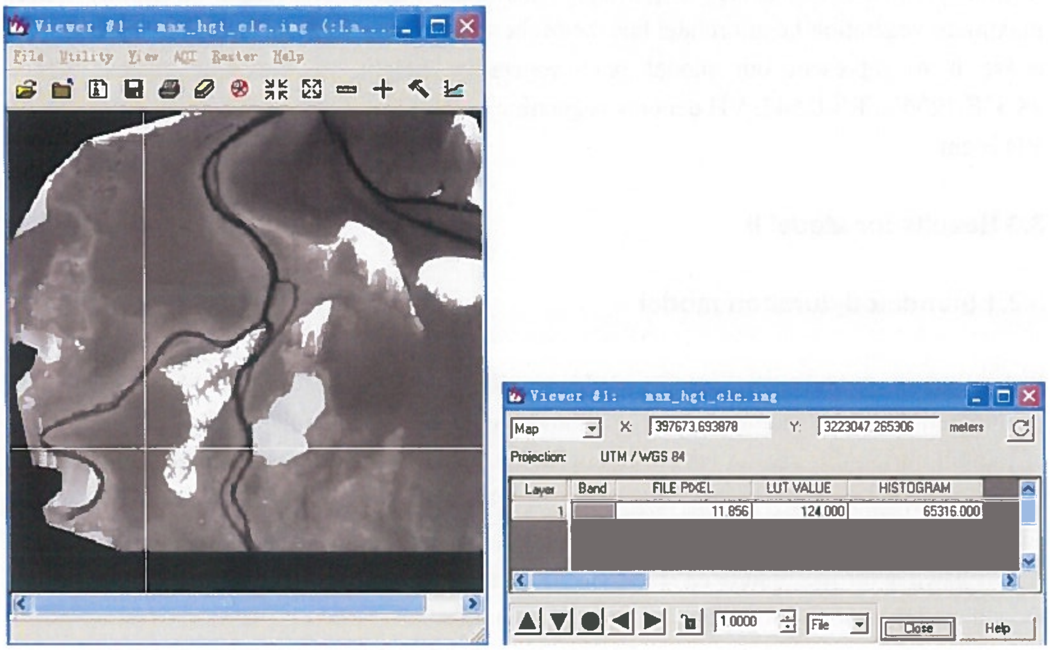

Figure 3-6 Elevation plus vegetation height map of our study area (the unit is meter).

Following the method in chapter 2.7, we compared cell value of elevation plus vegetation height map and daily water level value and created 366 binary maps. The final procedure is just to sum them together to get our inundated duration map, see Figure 3-7.

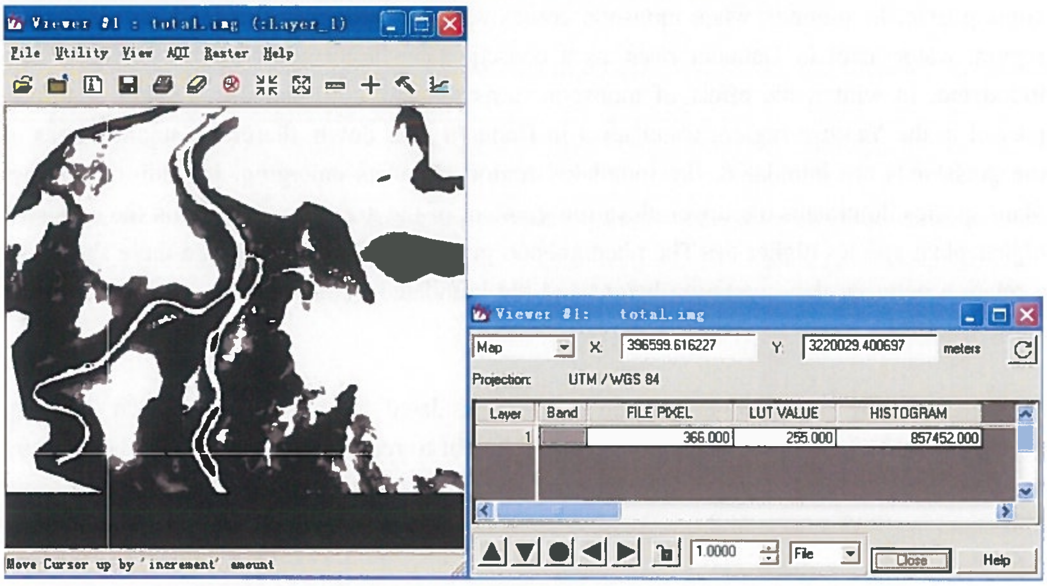

Figure 3-7 Duration of canopy inundation (the unit is meter).

We then loaded the inundated duration map into Arcmap, and added the legend, the compass and the scale bar to formalize the final inundated duration map of Dahuchi, see Figure 3-8.

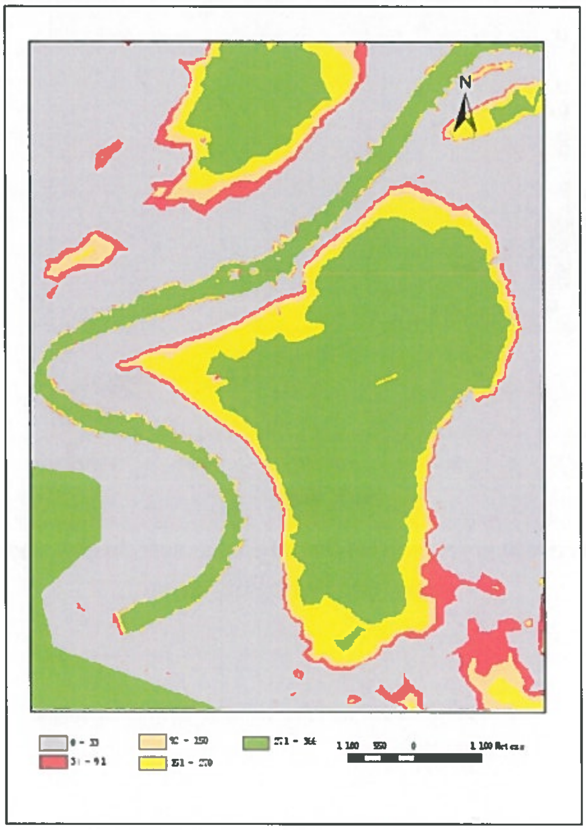

Figure 3-8 The final inundated duration map of Dahuchi (the unit is days).

3.3.2 Vegetation height vs. inundated duration model

The inundated status of the grasslands along Dahuchi varies consistently with monsoon's coming time. In summer, when monsoon comes which brings lots of rainfall to the Yangtze region, water level in Dahuchi rises, as a consequence, larger areas of the grasslands are inundated. In winter, the effect of monsoon turns to zero, cold and dry weather condition prevail in the Yangtze region, water level in Dahuchi goes down, therefore, smaller areas of the grasslands are inundated, the inundated region becomes emerging. In addition, shorter plant species dominates the lower elevation gradient of the grasslands, while on the opposite, higher plant species higher up. The phenomenon gives me a hint to speculate there should be a relation between the vegetation height and the inundated duration status of the grasslands along Dahuchi.

We calculated the vegetation height and also the inundated duration status for each sampling plot of our survey. We used average vegetation height to represent the vegetation height, and the inundated duration days to represent the inundated duration status. And then we input these data in SPSS 13.0, and did regression analysis. Here is the results, see Figure 3-9, Table 3-6.

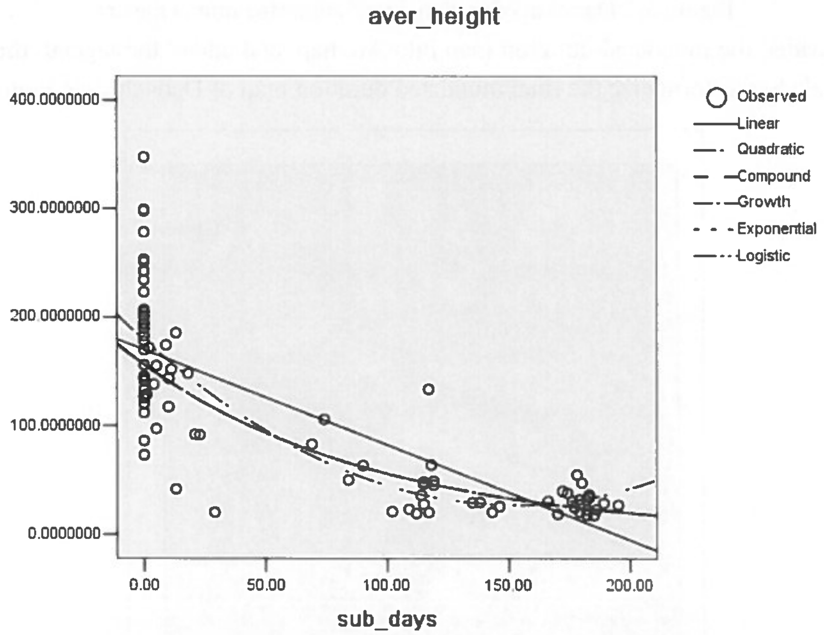

Figure 3-9 relation between vegetation height (labeled as aver_height) and inundated duration status (labeled as sub_days)

Model Summary and Parameter Estimates

Dependent Variable: aver_height

Equation	Model Summary					Parameter Estimates			
	R Square	F	df1	df2	Sig.	Constant	b1	B2	b3
Linear	.622	136.522	1	83	.000	169.813	-.876		
Quadratic	.678	86.421	2	82	.000	179.035	-2.005	.007	
Cubic	.697	62.095	3	81	.000	184.637	-4.090	.037	.000
Compound	.743	239.776	1	83	.000	156.203	.990		
Growth	.743	239.776	1	83	.000	5.051	-.010		
Exponential	.743	239.776	1	83	.000	156.203	-.010		
Logistic	.743	239.776	1	83	.000	.006	1.010		

The independent variable is sub_days.

Table 3-6 Statistics description of the regression models between vegetation height (labeled as aver_height) and inundated duration status (labeled as sub_days)

From Figure 3-9, we could observe that at a certain inundated duration values, there is a fluctuation of the average vegetation values, which means the x, y pair values (inundated duration days, average height) are not well located along the trend line: our regression line. In order to make the x, y pair values close enough to the regression line, we decided to use a logarithm base 10 function on average height: ln(average height), and then did regression analysis for the new data. Here is the results, see Figure 3-10, Table 3-7.

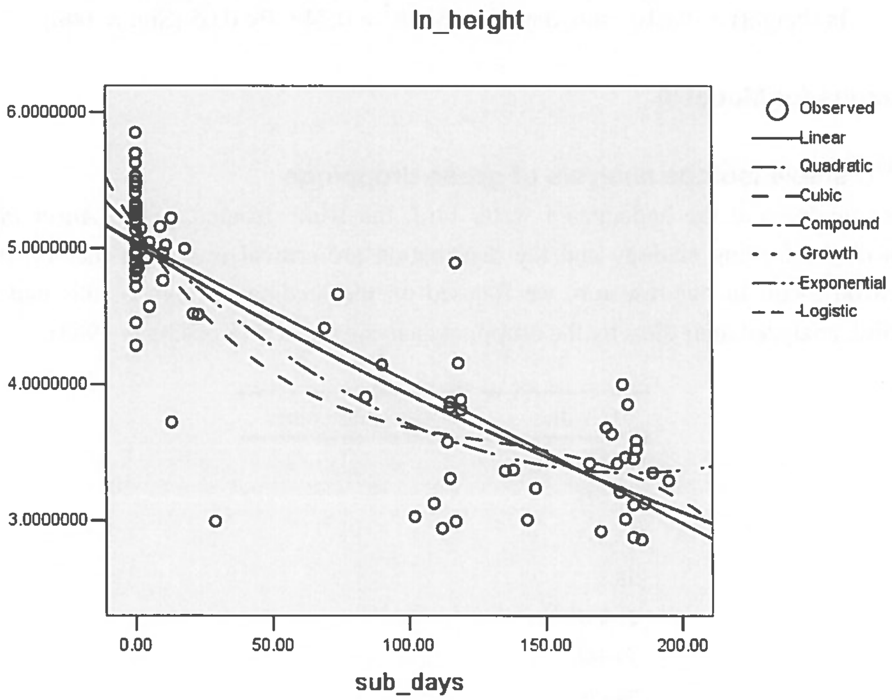

Figure 3-10 relation between vegetation height (labeled as ln_height) and inundated duration status (labeled as sub_days)

Model Summary and Parameter Estimates

Dependent Variable: ln_height

Equation	Model Summary					Parameter Estimates			
	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	.743	239.776	1	83	.000	5.051	-.010		
Quadratic	.775	141.473	2	82	.000	5.127	-.020	5.41E-005	
Cubic	.780	95.770	3	81	.000	5.157	-.031	.000	-5.77E-007
Compound	.737	232.079	1	83	.000	5.031	.998		
Growth	.737	232.079	1	83	.000	1.616	-.002		
Exponential	.737	232.079	1	83	.000	5.031	-.002		
Logistic	.737	232.079	1	83	.000	.199	1.002		

The independent variable is sub_days.

Table 3-7 Statistics description of the regression models between vegetation height (labeled as ln_height) and inundated duration status (labeled as sub_days)

The data for vegetation height vs. inundated duration model is listed in annex 8. From Table 3-6, Table 3-7, it's obvious that the logarithm function on vegetation height has improved the results significantly. R square values for Linear, Quadratic, Cubic equations have been increased greatly, while R square values for the other equations change slightly. For this reason, we selected the following equations to denote the vegetation height vs. inundated duration model:

$$\ln(\text{height}) = -0.010 * \text{sub\_days} + 5.051,\ R^2 = 0.743.\ P < 0.05\ (\text{Sig.} = .000).$$

3.4 Results for Model III

3.4.1 ^{13}C stable isotope analysis of geese droppings

In order to preserve the endangered water bird, the white fronted geese (*Anser albifrons albifrons*), the feeding ecology and the distribution are critical important factors for us to research on them. In our research, we focused on the feeding ecology of this endangered water bird, analyzed their diets by the dropping analysis method (Korschgen 1983).

^{13}C value	Geese droppings
27.99	
28.425	
28.535	
28.8	
28.437	
29.447	
29.986	
29.624	
30.334	
29.042	X-bar = 29.062

^{13}C	C3 plants	^{13}C	C4 plants
29.109	*Polygonum criopolitanum Hance*	13.871	*phalaris arundinacea. L*
29.48	*Polygonum hydropiper Linn*	13.646	*Cynodon dactylon*
29.86	*Potentilla tanacetifolia*	14.565	*Miscanthus sinensis Anderss*
29.756	*Polygonum flaccidum(Meissn.)Steward*	13.813	*Themeda japonica (Willd.) Tanaka*
29.997	*Polygonum minus Huds*	14.57	*Scirpus triqueter L*
			Miscanthus sacchariflorus (Maxim). Benth.
32.286	*Carex argyi*	14.422	*Ef. Hook. F*
30.29	*Paederia scandens*	13.675	*Phragmites communis Trin*
29.553	*Polygonum perfoliatum L.*	13.291	*Zoysia japonica Steud*
28.754	*Polygonum barbatum L*	14.76	*Setaria viridis (Linn.) Beauv.*
30.956	*Artemisia lavandulaefolia DC*	x-bar =	14.068
	Cynanchum glaucescens(Decne.) Hand.		
31.084	*-Mazz.*		
26.301	*Eragrostis ferruginea (Thunb) Beauv*		
28.603	*Arundo donax Linn.*		
31.362	*Kalimeris incisa (Fisch.) DC.*		
X-bar =	29.814		

Table 3-8 $\delta^{13}C$ Values (‰) for C_3, C_4 taxonomic groups as well as geese droppings

The results of $\delta^{13}C$ stable isotope analysis for C_3, C_4 taxonomic groups as well as geese droppings are listed in Table 3-8. The stable isotope ratio of geese droppings was significantly different from that of the C_4 species (Welch two sample t test, t = -50.585, d.f. = 15.892, P < .2.2e-16). It was however not significantly different from that of the C_3 species (two sample t test, t = 1.68, d.f. = 20.5, P = 0.115>0.05). See Figure 3-11.This finding suggests that white fronted geese forage exclusively on C_3 plant species.

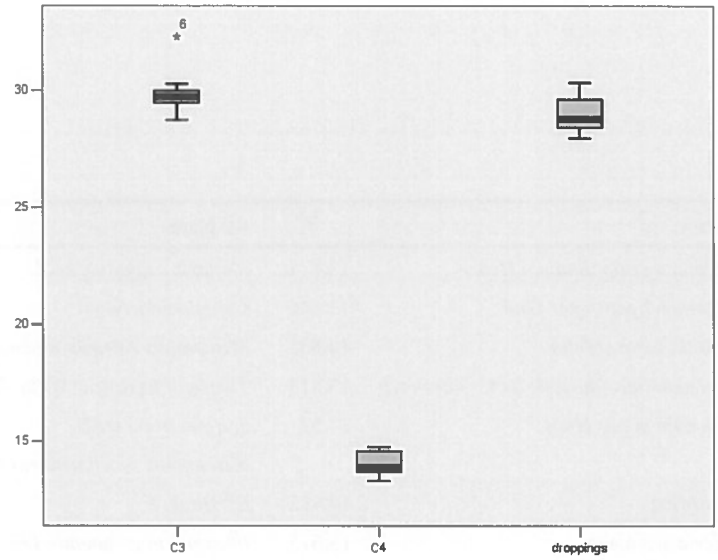

Figure 3-11 box plots for C3 plant species and geese droppings based on the values of Table 3-8

3.4.2 Photosynthetic pathways of plant species

Our previous knowledge acquired from literature as well as the staff of Poyang Lake NNR, together with the stable carbon isotope analysis could help us to identify the photosynthetic pathway for the plant species in the grasslands around Dahuchi Lake, see Table 3-9 below.

Table 3-9 Photosynthetic pathways of the main plant species in Poyang Lake NNR according to existing information and stable isotopes

		Photosynthetic pathway		
Species	**Family**	**Existing knowledge**	**$^{13}\delta$ C ratio (-)**	**\ C_3/C_4 categories**
Carex argyi	*cyperaceae*	C_3[3]	30.29	C_3
Polygonum criopolitanum Hance	*Polygonaceae*	-	29.109	C_3
Polygonum hydropiper Linn	*Polygonaceae*	C_3[6]	29.48	C_3
Polygonum barbatum L	*Polygonaceae*	-	28.754	C_3
Polygonum flaccidum(Meissn.)Steward	*Polygonaceae*	-	29.756	C_3
Polygonum perfoliatum L.	*Polygonaceae*	-	29.553	C_3
Miscanthus sacchariflorus (Maxim).		C_4[7]		
Benth. Ef. Hook. F	*Gramineae*		14.422	C_4
Arundo donax Linn.	*Gramineae*	-	28.603	C_4
Phragmites communis Trin	*Gramineae*	C_3[1]	13.675	C_4
Miscanthus sinensis Anderss	*Gramineae*	C_4[3]	14.565	C_4
phalaris arundinacea. L	*Gramineae*	-	13.871	C_4
Cynodon dactylon	*Gramineae*	C_4[7]	13.646	C_4
Zoysia japonica Steud	*Gramineae*	C_4[7]	13.291	C_4
Setaria viridis (Linn.) Beauv.	*Gramineae*	C_4[5]	14.76	C_4

Paederia scandens	*Rubiaceae*	-	30.29	C_3
Kalimeris incisa (Fisch.) DC.	*Compositae*	-	31.362	C_3
Artemisia lavandulaefolia DC	*Compositae*	C_3[2]	30.956	C_3
Cynanchum glaucescens(Decne.) Hand. -Mazz.	*Asclepiadaceae*	-	31.084	C_3
Eragrostis ferruginea (Thunb) Beauv	*Gramineae*	C_4[3]	26.301	C_4
Themeda japonica (Willd.) Tanaka	*Gramineae*	C_4[4]	13.813	C_4
Scirpus triqueter L	*Gramineae*		14.57	C_4
Potentilla tanacetifolia	*Rosaceae*	-	*29.86*	C_3

Source of information photosynthetic pathway: 1 from R. Z. Wang (Wang 2007); 2 from X. Q. Liu (X. Q and R. Z 2006); 3 from Lijuan Yin (Yin and Ling 1990); 4 from Ning (Ning, Liu et al. 2004); 5 from Journal of applied ecology (Yin and Ling 1990), 6 from Tree (Liu, G. M et al. 2003); 7 from Acta Ecological Sinica (Yin and Li 1997)

From the above table, we could see that *Phragmites communis Trin* have two types of photosynthetic pathways, C3 and C4. That's because in China there are two variations of *Phragmites communis Trin.* In northern China, *Phragmites communis Trin* tends to be C3 specie while in Southern China it tends to be C4 specie.

3.4.3 C_3/C_4 ratio vs. inundated duration model

According to our isotope analysis, *Carex* species which dominates at the lower elevation gradient tend to be C_3 plants, on the other hand, *Phragmites* spp. which dominates at the higher elevation gradient tend to be C_4 plants. In other words, we could allege that C_3/C_4 ratio changes along with the elevation gradient. Also, based on the inundated duration model, we could conclude that the inundated duration status varies along with the elevation gradient. So, it is time for us to ask: does the inundated duration status affect the C_3/C_4 ratio?

The isotope analysis as well as the percentage of every plant species for each sampling plot can help us to calculate the C_3/C_4 ratio for each sampling plot. At the same time, the inundated duration model built in Chapter 3.1 can give us the inundated duration value for each cell. So, we could do regression analysis for these two factors and check out their relation. Figure 3-12 and Table 3-9 show the results.

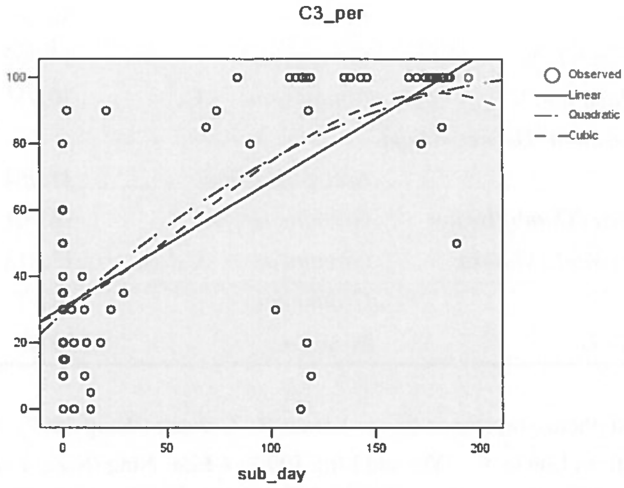

Figure 3-12 relation between C_3/C_4 ratio (labeled as C3_per) and inundated duration status (labeled as sub_days)

Dependent Variable: C3_per

Equation	Model Summary					Parameter Estimates			
	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	.593	121.049	1	83	.000	30.671	.380		
Quadratic	.602	62.065	2	82	.000	29.040	.579	-.001	
Cubic	.603	41.084	3	81	.000	29.679	.341	.002	-1.21E-005

The independent variable is sub_day.

Table 3-9 Statistics description of the regression model between C_3/C4 ratio (labeled as C3_per) and inundated duration status (labeled as sub_days)

From Figure 3-12, there seem to be five outliers which don't fit the linear regression we built. Their location can be shown in Figure 3-13. One outlier is located on the north of Dahuchi, close to the constructed dam and the road there. Lots of human activities and cattle grazing activities might contribute to the alteration of vegetation structure. Similarly, the four outliers on the west of Dahuchi encounter the same situation.

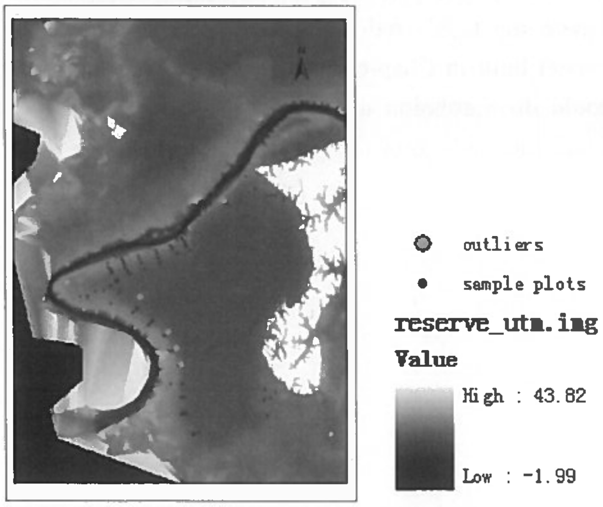

Figure 3-13 Locations of outliers for Model III (the unit is meter).

After considering removing these five outliers from our regression analysis, we did linear regression for C_3/C_4 ratio vs. inundated duration model, see Figure 3-14. Table 3-10.

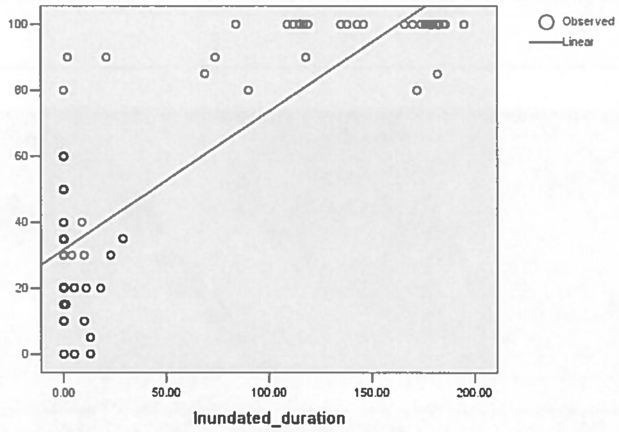

Figure 3-14 relation between C_3/C_4 ratio (labeled as C3_per) and inundated duration status (labeled as sub_days) after deleting the five outliers

Dependent Variable: C3_percent

Equation	Model Summary					Parameter Estimates	
	R Square	F	df1	df2	Sig.	Constant	b1
Linear	.738	219.482	1	78	.000	31.683	.419

The independent variable is Inundated_duration.

Table 3-10 Statistics description of the regression model between C_3/C_4 ratio (labeled as C3_percent) and inundated duration status (labeled as inundated duration) after deleting the outliers

From Figure 3-14 and Table 3-10, we could see that R square value for has been improved greatly from 0.593 to 0.738 and Sig. = 0.000 shows that the linear regression are satisfactorily acceptable statistically. Thus, we used it as C_3/C_4 ratio vs. inundated duration model:

$$C3\_per = 0.42 * sub\_days + 31.68,\ R^2 = 0.738.$$

3.4.4 C_3/C_4 distribution map

Based on the inundated duration model as well as the C_3/C_4 ratio vs. inundated duration model, we could generate our final C_3/C_4 distribution map. In Erdas 8.7, we applied the equation to the inundate duration map using arithmetic map algebra function ("+"):

$$C3\_per = 0.42 * sub\_days + 31.68,\ R^2 = 0.738.$$

(C3_per means the percentage of C_3 plants out of all plants at a plot, sub_days means the inundated duration of that plot), after that, we loaded the C_3 percentage map into ArcMap to finalize the output map. Here is the result, see Figure 3-15.

From Figure 3-15, we could figure out the zonal distribution pattern for the percentage of C_3 plant species: plant specie communities which are closer to the waterside of Dahuchi have higher C_3 percentage (around 88%~100%), while those plant specie communities which are at higher elevation gradient have lower C_3 percentage (around 31%~38%), and the C_3 percentage decreases gradually from low elevation gradient to high elevation gradient.

Figure 3-15 C_3 percentage map for Dahuchi, Poyang Lake NNR (the unit is %)

4. Discussion

4.1 DEM quality

Our reliability assessment for DEM quality showed very high correlation between DEM and Differential GPS, which can be expressed as: GPS = 1.258 * DEM -7.953, R^2 =0.774, $p< 0.05$ (Sig. = .000). However, the slope for this equation should be one and the intercept should equal to zero if the DEM quality is very accurate and the operation of Differential GPS is normative. We have several reasons for this problem: First, the wireless signal of Differential GPS can weaken if the rover is too far away from the base station. During our substrate elevation survey, the farthest test point is about 4km to the base station; we could not go any further away from the base station. Second, we applied RTK method based on a control point. Unfortunately, the control point's coordinates are not recorded by the nature reserve. And we just measured the points' coordinates using a portable GPS, the horizontal accuracy of which is within 10m. This might also cause bias (wrong elevation at the control point) and contribute to the error in intercept. Thirdly, as mentioned in 3.1, the re-projection between two projection systems might greatly contribute to this systematic error in the slope. Also the sonar measurements during high water levels in 1998 could not cover all the land part, it might have high accuracy for the elevation of water covered part, but it couldn't guarantee the same accuracy for the land part only through interpolation, which can be inferred from the abnormal steep edges along Xiu River on the DEM model.

Another proof for DEM quality is the three models we built for our research. Moreover, the outputs of the three models turn out to be very satisfactory and acceptable, which validates the DEM quality to some extent. So, during our research, we kept the original DEM model as our main input data and carried on our research with accepting its quality.

4.2 Relation between vegetation height and elevation reflected by Model I

The result of Model I: VH = 99.338*E-1236.330 (R^2=0. 542, $p< 0.001$) shows that there exits a highly significant between vegetation height and elevation. The relation is not perfect though as elevation explains only 54% of the variation in vegetation height. The unexplained variation might reflect natural variation in vegetation height but could also result from in measurement of vegetation height and elevation.

During our vegetation survey, we observed several facts which would help us to understand the correlation. The East part of Dahuchi are very steep hills, there are few grasslands there. On the north part of Dahuchi, a dam was built to protect Dahuchi to be inundated by the Xiu River, and lots of human disturbance exits there, such as fishing. Also, a road was constructed to connect to fishery at the northwest corner and the Wu town, the nearest town to Dahuchi. On the west side of Dahuchi, farmers grow *Phragmites communis Trin* on the outskirt of Dahuchi and harvest it during winter time. So, part of the grasslands are not crude enough but reclaimed according to farmers' will. Another phenomenon observed is that farmers graze cattle in the grasslands around Dahuchi. The movement of cattle certainly will alter the growing conditions for plant species in the grasslands.

4.3 Relation between vegetation height and inundated duration reflected by Model II

The result of Model II: ln (height) = -0.100* sub_days +5.051 ($R^2 = 0.743$. $P< 0.001$) showed a highly significant relation between vegetation height and inundated duration, which validates our hypothesis: taller plant species higher up, shorter plant species lower down along the elevation gradient.

We could also explain the phenomena from the growing condition for the grasslands. The plant species at higher elevation gradient are not influenced by the water inside Dahuchi, because of their advantageous location. They can grow all the year around without be inundated by the rising water level even during the monsoonal season. However, the situation is quite different for the grassland at lower elevation gradient. In spring, when the water level recedes, they begin to grow, and flourish during summer time, but begin to die out very quickly when the water level rises because of sufficient rainfall brought by the monsoon season. In other words, the grasslands at lower elevation gradient are greatly impacted by inundated days, which can be expressed in the way of water level.

4.4 Relation between C_3/C_4 ratio and inundated duration reflected by Model III

The result of Model III: C3_per = 0.42* sub_days + 31.68 ($R^2 = 0.738$. $P< 0.001$) showed that the percentage for C_3 plant species at a plot is significantly related to the inundated duration. This is the result after deleting five outliers, and the R^2 of this result has been greatly improved from 0.593 to 0.738. We deleted the five outliers for the reason that they are too close to human activities as well as cattle grazing activities.

Seen from the plot in 3.4.3 after deleting the outliers, we could still also observe that there existed variation in C_3/C_4 ratio of plant species at zero inundated duration and also the inundated duration varied at the same C_3/C_4 ratio of 100 % (C_3 plant species percentage out of total plant species). These could be explained from two aspects: 1). during our vegetation survey, we just estimated the percentage for each plant species visually, which can lead to subjective bias for C_3/C_4 ratio, for instance, we estimated 100 % as the C_3/C_4 ratio for one plot, which C_3/C_4 ratio was actually 85%. 2). Vegetation has a trend to expend themselves into other plant's realm. We observed *Carex* spp even on the higher elevation gradients and *Miscanthus* communities began to show at lower elevation gradients. The vegetation categories for one plot were more complex compared with the results in previous research (Si 2006; Zeng 2006).

The result of Model III could be explained ecologically. From our introduction, we could know that C_3 plant species prevail in lower temperature, high soil moisture environmental conditions, while C_4 plant species dominate the opposite environmental conditions. The closer the grasslands are to the riverside of Dahuchi, the more likely they are inundated for longer time. Therefore, their geographical location creates feasible growing condition for C_3 plant species.

4.5 C_3/C_4 distribution regarding to geese feeding ecology

From $\delta^{13}C$ isotope analysis, it's very clear to know that white fronted geese forage exclusively on C_3 plant species; although we need to further our research on what specific plant species they are foraging on. At the same time, C_3/C_4 distribution map in the form of percentage of C_3 plant species indicates the distribution of C_3 plant species.

5. Conclusion and recommendation

Hypothesis 1: Vegetation height at lower elevation is shorter than the one at higher elevation;

Our vegetation height vs. elevation model shows shorter plant species lower down, higher plant species higher up, although this model only explains 54% of the grassland communities have this kind of pattern.

Hypothesis 2: The duration of submergence of vegetation canopies decreases with elevation increasing;
Hypothesis 3: Spatial variation in duration of submergence can reliably be predicted from substrate elevation;

Our canopy submergence/ emergence model validates both these hypotheses. The grasslands in Poyang Lake take on a zonal distribution pattern of submergence every year, which can be visualized as Figure 3-8. The grasslands at lower elevation gradients have longer inundated duration while the grasslands at higher elevation gradients have shorter inundated duration.

Hypothesis 4: The distribution of C_3/C_4 species ratio and submergence pattern of the vegetation can be predicted,

Our C_3/C_4 distribution map proves this hypothesis. The research further demonstrated that the ratio of C_3/C_4 species increased with inundation duration. The relation was highly significant and relatively strong as inundation frequency explained 73.8 % of the variation in the natural logarithm of the C_3/C_4 ratio. From C_3/C_4 distribution map, there is an obviously zonal distribution of C_3/C_4 (denoted as C3 plant specie percentage out of total plant specie percentage). At lower elevation gradients, C_3/C_4 ratio approaches to 100 %, while at higher elevation gradients, C_3/C_4 ratio approaches to be 31%.

In addition, our observation that white fronted geese had stable isotope ratios similar to those of C_3 species, leads to the conclusion that this goose species forages on C_3 species. This conclusion corresponds to the finding of Markkola (Markkola, Niemela et al. 2003) .

The higher proportion of C_3 species at longer inundation duration was partly attributable to elevation. The effect of elevation on flood duration was enhanced because plants at lower elevations had significantly shorter stature and species higher up. The difference in vegetation height influenced the attractiveness of the vegetation while white fronted geese prefer shorter vegetation in the range of 10 to 15 cm above taller C_4 species which grow up to 50 cm or more, which is far above the range preferred by this goose species.

C_4 species dominate at the latitude (29 N) of Poyang Lake, because of the summer temperature at around 30 ℃. C_3 species dominate in the lower elevation grasslands of Poyang Lake, because flooding in summer forces vegetation at low elevation to shift the period of photosynthetic activity to spring and autumn when temperatures are around 20 □ or below. We have shown that this shift of the photosynthetic period is attributable to prolonged submergence of the canopies of vegetation at low elevation because of high water levels during the monsoon. We thus conclude that the availability of the C3 plant species, which are preferred by geese, depends of the monsoonal flooding of the grasslands around the Yangtze.

In our research, we used water level data for 2004 and vegetation data for 2008 as our input data. We are also curious to know the vegetation variability among years and the change pattern of C_3/C_4 distribution from year to year, with sufficient water level data as well as vegetation data provided. At the same time, if we could also link the change pattern of C_3/C_4 distribution with the variation in the total number of overwintering white fronted geese in Poyang Lake, we then could conclude which factor contributes greatly to the variation of the total number of white fronted geese, for preserving this world-widely endangered species. And this research should be furthered.

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7. Annexes

Vegetation Record Sheet Poyang Lake NNR				Recorder		
Date:	GPS	X:		Transect Nr:		
	RD	Y:		Plot Nr:		
Plot size:	$20*20m^2$		Other:			
Species info						
				Sample Species		
Species Name Latin/ Chinese	Plant height (cm)	Cover (%)		Taxonomy name	Isotope 13C determination	
Site information						
Elevation:		Vegetation height:		Average:		
				Maximum:		
Grazing Signs:	Defoliated tissue		No	Little	Moderate	Severe
	Dung		No	Little	Moderate	Severe
	Animals present		Yes / No	Species:		
Geese droppings	No	Little		Moderate	High	
	Dropping density (Nr/plot)					
	Sample for isotope determination			Code		
Other Observations						

Annex 1 Data sheet for Poyang Lake NNR vegetation cover description

ID	Name	North	Easting	Elevation
1	p1	3224897.414	397112.64	19.957
2	p10	3223657.546	395242.353	11.957
3	p11	3223179.677	394052.364	12.43
4	p12	3223152.09	394266.633	11.858
5	p13	3222827.822	394299.223	13.264
6	p14	3223653.6	395064.55	11.932
7	p15	3223729.494	395240.592	12.018
8	p16	3224092.197	395584.199	13.216
9	p17	3224280.976	396074.072	13.627
10	p18	3224365.201	396307.505	14.005
11	kzd	3224857.12	397067.45	14.664
12	p3	3223944.311	396165.723	11.493
13	p4	3223966.392	396147.286	11.913
14	p5	3224139.267	396082.851	12.988
15	p6	3224197.012	396012.104	13.423
16	p7	3223877.659	395794.701	12.274
17	p8	3223819.546	395800.647	11.715
18	p9	3223775.224	395811.565	11.613
19	pt002	3224991.588	397184.882	13.615
20	pt003	3225299.295	397398.862	14.529
21	pt004	3225222.484	397491.506	11.87
22	pt005	3225298.311	397599.045	11.568
23	pt006	3225846.051	397984.481	14.635
24	pt007	3225728.087	398175.999	11.652
25	pt012	3225848.847	398291.096	11.53
26	pt014	3225659.266	397796.07	13.518
27	pt015	3225565.706	397852.708	12.445
28	pt016	3225473.686	397893.324	11.52
29	pt017	3225319.443	397593.79	11.762
30	pt018	3225387.241	397505.071	13.571
31	pt019	3225125.662	397200.852	14.498
32	pt020	3225054.522	397240.816	12.718
33	pt021	3225054.552	397240.833	12.706
34	pt022	3224981.853	397275.954	11.854
35	pt023	3224790.623	397124.204	13.194
36	pt024	3224687.357	397174.879	12.378
37	pt025	3224383.666	397228.022	11.819
38	pt026	3224348.947	397182.396	11.459
39	pt027	3224614.989	396942.365	12.972
40	pt028	3224670.174	396802.494	14.327
41	pt029	3224519.159	396564.422	15.92
42	pt030	3224165.773	396381.842	12.414
43	pt031	3224063.002	396385.235	11.607

44	pt032	3223729.72	395538.551	11.671
45	pt033	3223872.693	396000.275	11.609

Annex 2 Sample points' x, y, z coordinates by differential GPS

Sample Nr	Species Name	Amount (mg)	Amt %	d 13C/12C	d 13C/12C(minus)	C3/C4
1	*Polygonum criopolitanum Hance*	1.337	51.0649564	-29.109	29.109	C3
2	*Polygonum hydropiper Linn*	0.926	49.7506173	-29.48	29.48	C3
3	*Potentilla tanacetifolia*	1.869	21.1405856	-29.86	29.86	C3
4	*phalaris arundinacea. L*	1.111	52.961856	-13.871	13.871	C4
5	*Cynodon dactylon*	1.589	54.8202215	-13.646	13.646	C4
6	*Polygonum flaccidum(Meissn.)Steward*	1.957	57.335292	-29.756	29.756	C3
7	*Polygonum minus Huds*	1.541	57.3329288	-29.997	29.997	C3
8	*Carex argyi*	1.153	53.115602	-32.286	32.286	C3
9	*Miscanthus sinensis Anderss*	1.504	50.1577508	-14.565	14.565	C4
10	*Paederia scandens*	1.757	52.8111386	-30.29	30.29	C3
11	*Polygonum perfoliatum L.*	1.829	58.5586993	-29.553	29.553	C3
12	*Polygonum barbatum L*	1.652	50.6862074	-28.754	28.754	C3
13	*Setaria viridis (Linn.) Beauv.*	0.921	52.4804415	-14.76	14.76	C4
14	*Themeda japonica (Willd.) Tanaka*	1.849	52.6296433	-13.813	13.813	C4
15	*Artemisia lavandulaefolia DC*	2.062	54.980293	-30.956	30.956	C3
16	*Cynanchum glaucescens(Decne.) Hand. -Mazz.*	1.221	65.1504984	-31.084	31.084	C3
17	*Scirpus triqueter L*	1.741	64.8324155	-14.57	14.57	C4
18	*Eragrostis ferruginea (Thunb) Beauv*	1.621	58.0442544	-26.301	26.301	C3
19	*Miscanthus sacchariflorus (Maxim). Benth. Ef. Hook. F*	1.807	59.4014425	-14.422	14.422	C4
20	*Phragmites communis Trin*	2.184	59.3620479	-13.675	13.675	C4
21	*Arundo donax Linn.*	2.331	55.9780519	-28.603	28.603	C3
22	*Zoysia japonica Steud*	2.267	58.9146565	-13.291	13.291	C4
23	*Kalimeris incisa (Fisch.) DC.*	1.23	56.4855949	-31.362	31.362	C3
24	geese droppings	1.337	49.8811555	-27.99	27.99	C3
25	geese droppings	2.137	54.7874236	-28.425	28.425	C3
26	geese droppings	1.306	56.2723484	-28.535	28.535	C3
27	geese droppings	1.691	52.886684	-28.8	28.8	C3
28	geese droppings	1.912	52.030827	-28.437	28.437	C3
29	geese droppings	1.834	54.4866464	-29.447	29.447	C3

30	geese droppings	1.428	53.1420023	-29.986	29.986	C3
31	geese droppings	1.058	43.9833283	-29.624	29.624	C3
32	geese droppings	1.471	54.3665389	-30.334	30.334	C3
33	geese droppings	1.328	59.0732628	-29.042	29.042	C3

Annex 3 Stable isotope analysis results for plant samples and geese droppings

```
COMMENT "Generated from graphical model: e:/data/dem/du1.gmd";
#
# set cell size for the model
#
SET CELLSIZE MIN;
#
# set window for the model
#
SET WINDOW UNION;
#
# set area of interest for the model
#
SET AOI NONE;
#
# declarations
#
Float RASTER n1_reserve_utm FILE OLD NEAREST NEIGHBOR AOI NONE "e:/data/dem/max_hgt_ele.img";
Integer RASTER n2_nr2 FILE DELETE_IF_EXISTING USEALL ATHEMATIC 8 BIT UNSIGNED INTEGER
"e:/data/dem/365/nr1.img";
#
# function definitions
#
n2_nr2 = EITHER 0 IF ( $n1_reserve_utm >= 12.9350 ) OR   1 OTHERWISE;
QUIT;
```

Annex 4 Codes behind du1.mdl file

```
int _tmain(int argc, _TCHAR* argv[])
{
    FILE *fpOrign = NULL;
    fpOrign = fopen("D:\\wrgmd\\2004.txt", "r");
    if (fpOrign == NULL)
        return 0;
    std::cout<<"Opend 2004.txt\n";
    FILE *fpGmd = NULL;
    char pszFileName[128];
```

```
char pszValue[64];
int    nCount = 1;
while (!feof(fpOrign))
{
        memset(pszFileName, 0, 128 * sizeof(char));
        sprintf(pszFileName, "D:\\wrgmd\\gmd\\du%d.mdl", nCount);
        memset(pszValue, 0, 64 * sizeof(char));
        fscanf(fpOrign, "%s", pszValue);
        fpGmd = fopen(pszFileName, "w");
        fprintf(fpGmd,"COMMENT \"Generated from graphical model: e:/data/dem/du%d.gmd\";\n",nCount);
        fprintf(fpGmd,"#\n");
        fprintf(fpGmd,"# set cell size for the model\n");
        fprintf(fpGmd,"#\n");
        fprintf(fpGmd,"SET CELLSIZE MIN;\n");
        fprintf(fpGmd,"#\n");
        fprintf(fpGmd,"# set window for the model\n");
        fprintf(fpGmd,"#\n");
        fprintf(fpGmd,"SET WINDOW UNION;\n");
        fprintf(fpGmd,"#\n");
        fprintf(fpGmd,"# set area of interest for the model\n");
        fprintf(fpGmd,"#\n");
        fprintf(fpGmd,"SET AOI NONE;\n");
        fprintf(fpGmd,"#\n");
        fprintf(fpGmd,"# declarations\n");
        fprintf(fpGmd,"#\n");
        fprintf(fpGmd,"Float RASTER n1_reserve_utm FILE OLD NEAREST NEIGHBOR AOI NONE
\"e:/data/dem/ max_hgt_ele \";\n");
        fprintf(fpGmd,"Integer RASTER n2_nr2 FILE DELETE_IF_EXISTING USEALL ATHEMATIC 8
BIT UNSIGNED INTEGER \"e:/data/dem/365/nr%d.img\";\n",nCount);
        fprintf(fpGmd,"#\n");
        fprintf(fpGmd,"# function definitions\n");
        fprintf(fpGmd,"#\n");
        fprintf(fpGmd,"n2_nr2 = EITHER 0 IF ( $n1_reserve_utm >= %s ) OR 1
OTHERWISE;\n",pszValue);
        fprintf(fpGmd,"QUIT;\n");
        std::cout<<"File du"<<nCount<<".mdl\n";
        nCount++;
        fclose(fpGmd);
        fpGmd = NULL;
}
std::cout<<"Finished\n";
if (NULL != fpOrign)
{
        fclose(fpOrign);
```

```
        fpOrign = NULL;
    }
    getch();
    return 0;
}
```

Annex 5 Codes to generate the other 365 script files

DEM	GPS
14.84056	11.557
13.8844	10.508
14.57745	11.422
13.51605	8.763
13.53124	8.461
15.31211	11.528
13.33805	8.545
13.2909	8.423
15	10.411
14.04251	9.338
13.31928	8.413
13.59383	8.655
14.66367	10.464
14.78607	11.391
13.87808	9.611
13.87811	9.599
13.4872	8.747
13.34701	10.087
12.95546	9.271
12.90132	8.712
12.97362	8.352
14.86038	9.865
15.56462	11.22
15.59276	12.813
13.67132	9.307
13.24176	8.5
13.47784	8.564
13.2545	8.502
13.52545	9.034
13.7253	9.507
13.75326	8.935
14.97686	10.341
13.76707	9.009
13.83297	9.095
15.12688	10.293

15.25386	10.704
15.42562	11.082
14.84056	11.741
13.1866	8.57
13.32825	8.99
14.31057	10.065
14.75218	10.5
13.69412	9.351
13.41072	8.792
13.18943	8.69

Annex 6 Elevation values derived from DEM and GPS measured values of test sampling plots

	vegetation height(cm)		
Elevation (m)	Minimum	Average	Maximum
14.011998	15	22.8	28
13.431499	12	18.6	23
13.912159	8	20	26
13.649679	19	20.2	21
14.859735	4	20	57
13.575869	17	25.5	34
13.197917	12	20.35	37
14.138793	3	20.7	48
12.904285	8	27	48
15.413925	57	189.1	310
14.219078	38	91.3	107
13.653974	48	48	48
14.712304	49	120.2	138
15.278374	42	201.1	347
15.704042	38	111.9	310
14.005094	9	19	34
13.58178	10	29.2	52
13.864575	10	27.4	46
13.589112	42	48.8	76
13.618772	9	29	52
12.916014	36	47.2	52
13.088379	8	22.8	32
13.422866	76	185.25	191
13.557584	75	105.9	195
13.809438	21	35.8	95
14.4289	65	200.15	224
14.855301	170	194	210
15.317219	163	297.55	370
13.46245	50	63.8	174

13.608852	8	45.3	100
13.12392	7	22.6	56
14.187024	72	278.1	345
14.774716	94	298.95	385
15.68348	133	347.2	385
12.993638	4	28.6	54
13.865894	66	82.65	167
13.828058	27	151.8	171
14.328927	39	182.65	260
14.937322	25	242.6	297
13.176539	18	39.8	86
13.76661	89	174.05	230
14.3028	53	193.6	220
14.858289	35	41.4	67
12.980405	32	36.2	47
13.730739	32	147.9	168
13.036045	29	31.7	38
14.498095	107	234	361
14.950411	66	241.7	378
13.211899	5	30.6	37
14.715669	98	133	148
13.803062	43	63.1	124
14.918263	86	145.4	291
14.593585	93	128.7	135
13.143659	4	17.5	19
13	34	34	34
13.964198	131	143.6	145
14.178959	155	155	155
14.940259	65	253.05	338
12.93335	47	54.7	58
13.980793	48	49.75	83
13.089799	32	32	32
14.747879	41	96.9	105
15.245416	48	177.55	227
15.658863	37	206.65	364
16	47	72.7	260
14.28792	44	117.1	144
13.18154	7	17.8	23
13.685522	39	46.2	47
14.828184	42	141.5	155
15.288077	118	222.9	264
15.708239	43	127.5	198
14.26455	48	91.7	117
13.382649	7	30.6	34

12.776589	119	133.4	137
15.153911	134	155.6	242
15.755827	124	169.6	181
14.102009	155	171.6	317
13.253857	7	24.8	27
14.701333	96	125.5	324
15.45723	95	204.5	330
14.370864	42	138.1	167
13.172123	36	38	40
15.150799	66	85.8	213
14.785984	38	250.75	345
16.007545	82	143.7	276

Annex 7 Vegetation heights in three categories and bottom elevation at the same plot

Average height	inundated days	Ln (height)
22.8	109	3.1267605
18.6	170	2.9231616
20	117	2.9957323
20.2	143	3.0056826
20	29	2.9957323
25.5	146	3.2386785
20.35	179	3.0130809
20.7	102	3.0301337
27	195	3.2958369
189.1	0	5.242276
91.3	23	4.5141508
48	115	3.871201
120.2	0	4.789157
201.1	0	5.3038023
111.9	0	4.7176056
19	112	2.944439
29.2	138	3.3741687
27.4	115	3.310543
48.8	119	3.8877303
29	135	3.3672958
47.2	180	3.8543939
22.8	186	3.1267605
185.25	13	5.2217063
105.9	74	4.6624953
35.8	114	3.5779479
200.15	0	5.2990671
194	0	5.2678582
297.55	0	5.6955823

63.8	118	4.1557532
45.3	119	3.813307
22.6	182	3.1179499
278.1	0	5.6279808
298.95	0	5.7002763
347.2	0	5.849901
28.6	189	3.3534067
82.65	69	4.4146148
151.8	11	5.0225639
182.65	0	5.2075718
242.6	0	5.491414
39.8	172	3.6838669
174.05	9	5.1593426
193.6	0	5.2657942
41.4	13	3.7232809
36.2	183	3.5890591
147.9	18	4.9965364
31.7	182	3.4563167
234	0	5.4553211
241.7	0	5.4876973
30.6	176	3.421
133	0	4.8903491
63.1	90	4.1447208
145.4	0	4.9794886
128.7	1	4.8574841
17.5	185	2.8622009
34	183	3.5263605
143.6	10	4.9670317
155	5	5.0434251
253.05	0	5.5335871
54.7	178	4.0018637
49.75	84	3.9070105
32	179	3.4657359
96.9	5	4.5736795
177.55	0	5.1792523
206.65	0	5.3310265
72.7	0	4.2863414
117.1	10	4.7630283
17.8	182	2.8791985
46.2	115	3.8329798
141.5	0	4.9522997
222.9	0	5.4067232
127.5	0	4.8481164
91.7	21	4.5185224

30.6	166	3.421
133.4	117	4.8933521
155.6	0	5.0472886
169.6	0	5.1334427
171.6	2	5.1451662
24.8	177	3.2108437
125.5	0	4.8323058
204.5	0	5.320568
138.1	4	4.9279781
38	174	3.6375862
85.8	0	4.452019
250.75	0	5.5244564
143.7	0	4.9677278

Annex 8 Input data for vegetation height vs. inundated duration model