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Exploring the possibility of estimating the aboveground biomass of *Vallisneria spiralis L.* using Landsat TM image in Dahuchi, Jiangxi Province, China

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ABSTRACT

The provision of food to breeding and migrating waterfowl is one of the major functions of submerged aquatic vegetation in shallow lakes. *Vallisneria spiralis L.* is a submerged aquatic plant species widely distributed within Jiangxi Poyang Lake National Nature Reserve, China. More than 95% of the world population of the endangered Siberian crane as well as significant numbers of Bewick's swan and swan goose over winter in this area, while foraging on the tubers of *Vallisneria*. The objective of this paper was to explore the possibility of estimating the aboveground biomass of *Vallisneria* in Dahuchi Lake using Landsat TM image. The relations between aboveground biomass and the bands of a Landsat TM image and their derived variables were investigated using uni- and multivariate linear and non-linear regression models. The results revealed significant but very weak relations between aboveground biomass and the remotely sensed variables. Hence Landsat TM imagery offered little potential to predict aboveground biomass of *Vallisneria* in this particular region. Possible reasons which could have caused these results were discussed, including: 1) the possible influence of suspended matter in the water; 2) the less accurate field sampling; 3) the limitations of spatial and spectral resolutions of Landsat TM image; 4) the methods used are not appropriate; 5) the homogeneously spatial distribution of aboveground biomass. We propose considering two alternative methods to improve the estimation of aboveground biomass of *Vallisneria*. First of all, results might be improved while combining alternative data sources (hyperspectral or high spatial resolution images) with innovative methods and more accurate sampling data; Secondly we propose assessing aboveground biomass while using productivity simulation models of submerged aquatic vegetation integrated with geographic information system (GIS) and remote sensing.

Keywords: Submerged Aquatic Vegetation; Vallisneria spiralis L.; Aboveground Biomass; Landsat TM Image

1. INTRODUCTION

Aquatic submerged vegetation (SAV) is an essential component of shallow lake ecosystems. On one hand, SAV plays important roles and has significant effects on abiotic and biotic components in providing food, shelters and breeding habitats for aquatic animals such as invertebrates, fishes and birds, cycling nutrient and other elements, stabilizing flow conditions,

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enhancing water clarity, driving primary production, improving bottom quality and composition, and protecting the lakeshore from erosion[1,2]. On other hand, SAV is readily impacted by it's surrounding abiotic and biotic factors, such as nutrient enrichment from industrial, municipal and agricultural sources, modifications of water regimes caused by the constructions of dams and the withdraws of water for industrial and agricultural purposes, as well as the over-grazing by birds and other plant-eating species[1,3]

Information on the areal aboveground biomass of SAV is necessary for monitoring, managing and understanding the shallow aquatic ecosystem. However, it is difficult to obtain this kind of information both at small and large spatial scales because of spatial heterogeneity in plant biomass[4]. Traditionally, researchers estimate SAV biomass using direct field surveys[5-7]. This method however is cost, time and effort consuming, which typically limits the size of the samples taken and unreliability of the estimates. At the same time, the complexity of natural conditions and the lack of prior knowledge of the aboveground biomass distribution limit the effective field surveys[8]. Remote sensing could potentially produce such information more efficiently. Several attempts have been made to map aboveground biomass of SAV. Armstrong[9] reported that almost 80% of the variability in canopy biomass of seagrass could be explained by band 2 and 3 of Landsat TM. Zhang[10] found a very strong correlation (r = 0.94) between the band 1 of Landsat TM and canopy biomass of SAV in Honghu Lake, China.

Vallisneria spiralis L. is a widely distributed submerged aquatic plant species in Jiangxi Poyang Lake National Nature Reserve (Nature Reserve)[11]. More than 95% of the world population of Siberian crane overwinter in this area, while feeding on the tubers of *Vallisneria*[11]. Significant numbers of Bewick's swan and the endangered swangoose also rely on *Vallisneria* tubers as a source of food[11]. So obtaining and managing the spatial distribution information of *Vallisneria* biomass is critically important for predicting spatial distribution of food habitatof Siberian crane, Bewick's swan and swangoose. However, such informations is lacking at present.

The objective of this paper is to explore the possibility of estimating the aboveground biomass of *Vallisneria* using Landsat TM image. The study was executed in Dahuchi, a lake within Poyang Nature Reserve, China. We, firstly review the effects using direct field surveys to obtain the spatial distribution information of *Vallisneria* biomass from Nature Reserve. Secondly, several commonly used univariable linear and non-linear as well as multivariable linear regression models between the aboveground biomass, the bands of Landsat TM image and their derived variables are developed. Thirdly, on the basis of results, the reasons causing the results are analyzed. Finally, two suggections for future research are presented for estimating the aboveground biomass of *Vallisneria* in this region.

2. STUDY AREA

Jiangxi Poyang Lake National Nature Reserve is located between 115º55′ - 116º03′E, 29º05′ - 29º 15′N in the northern part of Jiangxi Province, China[11]. The reserve is dominated by 9 lakes with associated grasslands which has a total area of 22,400 hectares: Dachahu, Banghu, Dahuchi, Shahu, Changhuchi, Zhonghuchi, Xianghu, Meixihu and Zhushihu[11]. The geographical and climatic conditions of the Nature Reserve make it a favorable place for migratory birds to overwinter in this region. Every year, the Nature Reserve shelters about a million waterfowl with more than 200 species, of which over 20 are rare species Poyang lake nature reserve is known as the world's largest nature reserve for birds[11]. More than 95% of the world population of Siberian crane overwinter in Poyang lake. Their main food are the tubers of *Vallisneria*[11]. Dahuchi is the third largest lake within Nature Reserve, with an area of 3000 hectares. There exists intensive human disturbance in Banghu and Dachahu and six other smaller lakes, and Dahuchi is extremely well protected. Becuase of this it has become a significant habitat of overwintering waterfowls such as Siberian crane, Bewick's swan and swangoose. Figure 1 shows the geographical locations of Nature Reserve and Dahuchi Lake.

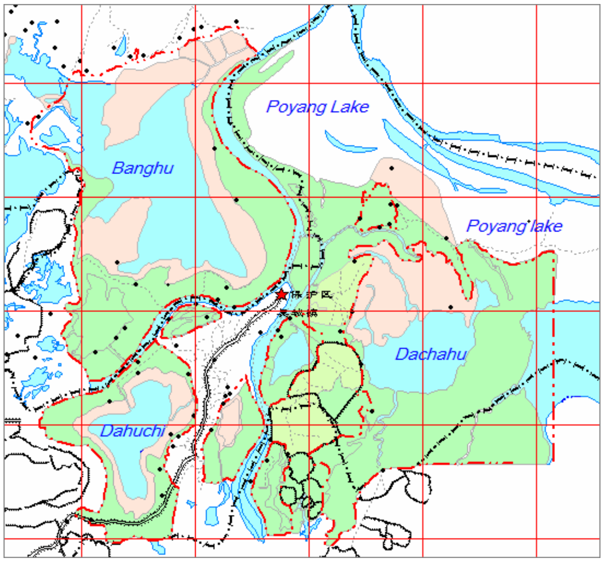

Figure 1 the geographical locations of Jiangxi Poyang Lake National Nature Reserve and Dahuchi

Figure 2 image of Dahuchi Lake and distribution of sampling points

3. PREVIOUS FIELD SURVEYS

In order to obtain the information on *Vallisneria* biomass and study the relations between biomass, water depth and water clarity, systematical field surveys of *Vallisneria* biomass-related informations have been implementing from 1998. The surveys in four lakes (Meixihu, Sixiahu, Dahuchi and Shahu) within the Nature Reserve, are made on sampling areas with about 50m interval along two fixed transects cross lake center in each lake in October and November every year[11]. The collected information includes species name, shoot number, aboveground biomass of aqutic vegetation, as well as tuber biomass of *Vallisneria*, water depth and secchi disk depth[11]. On the basis of the information collected in 1998 and 1999, various relations between *Vallisneria* growth, environmental factors and different growth indicators of *Vallisneria,* were analysized, which involve relation between shoot length and water depth, shoot length and water clarity, tuber density and water depth, shoot number and shoot biomass for per m^2, shoot number and individual shoot weight for per m^2, shoot number and tuber number, individual shoot weight and individual tuber weight[11]. Although the obtained information and the analyses did not cover flucturation of water level, chemical characteristic of the water, light intensity within water column, sediment, water temperature, water flow, wind speed, water wave etc, they gave an insight into the general understanding of the biomass and growth of *Vallisneria* in this shallow lake ecosystem, and more importantly, they provided important historical knowledge and laid the foundations for further research.

4. DATA COLLECTING AND PRE-PROCESSING

In order to estimate the aboveground biomass of *Vallisneria*, one Landsat TM image, which was acquired on October 28, 2004, was purchased. The pixel size of bands 1-5 of the image is 25*25m, and the image over the study area is cloudless. The image was georeferened using topographic maps with scale of 1:50,000, and the RMSE is 10.13m (less than half pixel). The processed image meets the requirement of the study.

The field sampling was implemented from 21 to 22 October 2004. 106 sites were selected with about 50m interval along five transects, and their geographical locations (latitude and longitude) were determined by global positioning system (GPS) with accuracy of about 10m. The aquatic vegetations (including emergent, floating-leaves and submerged vegetation) in each site were taken randomly by using a clamp with the size of 23 * 17cm. The clamp was lowered four times at each site. The fresh biomass of different species was weighted respectively. The average values of submerged vegetation in 4 clamps were taken as the fresh biomass of submerged vegetation of one sample area, and was expressed as fresh weight per square meter (g/ m^2). In most sites, *Vallisneria* was the only present species, or it biomass is dominant, so we simply expressed the total biomas of SAV as the aboveground biomass of *Vallisneria.*

Figure 2 displays the image with false color (band 4, band 3 and band 2) of Dahuchi lake and the distribution of sampling points within this lake.

5. METHODS

5.1 Open water area (no emergent, floating-leaves vegetation)

In some areas of Dahuchi, emergent, floating-leaves and submerged vegetations co-occurred. Due to the existences of emergent and floating-leaves vegetations and their strong reflections and absorptions to visible and near-infrared light, remote sensing technique shows limitations in detecting submerged vegetation. So it is necessary to distinguish open water area, and only focus this study on open water areas. The combination of NDWI[12] and mask technique was employed to obtain open water area image from the original one.

$$NDWI = \frac{GREEN - NIR}{GREEN + NIR}$$

Where, $GREEN$ represents the green band, and NIR represent the near-infrared band of Landsat TM image.

5.2 Regression models between aboveground biomass, bands of TM and their derived variables

Visible and infrared lights have different capacities of penetrating clear water body. The blue light (0.44 – 0.54 um) has strongest capacity of penetrating 20m with the peak in 0.48 um, and the red light is able to penetrate less than 3m, while near-infrared light (0.76 – 0.90 um) is absorbed strongly by water body, but it is still able to penetrate some water body less than 2m[13]. For this reason, the visible and near-infrared bands were commonly used to detect the aboveground biomass of SAV[8-10]. According to these, it could be assumed that the visible and near-infrared bands of TM image could have the abilities of estimating the aboveground biomass of SAV in *Vallisneria*.

Based on the analyses of band 1 (blue), band 2 (green), band 3 (red), band 4 (near-infrared) and digital elevation model (DEM), although very strong correlations between band 1 and band 2, band 2 and band 3, as well as band 4 and water depth were found, the four bands still were used to estimate the aboveground biomass in order to find the optimal resolutions. The following regression models were used:

(1) Univariate linear and non-linear regression models between biomass and original bands
The following 10 univariate linear and non-linear regression models were involved:

$$Linear: Y = b_0 + b_1 * X$$

$$Logarithmic: Y = b_0 + b_1 * ln(X)$$

$$Inverse: Y = b_0 + b_1 / X$$

$$Quadratic: Y = b_0 + b_1 * X + b_2 * X^2$$

$$Cubic: Y = b_0 + b_1 * X + b_2 * X^2 + b_3 * X^3$$

$$Power: Y = b_0 * X^{b_1}$$

$$or\ ln(Y) = ln(b_0) + b_1 * ln(X)$$

$$Compound: Y = b_0 * b_1^X$$

$$or\ ln(Y) = ln(b_0) + ln(b_1) * X$$

$$S\text{-}curve: Y = e^{(b_0 + \frac{b_1}{X})}$$

$$or\ ln(Y) = b_0 + \frac{b_1}{X}$$

$$Growth: Y = e^{(b_0 + b_1 * X)}$$

$$or\ ln(Y) = b_0 + b_1 * X$$

$$Exponential: Y = b_0 * e^{b_1 * X}$$

$$or\ ln(Y) = ln(b_0) + b_1 * X$$

Where, Y is the aboveground biomass of SAV, X is band value or its derived varible, $b_0, b_1, \dots b_n$ are constants.

(2) Univariate linear and non-linear regression models between biomass and water depth-independent variables

The water body has strong absorption and scatter to the light, and magnitude of absorption and scatter is water depth-dependent. Removing the effect of water depth on band values could possibly improve the accuracy of results. The method cited by Armstrong[9] was employed to achieve this goal:

$$X_i = ln(Band_i)$$

$$A_{ij} = \frac{Var_i - Var_j}{2 * Covar_{ij}}$$

$$K_{ij} = A_{ij} + sqrt(A_{ij} * A_{ij} + 1)$$

$$Y_{ij} = X_i - K_{ij} * X_j$$

Where, $Band_i$ is original band value, X_i is the logarithm transformation of $Band_i$, Var_i is the variance of X_i, $Covar_{ij}$ is the covariance of X_i and X_i, Y_{ij} is the water depth-independent variables.

The univariate linear and non-linear regression models mentioned in (1) between biomass and derived water depth-independent variables were developed.

(3) Univariate linear and non-linear regression models between biomass and combinations of original bands, their logarithm transformations or water depth-independent variables

Based on the implementations of the following combinations of original bands, their logarithm transformations and water depth-independent variables, the regression models same as (1) were built.

$$Y = \frac{X_i}{X_j}$$

$$Y = \frac{X_i - X_j}{X_i + X_j}$$

$$Y = \frac{X_i / X_j}{X_i + X_j}$$

Where, X_i、X_j are original bands, their logarithm transformations, or their water depth-independent variables, Y is the derived value of combination of X_i and X_j.

(4) Multi-variable linear regression models between biomass, original bands, the logarithm transformations or the water depth-independent variables were implemented.

$$Y = b_0 + b_1 * X_1 + b_2 * X_2 + \ldots + b_n * X_n$$

Where, Y is the aboveground biomass of SAV, $X_1, X_2, \ldots X_n$ are original bands, their logarithm transformations, or their water depth-independent variables, $b_0, b_1, \ldots b_n$ are constants.

6. RESULTS

Table 1 shows the linear and non-linear correlations with R^2 between biomass, band 1-4 and their depth-independent variables.

Model	B1	B2	B3	B4	DIB12	DIB13	DIB14	DIB23	DIB24	DIB34
Linear	0.104	0.145	0.116	0	0.010	0	0.020	0.003	0.061	0.104
Logarithmic	0.107	0.135	0.126	0	0.010	0	-	0.003	0.048	0.104
Inverse	0.110	0.141	0.136	0	0.010	0	0.030	0.003	0.033	0.104
Quadratic	0.139	0.138	0.132	0.011	0.010	0	0.020	0.003	0.104	0.104
Cubic	0.139	0.138	0.132	0.012	0.010	0	0.020	0.003	0.101	0.104
Power	0.066	0.089	0.093	0.014	0.012	0.005	-	0	0.010	0.058
Compound	0.064	0.084	0.085	0.017	0.012	0.005	0.007	0	0.018	0.058
S-curve	0.068	0.093	0.085	0.012	0.012	0.005	0.005	0	0.018	0.058
Growth	0.064	0.084	0.085	0.017	0.012	0.005	0.007	0	0.018	0.058
Exponential	0.064	0.084	0.085	0.017	0.012	0.005	0.007	0	0.018	0.058

Table 1 correlations with R^2 between biomass, band 1-4 and their depth-independent variables

Where: B1, B2, B3 and B4 represent the green, blue, red and near-infrared band of Landsat TM image, and DIB12, DIB13, DIB14, DIB23, DIB24 and DIB34 represent the depth-independent variables of original bands of Landsat TM image.

Table 2 shows the linear and non-linear correlations with R^2 between biomass, $\frac{X_i}{X_j}$ and $\frac{X_i - X_j}{X_i + X_j}$ combinations of original bands. Since the diversity of combinations, other above-mentioned combinations are not listed in here.

Model	$\frac{B_1}{B_2}$	$\frac{B_1}{B_3}$	$\frac{B_1}{B4}$	$\frac{B_2}{B3}$	$\frac{B_2}{B4}$	$\frac{B_3}{B4}$	$\frac{B_1-B_2}{B_1+B_2}$	$\frac{B_1-B_3}{B_1+B_3}$	$\frac{B_1-B_4}{B_1+B_4}$	$\frac{B_2-B_3}{B_2+B_3}$	$\frac{B_2-B_4}{B_2+B_4}$	$\frac{B_3-B_4}{B_3+B_4}$
Linear	0.144	0.124	0.022	0.034	0.065	0.075	0.140	0.117	0.015	0.035	0.050	0.062
Logarithmic	0.141	0.119	0.017	0.035	0.053	0.066	0.136	0.107	0.012	-	0.015	0.042
Inverse	0.138	0.113	0.013	0.034	0.040	0.054	0.132	0.096	0.009	0.020	0	0.021
Quadratic	0.142	0.137	0.044	0.035	0.093	0.089	0.142	0.141	0.053	0.035	0.107	0.100
Cubic	0.142	0.136	0.042	0.035	0.090	0.087	0.142	0.139	0.053	0.105	0.106	0.100
Power	0.098	0.095	0	0.044	0.012	0.023	0.095	0.085	0	0.029	0	0.007
Compound	0.098	0.100	0.001	0.044	0.020	0.030	0.097	0.094	0	0.044	0.012	0.020
S-curve	0.098	0.100	0.001	0.044	0.020	0.014	0.097	0.094	0	0.044	0.012	0.020
Growth	0.098	0.100	0.001	0.044	0.020	0.030	0.097	0.094	0	0.044	0.012	0.020
Exponential	0.098	0.100	0.001	0.044	0.020	0.030	0.097	0.094	0	0.044	0.012	0.020

Table 2 correlations with R^2 between biomass, $\frac{X_i}{X_j}$ and $\frac{X_i - X_j}{X_i + X_j}$ combinations of original bands

Where: B1, B2, B3 and B4 represent the green, blue, red and near-infrared band of Landsat TM.

Table 3 shows the Multi-variable linear correlations with R^2 between biomass, band 1-4, and their logarithm transformations and water depth-independent variables of Landsat TM image.

Model	B1-4	logarithm transformations of B1-4	water depth-independent variables of B1-4
Multi-variable linear	0.103	0.109	0.109

Table 3 linear correlations with R^2 between biomass, band 1-4, and their logarithm transformations and water depth-independent variables

Using the above-mentioned methods, the best regression model is the linear regression model between the aboveground biomass and the band 2 (green band) of Landsat TM with $R^2 = 0.145$ at significance level 0.003.

7. CONCLUSIONS AND SUGGESTIONS

On the basis of the results, we achieve such conclusion: although the correlations between the aboveground biomass and the bands of Landsat TM and their derived variables were found, none of these correlations are strong enough to be used to estimate the aboveground biomass of *Vallisneria*. Apparently it is impossible to estimate the aboveground biomass of *Vallisneria* using Landsat TM image and the above-mentioned methods in this particular region. The possible causes inducing the results are analyzed as following:

(1) the suspended materials in the water body might influence the result. There are various abiotic and biotic suspended materials in the water body, which selectively absorb or reflect visible or near-infrared lights, and reduce the light reflected from SAV. Meanwhile, many researchers found that there were strong correlations between suspended materials and the visible or near-infrared bands of Landsat TM[14-17], which might limit the estimation of aboveground biomass of SAV.

(2) the field samples are less accurate. The sampling were made on sampling areas with about 50m interval along several transects, and each sample area consisted of 4 sample points. The biomass in each sample point was taken randomly by using a clamp with the size of 23 * 17cm, and the average value in 4 sample points was taken as the fresh biomass of one sample area, and was expressed as fresh weight per square meter (g/ m^2). The result from this kind of sampling method could not accurately represent the real spatial distributionof biomass.

(3) the spectral and spatial resolution of Landsat TM image might not be enough to achieve good results. There are 7 bands for Landsat TM image, in which only 4 bands (visible and near-infrared bands) can be used to estimate aboveground biomass of SAV for the strong absorption of other bands by the water column. But from the analyses of these 4 bands, the remarkable correlations between band 1 and band 2, band 2 and band 3 as well as band 4 and water depth, were found. The spatial resolution of band 1-4 of Landsat TM is 25*25m, which is not accordant with the sampling unit with 1*1m and might affect the results.

(4) in this paper, we only tested several commonly used methods for calculating biomass of SAV. These methods might not be fit for achieving the objective of this research.

(5) we can not deny the homogenously spatial distribution of the aboveground biomass of *Vallisneria*. However, how to check the homogeneity is a challenge also.

Due to the reality of the results, we present the following suggestions for future research:

(1) the alternative data sources (hyperspectral or high spatial resolution images) combined with innovative methods and more accurate sampling data should be employed to estimate the aboveground biomass of *Vallisneria*.

(2) the productivity simulation model of submerged aquatic vegetation[2,18-20] integrated with geographic information system (GIS) and remote sensing presents possible potential in predicting the aboveground biomass of *Vallisneria*.

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