Estimating the biomass of *Carex cinerascens* (Cyperaceae) in floodplain wetlands in Poyang Lake, China

Ya Li\(^{a,b}\), Xiubo Yu\(^{a,b}\), Qun Guo\(^a\), Yu Liu\(^a\), Shaoxia Xia\(^a\), Guangshuai Zhang\(^{a,b}\), Quanjun Zhang\(^{a,b}\), Houlang Duan\(^{a,b}\) and Liang Zhao\(^a\)

\(^{a}\)Key Laboratory of Ecosystem Network Observation and Modeling, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing, China; \(^{b}\)College of Resources and Environment, University of Chinese Academy of Sciences, Beijing, China

**ABSTRACT**

The estimation of wetland plant biomass is key to understanding the dynamic changes of the structure and functions of wetland ecosystems. Relatively few studies on the spatiotemporal dynamics of wetland plant biomass have been conducted because of the difficulties in obtaining detailed and accurate data. *Carex cinerascens* meadows are important patches in Poyang Lake in eastern China and provide significant food resources and habitats for wintering waterbirds, particularly geese. We proposed a method to estimate the biomass of *C. cinerascens* in a subsection of Poyang Lake, i.e. Baisha Lake, employing the digital elevation model and water level gradient of the lake combined with the logistic regression model based on data from field measurements in different elevations. We obtained four *C. cinerascens* biomass estimation models based on four elevations divided. The maximum biomass decreased with decreasing elevation. Meanwhile, the maximum growth rate initially increased and subsequently decreased. The biomass of *C. cinerascens* per unit area ranged from 0.10 to 0.58 kg/m\(^2\) in the autumn and winter. Significant differences in the growth process of *C. cinerascens* were observed in different water level gradients. The total biomass of *C. cinerascens* in Baisha Lake changed following an S-shaped curve and reached 221, 503, and 615 t in the middle of October, November, and December, respectively. The research results can be used to forecast the biomass of *C. cinerascens* under different hydrological conditions in Poyang Lake, and to provide wetland plant biomass estimation methods for other similar regions.

**INTRODUCTION**

Plant biomass is a key driver of ecosystem dynamics, thus influencing ecosystem structures and functions. As an important component of terrestrial ecosystems, biomass...
of wetland plant is an indispensable part of the global carbon cycle (Li and Liu 2002; Vis et al. 2003; Liao et al. 2013; Shen et al. 2015; Du et al. 2017; Guo et al. 2017). Regional plant biomass changes were associated with the important outcomes in wetland ecosystem functional characteristics such as primitive productivity and carbon balance. Therefore quantifying biomass of wetland plant could benefit to evaluate the ecological status of wetlands (Lu 2006; Sang et al. 2014). Moreover, the knowledge of the spatial and temporal dynamics of wetland plant biomass is essential for not only informing the management of natural resources such as the growth and distribution of plant especially in conservation areas and focal areas, which contribute to the environment capacity of wetland ecosystem, especially to the animals (Lumbierres et al. 2017), but also providing basic information for the planning and utilization of wetlands (Lauck and Benscoter 2015; Guo et al. 2017). Hence, evaluating the biomass of wetland plants accurately is necessary.

In seasonally flooded wetlands, plant growth and distribution are closely related to temperature, soil moisture, and soil nutrients etc. (Miguez et al. 2008; Xu et al. 2015). Wetland vegetation exhibits zonal distribution from the lake center to the shorelines mainly because of uniquely zonal environmental factors, e.g. soil moisture and temperature when the growth begins (You et al. 2015; Tan et al. 2016), leading to different spatial and temporal distribution characteristics of wetland plants (Liao et al. 2013; Zhang, Ni, et al. 2013; Zhang, Yu, et al. 2013). These environmental factors are in turn reflected by some easily obtained data, i.e. water levels and elevations (Dwire et al. 2006; Deng et al. 2013). Nevertheless, varied patterns of growth dynamics and the difficult accessibility in wetland make it difficult to estimate the plant biomass in lake areas (Silva et al. 2010; Zhang, Ni, et al. 2013; Zhang, Yu, et al. 2013). Therefore, we need a more general model to estimate the spatiotemporal dynamics of biomass of wetlands based on limited field data.

As an important part of the Yangtze River floodplain, Poyang Lake wetland is a focus region in the protection of waterbirds, e.g. the *C. cinerascens* (Cyperaceae) meadows can provide habitats and food resources for winter geese (Zhao et al. 2012; Guan et al. 2014). During the flood recession period (from October to April of the following year) in Poyang Lake, vegetation grows rapidly and the total biomass is high. Meanwhile, in the flooded period (from May to September), most vegetation is submerged and the total biomass decreases (Liao et al. 2013). The overlap between the growth of *C. cinerascens* and the arrival of wintering waterbirds makes *C. cinerascens* an important food source for many herbivorous wintering waterbird species, particularly geese (Cao et al. 2008). Moreover, the implementation of the Poyang Lake water conservancy hub project, which is planned to establish and/or change the timing of water level recessions, is an important factor that can influence the biomass of *C. cinerascens* in wetlands (Guan et al. 2014; Jing et al. 2017). Therefore, estimating the biomass of *C. cinerascens* in Poyang Lake wetland during the flood recession period is important to elucidate the functions of wetland in providing habitats for waterbirds (Liao et al. 2013), and to evaluate the effects from the Poyang Lake water conservancy hub project.

In this study, we proposed a method to estimate the biomass of *C. cinerascens* in seasonal wetlands in Poyang Lake by combining the logistic model of the plant growth process in different water level gradients, based on field survey data and, the digital elevation model (DEM) of the lake. This study aimed to: (1) estimate the total biomass of *C. cinerascens* in Baisha Lake, a part of Poyang Lake; and (2) provide a more general methods to estimate biomass of wetland plant according to elevation and water level gradients, and discuss its possible applications in predicting biomass of other wetland regions.
Materials and methods

Study area

Poyang Lake is the largest freshwater lake in China. It is one of only two large remaining lakes with free connections to the Yangtze River, and is situated in the middle-to-lower reaches of the Yangtze River. It is located in northern Jiangxi Province between 115°49′–116°46′E and 28°24′–29°46′N with an area of 5156 km². It has a humid subtropical monsoon climate with annual average temperature of 16–20 °C, annual average precipitation of 1387–1795 mm, and average annual evaporation of 800–1200 mm. The water level in Poyang Lake changes seasonally because of catchment inflows from five tributaries (i.e. Ganjiang, Fuhe, Xinjiang, Raohe, and Xiushui) and the hydraulic interaction with the Yangtze River. In the flood season (from May to September), the annual average maximum water level, which substantially happened in August, could reach 17.14 m, and the surface water coverage can reach 4000 km² and are the main type of wetlands in Poyang Lake. When the flooding recedes (from October to April of the following year), the average annual minimum water level, which substantially happened in February, could reach 5.15 m, and the surface water coverage is less than 1000 km² and mudflats, sediment beds, and wet meadows are the primary types of wetlands in Poyang Lake (Dronova et al. 2011; Xia et al. 2017).

Our research was conducted in a sub-lake of Poyang Lake, i.e. Baisha Lake (28°54″21N, 116°19″13E), which is located in the Poyang Lake Nanji Wetland National Nature Reserve (Figure 1). We selected a region where the elevation was 12–13 m at the shoreline of the sub-lake as our experimental site. The area had a gentle slope, which formed large areas of C. cinerascens meadows and was an ideal venue for the experiment.

C. cinerascens is a perennial herbaceous plant with rhizomes, which is widely distributed in eastern mainland China and is the dominant species with the highest coverage and biomass in Poyang Lake (Du et al. 2017). Depending on the hydrological characteristics of Poyang Lake, C. cinerascens usually has two growing seasons in a year. In autumn (September or October) after the flood recession when the soil is exposed, the C. cinerascens shoots begin to grow and continue until winter (January of the following year) when the aboveground plant parts become withered because of the cold temperatures, this is called the “autumn grass” (Deng et al. 2015). C. cinerascens is the dominant community in Baisha Lake and is widely distributed in the experimental area. The grass coverage is more than 98%, and its companion species mainly include small Polygonum criopolitanum, Potentilla leuconota, and Cardamine which hardly influence the area of bare land.

Experimental design

The experiment was conducted from October 2016 to January 2017 in Poyang Lake during the flood recession period. We selected typical C. cinerascens wet meadows to establish the experimental field site. The wet meadows were slightly disturbed by humans where the water level elevation difference was obvious and where several waterbirds, particularly geese, always overwintered and foraged. The vegetation presents a zonal distribution in the lakeshore of Baisha Lake because of the different water levels and elevations. When the water level decreased, the high elevation soil was exposed and the plant began to grow. As the water gradually receded, the low elevation soil was exposed and the plants began to grow (Guan et al. 2014; You et al. 2015). The timing of water level recession led to the zonal vegetation distribution in Poyang Lake.
The water level can decide the timing of soil exposure, the growth time of the wetland plants, and the climatic factors such as temperature and precipitation, which can have an effect on the growth of plants. Different water levels can also decide the soil environment, such as soil temperature, soil nutrient content, and soil microbial community, which can affect the growth of plants. The elevation data can be obtained simply and relatively easily and can reflect the different water level conditions. The growth and distribution of *C. cinerascens* in Poyang Lake were mainly affected by the water levels and elevations. Thus, we divided the study area into gradient zones based on the different elevations to decrease sampling effort, to ensure the accuracy of the research, and to estimate the biomass from a model in different elevation gradients.

The elevation data of the sample points were calculated depending on the latitude and longitude coordinates and the DEM of Baisha Lake in the software ArcGIS (Table 1). The precision of the DEM is 5 m. According to the elevation of the study area and in reducing the spatial autocorrelation between sampling sites, we set four sampling lines parallel to the water level gradient from the lakeshore to the lake center, which are high elevation (H), medium-high elevation (HM), medium-low elevation (ML), and low elevation (L), of which the distance between two sampling lines was greater than 100 m. The sampling area covered all of the plant distributions in our study region.

Along each of the sampling lines, three to six sample points were located randomly according to small terrain differences. We embedded small caliber (diameter of 2 cm) polyvinyl chloride (PVC) tubes (buried to ~70 cm depth) to measure the underground...
water level at each sample point. Then, a PVC pipe with a height of 1 m and a diameter of 0.4 m was fixed at every sample point (buried to 0.6 m in the soil). We set up a 5 m × 5 m sample plot where the C. cinerascens with consistent vigorous grow near the PVC pipe at each sampling site. Then we erected a range pole as the sample tag so that we could sample the plants at the sample plot every time.

Data acquisition

Plant biomass includes the aboveground and belowground living mass, however, most biomass estimations focused on aboveground biomass because of the difficulties in collecting field data on belowground biomass in wetlands (Lu 2006). In this study, biomass refers to aboveground biomass. During the experimental period, we recorded the mean plant height and the aboveground biomass at 10–day intervals. However, based on the weather, the sampling day could be 1 or 2 days before or after the 10–day interval. At each sample plot the plant growth is similar and 5 individual plants were selected randomly to measure the plant height. The plant height was measured by rulers and determined by the average of sampled five plant heights. The soil temperature was determined using a soil hygrothermograph (Aquaterr T-350, Aquaterr, Costa Mesa, CA, USA). The aboveground biomass was measured using the harvest method. We made a 25 cm × 25 cm plot using small caliber (diameter of 2 cm) PVC tubes to sample the plants. We harvested all of the plants within the plots on the ground. The harvested plants were placed in envelopes and carried to the laboratory. Then, we dried the plants in an oven at 60°C for 72 hours before weighing them. The dry weight of the plants was measured by an electronic balance within 3 minutes of being removed from the oven to prevent the plants from getting damp again. The dry weight obtained by a weighing scale. The biomass of C. cinerascens per unit area was obtained by unit conversion depending on the biomass weighed.

Establishment of the growth curve

Logistic models have been widely used to simulate the growth of plant biomass and plant height over time (Miguez et al. 2008; Archontoulis and Miguez 2015; Jeke et al. 2015). Research has indicated that the logistic model is one of the best techniques to simulate the aboveground and belowground biomass of the wetland plant cattail (Typha latifolia L.) (Jeke et al. 2015). In this study we established four models from different elevation gradients. We used seven data collected from October to December 2016 to establish the model. We set up three repeats in H gradient, five repeats in HM gradient, six repeats in ML gradient and five repeats in L gradient (Figure 1). We performed the statistical calculations using Excel 2010 and SPSS 18.0. We established the logistic regression models between biomass production and time in the software Matlab (R2013a) and completed the figures in Matlab and Origin. The relationships between plant aboveground

| Gradient zone | Elevation (m) | Water table depth (cm) | Plant height (cm) | Soil temperature (°C) | Soil pH | SOC | Area (m²) |
|---------------|--------------|------------------------|------------------|-----------------------|--------|-----|----------|
| H             | 13.31–13.50  | −60 ± 10               | 40.25 ± 7.70     | 25.33 ± 0.58          | 4.59 ± 0.08 | 0.88 ± 0.12 | 2.99 × 10² |
| HM            | 13.11–13.30  | −40 ± 10               | 29.55 ± 2.36     | 25.80 ± 1.30          | 4.67 ± 0.05 | 0.80 ± 0.09 | 4.19 × 10² |
| ML            | 12.91–13.10  | −20 ± 10               | 27.48 ± 3.70     | 24.67 ± 0.82          | 4.83 ± 0.06 | 0.86 ± 0.18 | 2.60 × 10² |
| L             | 12.71–12.90  | 0 ± 10                 | 12.88 ± 9.02     | 24.33 ± 0.52          | 4.99 ± 0.09 | 0.45 ± 0.06 | 3.81 × 10² |
biomass and growth time using the classic logistic equation model is as follows:

\[ \frac{dy}{dt} = ry \left(1 - \frac{y}{k}\right) \]  

(1)

The general solution is derived as follows:

\[ y = \frac{K}{1 + e^{a-rt}} \]

(2)

where \( y \) is the dry biomass per unit area in grams; \( K \) is the upper limit biomass under certain conditions and represents the growth potential of biomass under certain conditions; \( a \) is a parameter; \( t \) is the time in days, and \( r \) is the plant intrinsic growth rate of the biomass, which represents the maximum instantaneous growth rate the plant can achieve under certain conditions (Birch 1999). This comprehensive index of plant growth capability is commonly used to reflect specific biological indicators of environmental quality.

**Model calibration and verification**

In our study three observed biomass data obtained in January 2017 were used to evaluate the accuracy assessment of the predicted biomass. And the biomass data of \( C. \) cinerascens were obtained along the four sampling lines consistent with the elevation gradients in the experiment. Model accuracy is mainly decided by the coefficient of determination \( (R^2) \), the root mean square error \( (RMSE) \) assessed, and the variance test \( F \) value. In general, a high \( R^2 \) or a low \( RMSE \) value often indicates a good fit between the model developed and the sample plot data. \( RMSE \) is expressed as follows:

\[ RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (y_i - O_i)^2} \]

(3)

where \( y_i \) is the model-predicted biomass value of the \( i \)th gradient zone, \( O_i \) is the observed biomass value of the \( i \)th gradient zone, and \( n \) is the number of gradient zones.

The predicted biomass was obtained based on the logistic model we established previously and we obtained the predicted biomass on the same day as the observed biomass to make a comparison. The scatter plots involved comparing the predicted biomass of \( C. \) cinerascens with the observed biomass to evaluate the performance of biomass estimation. The absolute accuracy of the modeling scheme was assessed using the relative error. Relative error \( (RE) \), which is expressed as follows:

\[ RE = \frac{y_i - O_i}{O_i} \times 100\% \]

(5)

where \( y_i \) is the model-predicted biomass value of the \( i \)th gradient zone, and \( O_i \) is the observed biomass value of the \( i \)th gradient zone.

**Estimation of the biomass of the entire lake**

Based on the four gradient zones according to the ground elevation and underground water level in the study region, we divided the entire Baisha Lake into four gradient zones and the elevation of each gradient zone was consistent with the study region. We established four biomass estimation models in different elevation gradients based on the preceding data and calculation. Then the classification of the area into different elevations was calculated in the software ArcGIS.
Our experiment was set at the lakeside where the water level was obviously different and represented all of the elevations in which *C. cinerascens* was distributed. From the results of the experiment, we can estimate the total biomass of *C. cinerascens* based on the hypothesis that the growth process at a similar elevation is consistent with the soil exposure when the flooding recedes. The biomass of *C. cinerascens* in the entire lake was calculated by the biomass per unit area estimated with the logistic model and the area of each gradient zone. The plant biomass of the entire lake can be calculated as follows:

\[
Y = \sum_{i=1}^{4} y_i \times S_i
\]

where *Y* is the total plant biomass of the entire lake, *y*_i is the model-predicted biomass value of the *i*th gradient zone, 4 is the number of gradients, and *S*_i is the area of the *i*th sampling site. By using the formula, we can calculate the biomass of plants at any time during the growth period.

**Biomass mapping**

From the logistic model we specified the biomass of *C. cinerascens* in different elevation gradients at growing season. And the distribution of biomass of *C. cinerascens* per unit at different time could be obtained using the model under different elevation gradients. According to the range of predicted biomass values, the values were divided into five levels. Biomass values of 0–0.1 kg/m² were categorized as level I, values of 0.1–0.2 kg/m² were categorized as level II, values of 0.2–0.3 kg/m² were categorized as level III, values of 0.3–0.4 kg/m² were categorized as level IV, and values higher than 0.4 kg/m² were categorized as level V. Then, the biomass distribution maps were completed in the software ArcGIS, and the area percentages for the different levels were calculated.

**Results**

**Establishment of the Poyang Lake *C. Cinerascens* growth curve**

Four logistic growth models for *C. cinerascens* in different elevation gradients were established based on the plant biomass and its growth time (Figure 2). The results showed that the growth of *C. cinerascens* in the four gradients all fitted the logistic growth model \(R^2 > 0.8, p < 0.001; \) Table 2). Therefore the fitted logistic growth model can represent the biomass change of different gradients in autumn.

From the high elevation gradient to the low elevation gradient, the initial growth time of *C. cinerascens* were 18 September, 28 September, 8 October, and 18 October 2016 in the H, HM, ML, and L gradients, respectively. The biomass changes of *C. cinerascens* in the growth season all fitted an S-shaped curve (Figure 2). Initially, the biomass was relatively small and increased gradually over time. Subsequently, rapid growth occurred. Finally, the biomass reached its peak and stabilized when the temperature decreased. The upper limit of biomass of the four gradients decreased, followed by elevation reduction, showing that the largest biomass of *C. cinerascens* decreased as the growth time was delayed. This result indicated that the growth time, growth process, and biomass accumulation of *C. cinerascens* could be significantly affected by the flood recession time in Poyang Lake.

The plant growth rate and growth characteristics varied among different elevation gradients. From the growth model of *C. cinerascens*, we obtain the plant growth rate curve
in the four gradient zones according to the plant logistic growth curve (Figure 3). *C. cinerascens* has different growth characteristics with its different growth times. The comparative maximum growth rates in the four gradients initially increased and subsequently decreased with the elevation reduction (Table 3). The result also shows that the high elevation gradient took the longest time to reach the maximum growth rate, whereas the medium-low elevation gradient took the shortest time to reach the maximum growth rate (Table 3), which indicated that the shallow water table depth was more suitable for the growth of *C. cinerascens*.

**Accuracy assessment**

The observed biomass data collected in January 2017 were used to examine the accuracy of the logistic predicted biomass. The scatter plots between observed and predicted
biomass in January showed that most of the validated biomass values were near the 1:1 line (Figure 4). Although some predicted biomass values were larger than the observed data, whereas others were smaller than the observed data. \( RE \) was also calculated for the estimated and observed data to validate the biomass estimation. The results show that most of the \( RE \)s were near the zero value of the vertical coordinate axis. The percentage of the field sampling site with \( RE \) between \(-30\%\) and \(30\%\) was 100\%, whereas the percentage of the field sampling site with \( RE \) ranging from \(-20\%\) to \(20\%\) accounted for 75\% (Figure 5). This finding indicated that the proposed logistic model obtained a relatively satisfactory accuracy of biomass estimation.

**Total biomass estimation of C. Cinerascensin Baisha Lake**

We estimated the total biomass of \textit{C. cinerascens} in Baisha Lake based on the different growth curves and the area at different elevations (Figure 6). The total biomass of the
lake changed following an S-shaped curve in the autumn and winter whose growth rate initially increased and subsequently decreased, which coincided with the growth process of *C. cinerascens*. The total biomass of *C. cinerascens* in Baisha Lake reached 221, 503,

Figure 4. Observed versus predicted biomass.

Figure 5. Relative error of the biomass estimation.

Figure 6. Total biomass of *C. cinerascens* in Baisha Lake in 2016.
and 615 t in the middle of October, November, and December respectively. We also calculated the biomass distribution of *C. cinerascens* at any time during the growth period in Baisha Lake. The biomass distribution was obviously different at different times (Figure 7). In October, the percentage of the biomass per unit area, ranging from 0.1 to 0.2 kg/m² (level II accounted for 41.13% of the total study area). Meanwhile in December, the percentage of the biomass per unit area >0.4 kg/m² which is level V accounted for 71.96% of the total study area.

**Discussion**

**Reliability of the results of the study**

In this study, we proposed the application of a local scale biomass estimation method. Although many applications using logistic models have been employed to simulate the plant growth process (Jeke et al. 2015), only a few studies have combined it with the water level gradient to estimate the wetland biomass of lakes. The results of this study indicated that this method is an accurate approach to estimate biomass and can provide a time series of accurate biomass maps of wetland plants for the ecological management of lakes.

The results of this study showed that the *C. cinerascens* biomass per unit area ranged from 0.10 to 0.58 kg/m² during the winter in Poyang Lake, which was consistent with the results of other studies of Poyang Lake that showed that the biomass per unit area ranged from 0.14 to 0.83 kg/m² (Wu et al. 2012; Wu et al. 2015; Xu et al. 2015). Study used synthetic aperture radar to retrieve *Carex* biomass in Poyang Lake reported that the retrieved biomass were from 0.3 to 0.5 kg/m² (Shen et al. 2015). Our validated results showed that the RE between the observed biomass and the predicted biomass are all between −30% and 30%, while in other studies accounted for 62.5% (Gao et al. 2017). This finding indicated that describing the growth process and biomass change of *C. cinerascens* in Poyang Lake using a logistic model was feasible.

From the results, we determined that, although the difference of the mean growth rate among the four gradient zones is not so obvious, the difference of the maximum growth rate is substantial. At the medium-low elevation, the maximum growth rate of *C. cinerascens* was the largest, whereas at the high elevation, the maximum growth rate of *C. cinerascens* was the smallest, indicating that the growth of *C. cinerascens* would be restricted when the water table level was deep. This result was consistent with those of other studies (Feng et al. 2016). The high elevation generally has a deep water table level, which means that the first exposure area usually have the higher air temperature that can
affect the growth of *C. cinerascens* (Miguez et al. 2008; Jing et al. 2017). *C. cinerascens* preferred a relatively shallow groundwater table (Xu et al. 2015). A deep water table level can lead to a low soil moisture content around *C. cinerascens* roots, which does not satisfy the normal physiological activity that the plant requires to grow, thus affecting the growth of the plant significantly (Feng et al. 2016).

Differences in the time to reach the maximum growth rate among the four gradient zones exist. From the high elevation gradient to the low elevation gradient, the time at which *C. cinerascens* reaches the maximum growth rate is short following the delayed flood recession time. This finding is contradictory to the result in East Dongting Lake where the research has shown that *C. cinerascens* takes a significantly longer time to reach the maximum growth rate because of prolonged inundation (Guan et al. 2014). This finding can be attributed to the different times of water recession and the different environmental conditions. The different growth characteristics of *C. cinerascens* at different water table levels indicated that dividing the water level into a gradient to establish the growth model and estimate the biomass of *C. cinerascens* in Poyang Lake was reasonable.

The seasonal changes of water level in Poyang Lake had a significant effect on the wetland plant biomass, and this research provided a simple method for predicting the plant biomass of *C. cinerascens* by analyzing the growth pattern of plant biomass in different growth time. Wetland plant biomass is an important indicator of the carbon sequestration of wetlands (Wu et al. 2012) and controls the carbon that could potentially be released to the atmosphere. Thus, wetland plant biomass is a key index to the health of the wetland ecosystem and provides quantitative information for understanding its ecological and environmental functions (Li and Liu 2002; Guo et al. 2017). The biomass of wetland plant in some areas such as the feeding area for waterbirds and animals could be used to estimate the environmental capacity of the wetland to the herbivores. Also the results of the entire biomass of *C. cinerascens* in this study can provide basic information to evaluate the wetland carbon balance in Poyang Lake.

**Implications for waterfowl habitat management and biomass estimation in similar lake area**

*C. cinerascens* meadows provide important habitats for avian herbivores, particularly geese in the middle and lower reaches of the Yangtze drainage basin (Zhang and Lu 1999; Cong et al. 2012; Wang et al. 2012). The biomass of *C. cinerascens* has an essential effect on the carrying capacity of the lake for geese (Cong et al. 2012; Zhang et al. 2015). The growth process, biomass, and palatability of the food resource of *C. cinerascens* can be affected by the change of water levels and the time of flood recession, which in turn has an effect on the distribution of herbivorous birds (Wang et al. 2012). After the impoundment of the Three Gorges Dam (TGD), the dry season in Poyang Lake came early (Guo et al. 2012; Feng et al. 2013; Lai et al. 2014) and caused the expansion of *C. cinerascens* to the *Phalaris* zone in Dongting Lake (Wu et al. 2017), which in turn affected the distribution of the birds. Moreover, when the water receded earlier, the plant could start growing at an earlier time and the meadow would be covered with tall and low quality plants for geese to utilize when they arrive in the autumn (Zhao et al. 2012; Zhang et al. 2016). Through the growth model established in our study at different growth times combined with the functional traits that the geese feed, managers could provide suitable habitats for the waterbirds by controlling the growth and distribution of *C. cinerascens* meadows, to evaluate the carrying capacity of the lake on the geese. Given that the growth process of *C. cinerascens* was primarily affected by the timing of water recession (Jing et al. 2017),
we can manage the biomass of *C. cinerascens* by controlling the water level and the timing of water recession.

Our study showed that the proposed method, i.e. data collection along sampling lines, modeling the plant growth process and statistical analysis, has advantages in estimating the biomass of a dominant species in a small lake. As the growing status of *C. cinerascens* is mainly controlled by flooding recession time and relevant weather conditions in Poyang Lake (Guan et al. 2014; Sang et al. 2014), we can implement this estimation of biomass of *C. cinerascens* in some other places in Poyang Lake to forecast its temporal and spatial distribution easily basing on the growth time and the relevant logistic model established. The estimated biomass can also be used to verify other estimating methods, such as the remote sensing to improve the precision of the biomass estimation of wetland plants. However the applicability of the method proposed in this study may not be used for some special conditions, for instance, the hydrological conditions changed because the TGD regulates water storage (Guo et al. 2012; Zhang et al. 2012; Lai et al. 2014). The water level of Poyang Lake may increase in October and the growing *C. cinerascens* would stop growing when it becomes submerged in the increased water level (Wang et al. 2017), hence, the logistic model cannot described the growth process accurately.

The method can be used to identify the location where the plants present a zonal distribution to estimate the entire biomass. In this study, the proposed method was used for biomass estimation tests only in a sub-lake of Poyang Lake. Further research should be conducted to test the proposed modeling scheme in other lakes, particularly in regions where large congregations of overwintering waterbirds gather. In addition, only *C. cinerascens* was tested in this study. Further research can also be conducted based on other plant species, particularly vegetation that can provide food resource for birds and are essential for the protection and management of waterbirds.

**Conclusions**

Our study showed that by using logistic models and DEM of the lake, providing accurate estimations of tempo-spatial dynamic of plant biomass production in seasonal wetlands was possible. Estimates based on the logistic model provided accurate predictions and were robust to environmental variation and spatial heterogeneity. We can estimate the biomass of *C. cinerascens* in some other place to forecast its spatial distribution easily in Poyang Lake based on the growth time and the relevant logistic model established in this study. The estimation of plant biomass using logistic models can provide a time series of accurate biomass maps of wetland plants and may represent a useful tool for the monitoring and management of ecosystems, particularly in protected areas where natural resources are affected by human use.

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ORCID

Guangshuai Zhang http://orcid.org/0000-0002-7881-6355

Notes on contributors

Ya Li is currently a PhD for research on wetland monitoring and biogeochemistry at Key Laboratory of Ecosystem Network Observation and Modeling, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences.

Xiubo Yu is the research program leader in Poyang Lake wetland ecology, and a researcher of Key Laboratory of Ecosystem Network Observation and Modeling, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences. He is currently a coordinator of Ecosystem Monitoring and Capacity Building at UNEP International Ecosystem Management Partnership.

Qun Guo is currently a research assistant of Key Laboratory of Ecosystem Network Observation and Modeling, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences and specialized in grassland productivity.

Yu Liu is an associate research fellow of Key Laboratory of Ecosystem Network Observation and Modeling, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences and specialized in the trade-off of wetland ecological service.

Shaoxia Xia is currently a research assistant of Key Laboratory of Ecosystem Network Observation and Modeling, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences and specialized in wetland ecology and ecological service.

Guangshuai Zhang is currently a research assistant of National Marine Environmental Monitoring Center, People’s Republic of China, and a PhD of Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences.

Quanjun Zhang is currently a PhD candidate for research on wetland monitoring and biogeochemistry at Key Laboratory of Ecosystem Network Observation and Modeling, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences.

Houlang Duan is currently a PhD candidate for research on wetland monitoring at Key Laboratory of Ecosystem Network Observation and Modeling, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences.

Liang Zhao is currently a Master Degree Candidate in Chengdu University of Technology.

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