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Research Article

Estimating Net Primary Productivity and Nutrient Stock in Plant in Freshwater Marsh, Northeastern China

We have investigated the contributions of three dominant macrophyte species, *Deyeuxia angustifolia*, *Carex lasiocarpa*, and *Carex pseudocuraica* (covering about 10 304 km^2), to carbon (C), nitrogen (N), and phosphorus (P) stocks in the largest freshwater marsh (17 300 km^2) in China for a 3-year period (from 2002 to 2004). The monthly biomass, seasonal, and annual net primary productivity (NPP), and nutrient concentrations of three species were measured. All three plant species showed rapid growth in the rainy season. The maximum and minimum production rates in the freshwater marsh were ~36.19 and ~9.92 $g\,m^{-2}\,day^{-1}$, respectively. The total NPP accounts 1900–2700 $g\,m^{-2}\,year^{-1}$ in the studied area. Total organic carbon (TOC), total nitrogen (TN), and total phosphorus (TP) concentrations in roots were higher than those in stem and leaf tissues. The vast beds of the three studied species comprise 80% of the grass covered marsh of Sanjiang plain, contributing annual nutrient stocks of $\sim 10.99 \times 10^6$, $\sim 788.36 \times 10^3$, and $\sim 18.10 \times 10^3$ t (tonnes) for TOC, TN, and TP, respectively. Our results suggest that the nutrient bioaccumulation capacity in freshwater marshes depend mainly on plant species, which are decided by hydrological conditions. The nutrient stocks in the Sanjiang plain marsh have been greatly reduced because some of the area occupied by *C. lasiocarpa* was replaced by *D. angustifolia* as a result of succession caused by the changes of water table.

Keywords: Biomass; Freshwater marsh; NPP; Nutrient stock

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1 Introduction

Biomass, productivity, and decomposition in ecosystems represent a large portion of the stock and flow of nutrients through ecosystems. An improved understanding of nutrient dynamics in biomass is essential to understand nutrient cycle in ecosystems, biosphere–atmosphere interactions and the response of ecosystem to climate changes and CO_2 fertilization [1–5]. Wetlands are important carbon pools, containing approximately 10% (15 Gt) of the terrestrial carbon store [6]. They exhibit high primary productivity and are one of the most important nutrient reservoirs among the terrestrial ecosystems [7–9].

Biomass and nutrient concentrations of plant parts differ significantly between species, therefore species composition may influence ecosystem processes, such as nutrient cycling and carbon storage in wetlands [10–14]. The species distributions are strongly relegated by hydrologic zones, individual species retain different physiological capabilities that influence their rates of biomass accumulation and tissue quality [15, 16].

Net primary productivity (NPP) and nutrient cycling have been regarded as the most important functions of a wetland [17]. The quantification of biomass production in wetland systems is of primary importance in estimating the impact of biomass on the material and energy balance. In the studied site, three typical plant communities of a freshwater marsh in northeast China were chosen according to hydrological regimes. The objectives of this study are: (a) to explain the changes of biomasses and plant growth rates in above and belowground in different hydrological regimes; (b) to estimate the bioaccumulation storage of total organic carbon (TOC), total nitrogen (TN), and total phosphorous (TP) in plants in a temperate freshwater marsh in China. The results would be great helpful for accurate estimation of stocks of carbon and nitrogen in terrestrial ecosystems. The obtained knowledge of the dependence of NPP on plant species will provide a theoretical base to protect and evaluate temperate freshwater marsh.

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Abbreviations: **ANPP**, aboveground net primary productivity; **BNPP**, belowground net primary productivity; ***Da*^{1}**, *D. angustifolia* in NW marsh; ***Da*^{2}**, *D. angustifolia* in SW marsh; ***Cl***, *C. lasiocarpa*; ***Cp***, *C. pseudocuraic*; **NPP**, net primary productivity; **NW**, non-waterlogged; **TN**, total nitrogen; **TNPP**, total net primary productivity; **TOC**, total organic carbon; **TP**, total phosphorus; **SW**, seasonally waterlogged.

2 Materials and methods

2.1 Site description

The studied region is located in Sanjiang Plain (45°01′N to 48°28′N, 130°13′E to 135°05′E) in Heilongjiang Province, northeastern China, near Russia. It is the largest continuous freshwater marsh in China [18], covering an area of about 17 300 km^2 including water surface area and *Deyeuxia angustifolia* meadow [19]. Marsh initiation started during the late-pleistocene epoch due to convergence of the water from Heilongjiang river, Songhuajiang river, and Wusulijiang river and a blockage of water seepage caused by clay soil in the study area [18]. The marshes in the Sanjiang plain are divided into four major community types according to plant species, i.e., *Carex lasiocarpa*, *Carex pseudocuraica*, *Carex meyeriana*, and *D. angustifolia* [18]. The areas of *D. angustifolia* marsh, *C. lasiocarpa* (*Cl*) marsh, and *C. pseudocuraic* (*Cp*) marsh comprise about 27.7, 45.8, and 6.1% of the total marsh area, respectively, excluding open water area (about 12 900 km^2) [20]. In the past 45 years, most of the *C. meyeriana* marsh has been replaced by *D. angustifolia* marsh, associated with continuous farmland with drainage system expansion, which caused major changes in the hydrological conditions of the wetland.

The studied site is located at the Sanjiang Experimental Station of Marsh Wetland Ecology, Chinese Academy of Sciences, at approximately 47°35′N, 133°31′E. The mean annual precipitation is 500–650 mm, concentrated in July and August, and the mean annual temperature is 1.9°C with a lowest monthly average temperature of −20°C in January and a highest monthly average temperature of 22°C in July. The altitude is 56 m above sea level.

Three dominant emergent macrophytes, namely *D. angustifolia*, *Cl*, and *Cp* were selected for this study (Fig. 1). The *D. angustifolia* marsh is further classified into two types, according to the hydrological regime; seasonally waterlogged (SW) marsh and non-waterlogged (NW) marsh. In the NW *D. angustifolia* marsh there is no standing water and the topsoil (0–5 cm) is relative dry during the plant growing season, except in July and August. Standing water depth ranged from 0 to 10 cm, from 5 to 20 cm, and from 15 to 40 cm in SW *D. angustifolia*, *Cl*, and *Cp* marsh, respectively, during the sampling period. Both of the *Carex* marshes are permanently inundated throughout the year. The compositions of the various vegetation types are pure *D. angustifolia* in SW and 90% *D. angustifolia* with 10% shrubs in NW *D. angustifolia* marsh. The vegetations of the other two types of marshes are pure *Cl* and *Cp*, respectively.

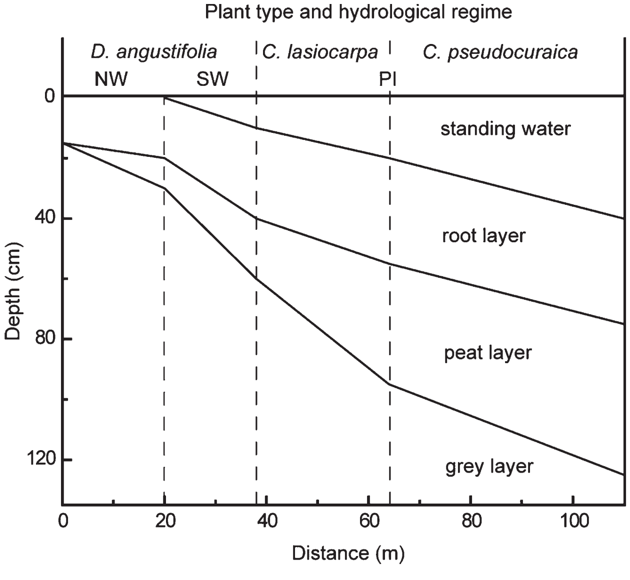

Figure 1. Profile characters in freshwater marsh with different plants and hydrological regime in Sanjiang plain. NW, SW, and PI represent the NW, SW and permanently inundated.

2.2 Sample collection

According to dominant plant species and hydrological conditions, four plots, i.e., NW *D. angustifolia* marsh, SW *D. angustifolia* marsh, *Cl* marsh, and *Cp* marsh were chosen for this study. In each plot, live plants were sampled from five different replicates which were selected randomly. Biomass was measured twice a month on the 11th and 26th, during the growing seasons (early May to late October) from 2002 to 2004.

Aboveground biomass was determined in 50 cm × 50 cm plots. The live plants were clipped to ground level and sorted into leaves and stems. Belowground biomass was collected to a depth of 60 cm using a round serrated edged stainless-steel corer, with a diameter of 10 cm. The soil core sections were gently washed in mesh bags (2 mm^2 mesh) to remove mud. Plant material dried to a constant weight in an oven at 80°C for 72 h. The biomass was calculated on a dry mass basis and expressed as mass of dry matter per unit area (g m^{-2}). The monthly growth rate of plants was calculated by the Eq. (1):

$$\mathrm{RGR} = (\mathrm{AGB}_{i+1} - \mathrm{AGB}_i)/\Delta D + (\mathrm{BGB}_{i+1} - \mathrm{BGB}_i)/\Delta D \qquad (1)$$

where RGR is the monthly growth rate of plants (g m^{-2} day^{-1}), AGB the aboveground biomass (g m^{-2}), BGB the belowground biomass (g m^{-2}), i and $i+1$ are i time and $i+1$ time biomass measured, respectively, ΔD is the interval of i and $i+1$ biomass measurements (day).

Several algorithms are used to estimate the NPP from biomass measurement in grassland vegetation [3, 21], depending on the types of vegetation. In this study, the method of maximum minus minimum live biomass, which is suitable for the temperate grasslands, was used for estimating NPP [3, 21–23].

2.3 Plant nutrients analysis

The TOC, TN, and TP contents were determined using half-monthly sampled plant material crushed to powders. According to the plants morphological traits, we determined nutrient contents in the stem, leaf, and root of *D. angustifolia* and stem/leaf and root of *Cl* and *Cp*. Plant materials were first ground in a centrifugal mill and then digested with a modified Kjeldahl procedure (1 h at 200°C and 2 h at 340°C in a mixture of concentrated sulfuric acid, salicylic acid, copper, and selenium). Concentrations of N and P in the digests were analyzed colorimetrically on a continuous-flow analyzer (Skalar San^{++}, Skalar, Breda, Netherlands). The TOC was determined by Total Organic Carbon Analyzer Model TOC-V$_{\mathrm{CPH}}$ (Shimadzu, Japan). The yearly stocks of C, N, and P from biomass were calculated using Eq. (2):

$$S_\mathrm{i} = (\mathrm{LANPP}\,\mathrm{LAC_i} + \mathrm{SANPP}\,\mathrm{SAC_i} + \mathrm{BNPP}\,\mathrm{BC_i})k \qquad (2)$$

Where i is a certain nutrient (TOC, TN, or TP), S_i is the yearly stock of i (g m^{-2} year^{-1}), LANPP and SANPP are NPP of leaf and stem, respectively, LAC$_\mathrm{i}$ and SAC$_\mathrm{i}$ are the average concentration of i in leaf and stem, respectively ($g\,kg^{-1}$), BC_i is the average concentration of i in belowground biomass ($g\,kg^{-1}$), and k is 10^{-3}.

3 Results and disscussion

3.1 Biomass and NPP

Both above- and belowground were low in May, which was during an early stage of plant growth, reached maximum values in late July for aboveground parts and in early August for below-ground parts during the warm rainy season, and then decreased sharply (Fig. 2a and b). A positive relation between aboveground biomass and air temperature (Fig. 2c, monitoring data of 2002–2004 from Sanjiang Experimental Station of Marsh Wetland Ecology, Chinese Academy of Sciences) were observed in the study ($R > 0.78^{**}$, $p < 0.01$). Our results showed a similar seasonal trends as reported by other studies on wetland plants in this region [24, 25].

Total biomass ranged from 639.06 to 3626.23 $g\,m^{-2}$ with a mean of 2094.66 $g\,m^{-2}$ in Sanjiang plain freshwater marsh. The mean values of total biomass are 2094.19, 1618.26, 2439.03, and 1903.16 $g\,m^{-2}$ in NW *D. angustifolia* marsh, SW *D. angustifolia* marsh, *Cl* marsh, and *Cp* marsh, respectively. Belowground biomass comprised the greatest proportion of the total biomass, especially for the *Cl* and *Cp* marshes, accounting for more than 80% of the total biomass. The average aboveground biomass was 748.88, 540.26, 425.21, and 318.05 $g\,m^{-2}$ in NW *D. angustifolia* marsh, SW *D. angustifolia* marsh, *Cl* marsh, and *Cp* marsh, respectively. The leaf biomass was 21–34% (mean 27%) of aboveground biomass of *D. angustifolia*. The average belowground biomass was 1345.32, 1078.00, 2013.82, and 1585.12 $g\,m^{-2}$ in NW *D. angustifolia* marsh, SW *D. angustifolia* marsh, *Cl* marsh, and *Cp* marsh, respectively. Among these four types of marshes, the aboveground biomass of NW *D. angustifolia* marsh was the greatest, whereas both belowground and total biomasses of *Cl* marsh were higher than others. Comparing to other aquatic ecosystem, our results are higher than that of temperate lakes (0.07–680 $g\,m^{-2}$), floating zone (0.56–1191 $g\,m^{-2}$), and submerged zone (5.75–71.4 $g\,m^{-2}$), New Zealand lakes (50–1000 $g\,m^{-2}$) [26, 27], Nabugabo wetland (Uganda; 1638 $g\,m^{-2}$) [7], but lower than the values reported for reed swamps in Minnesota (USA) (630–4640 $g\,m^{-2}$) [27] and similar to *Sarcocarnia fruticosa* and *Phragmites australis* in the Po delta [28] and salt marshes of the Ebre delta [29].

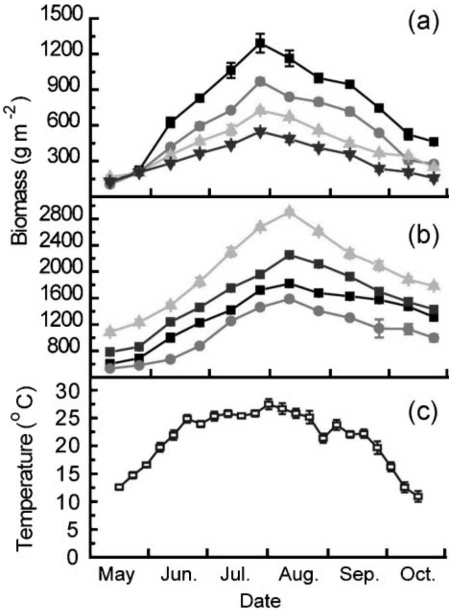

Figure 2. Seasonal dynamics of biomass in three species of freshwater marsh and air temperature. Vertical bar stands for standard deviation. (a) Aboveground biomass, (b) belowground biomass, and (c) air temperature. (■) Da^1, (●) Da^2, (▲) *Cl*, and (▼) *Cp*.

The monthly growth rates of the three kinds of plants studied in the Sanjiang plain marsh are shown in Fig. 3. The maximum biomass accumulation rate was ~36.19 $g\,m^{-2}\,day^{-1}$ for *Cl* in July and the minimum value was ~9.92 $g\,m^{-2}\,day^{-1}$ for *D. angustifolia* in SW marsh (Da^2) in May. The monthly growth rate in July was 2–4 times higher than that in May for each plant and belowground biomass is 1.4–3 time higher than aboveground biomass in July. Therefore, the greatest biomass was observed in late of July and belowground biomass was higher than aboveground biomass in this study (Fig. 2). The average growth rates of *D. angustifolia* in NW marsh (Da^1) and in SW marsh, *Cl* and *Cp* from early May to late July were 21.56, 17.02, 22.14, and 17.41 $g\,m^{-2}\,day^{-1}$, respectively. The rates of production of the three species in the freshwater marsh in this study were 2.54–16.17 $g\,m^{-2}\,day^{-1}$ for aboveground parts and 3.10–25.33 $g\,m^{-2}\,day^{-1}$ for belowground parts during May to July and the maximum value of production for each species appeared in the rainy season when optimum temperature and light conditions prevailed, whereas the rate was negative for aboveground parts and belowground parts after August because most of the parts of the plants were dead and live biomass decreased quickly when the temperature started to decline (Figs. 2 and 3). Our observations are similar with other reports about the maximum aboveground productivities of *Cl*, *Clyceria spiculosa*, and *D. angustifolia* in the Sanjiang plain [30], but higher than the net productivity of submerged macrophytes in a tropical wetland (0.74 $g\,m^{-2}\,day^{-1}$) [26].

The species distribution in the studied area was *D. angustifolia*, *Cl*, and *Cp*, which changed as the depth of standing water increased (Fig. 1). We observed that the correlation coefficient was −0.95 and correlation was significant at the 0.05 level, between the aboveground biomass and standing water, while definite relations between belowground, total biomass, and standing water were not found in this study. The difference of total biomass was 284.89–820.77 $g\,m^{-2}$ between the three species in our studied sites and 475.93 $g\,m^{-2}$ between *D. angustifolia* located at different sites.

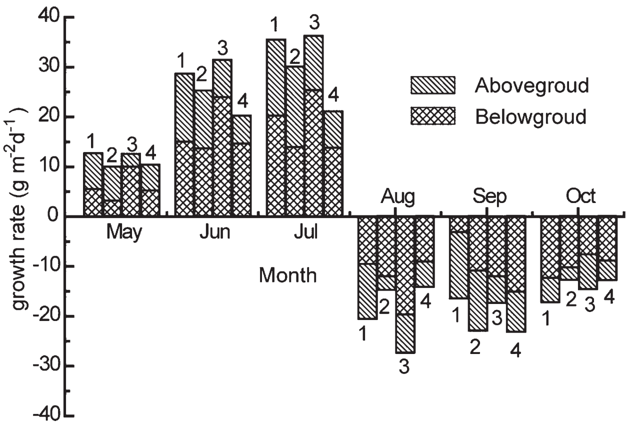

Figure 3. The production rates of above- and belowground biomass of marsh species in different month during growth season. (1) Da^1, (2) Da^2, (3) *Cl*, and (4) *Cp*

The results show that the biomass was determined by species, which distribution was decided by hydrological condition. Other study also found that species distributions were strongly related to the hydrologic zones [15].

The net productivity values are estimated using the method of maximum minus minimum live biomass [21, 23] in the study. The total net primary productivity (TNPP) ranged from 1900 to 2700 g m^{-2} year^{-1} (Tab. 1). The mean values of TNPP were about 2508.46, 2048.67, 2546.12, and 2017.86 g m^{-2} year^{-1} for *Da*^{1}, *Da*^{2}, *Cl*, and *Cp*, respectively, which was ~700 g m^{-2} year^{-1} lower than that of grasslands [31]. TNPP of *Cl* was the greatest among all the species in the marsh, because of the high belowground biomass growth rate during the growing season (Tab. 1, Fig. 3). TNPP of *Cp* located in deep standing water area was the smallest among the studied plants. Comparing the *D. angustifolia* in different hydrological regimes, the total net production of *Da*^{1} was higher than that in SW marsh. The mean value of belowground net primary productivity (BNPP) ranged from 1070 to 1820 g m^{-2} year^{-1} and the mean values of aboveground net primary productivity (ANPP) ranged from 540 to 1300 g m^{-2} year^{-1}. The average ANPP in this study was high in comparison to the data of various workers on biomass of grasslands in temperate regions of northern China summarized by Ni (2004). The average BNPP of marsh vegetation was about half of that of grasslands (2425 g m^{-2} year^{-1}) [31]. The BNPP of *Cl* was the greatest and nearly 1.8 times greater than that of *Da*^{2}, while the ANPP of *Da*^{1} was the greatest and more than two times of the value for *Cp* (Tab. 1). The stem NPP of *Da*^{1} and in SW marsh varied from 756.94 to 1043.15 g m^{-2} year^{-1}, with a mean value of 936.69 g m^{-2} year^{-1} and from 651.33 to 753.70 g m^{-2} year^{-1}, with a mean value of 699.21 g m^{-2} year^{-1}, respectively. About 24.8–33.6% of ANPP of *D. angustifolia* was contributed by leaves.

3.2 Nutrient concentrations in plants

The average TOC, TN, and TP concentrations decreased in the following order: root > stem > leaf in *D. angustifolia*, root > leaf/stem in both *Cl* and *Cp* (Tab. 2). The mean annual TOC concentration ranged from 403.0 g kg^{-1} in leaves of *Da*^{2} to 448.3 g kg^{-1} in roots of *Cl*. The mean annual TN varied between 5.21 g kg^{-1} in leaves of *Da*^{1} and 47.48 g kg^{-1} in roots of *Cp*. TP ranged from 0.48 g kg^{-1} in leaves of *Da*^{2} to 1.50 g kg^{-1} in roots of *Cp*. The average nutrient concentration of *D. angustifolia* was lower than that of *Cl* and *Cp* in the freshwater marsh of Sanjiang plain, especially TN, which was about half. The mean annual nutrient content (2002–2004) ranged 5.21–47.47 g kg^{-1} for N and 0.46–1.50 g kg^{-1} for P for the three species studied, these nutrient levels were similar to those recorded in previous studies for N but much lower for P [32–34]. The nutrient accumulative value of aboveground and belowground parts of different wetland plants is obviously different [35, 36]. The present study showed that the three species had relatively high belowground accumulation of N and P but low aboveground accumulation values (Tab. 2). Kao et al. [37] had

Table 1. NPP for three wetland species (g m^{-2} year^{-1}).

Species	ANPP		BNPP		TNPP	
	Range	Mean	Range	Mean	Range	Mean
Da^1	1413.53–1123.87	1291.83	1052.74–1327.25	1216.63	2272.34–2708.04	2508.46
Da^2	923.87–1032.67	969.50	989.24–1432.57	1079.17	1934.91–2398.03	2048.67
Cl	679.77–772.33	724.32	1700.73–1917.33	1821.80	2467.18–2677.85	2546.12
Cp	522.47–584.24	547.56	1371.90–1583.30	1470.31	1901.34–2131.51	2017.86

Da^1, *D. angustifolia* in NW marsh; *Da*^{2}, *D. angustifolia* in SW marsh. *Cl*, *C. lasiocarpa*; *Cp*, *C. pseudocuraic*.

Table 2. Mean values of nutrient concentrations (g kg^{-1}) in marsh species.

	Da^1			*Da*^{2}			*Cl*		*Cp*	
	Root	Stem	Leaf	Root	Stem	Leaf	Root	Leaf/Stem	Root	Leaf/Stem
2002										
TOC	437.4	417.5	407.5	439.0	408.2	407.5	448.3	427.6	441.2	418.6
TN	29.99	7.38	5.21	34.30	8.61	7.10	46.49	14.48	47.48	16.51
TP	0.66	0.57	0.55	0.71	0.66	0.55	0.81	0.71	0.87	0.75
2003										
TOC	440.0	419.1	403.0	439.3	41.37	403.6	445.1	426.5	441.5	419.3
TN	29.40	6.85	5.24	33.99	8.27	7.15	46.37	15.77	47.08	16.17
TP	0.66	0.59	0.54	0.73	0.66	0.55	0.73	0.66	0.66	0.59
2004										
TOC	435.4	410.7	407.5	443.3	415.5	407.9	448.1	428.6	444.1	417.7
TN	29.78	8.32	5.64	34.04	9.07	7.36	46.27	14.40	47.47	16.31
TP	0.66	0.58	0.53	0.72	0.66	0.46	0.82	0.73	0.66	0.82
2002–2004										
TOC	437.6	415.8	406.0	440.5	412.5	406.3	447.2	427.6	442.2	41.85
TN	29.72	7.52	5.36	34.11	8.65	7.20	46.38	14.89	47.34	16.33
TP	0.66	0.58	0.54	0.72	0.66	0.52	0.79	0.70	0.73	0.72

Da^1, *D. angustifolia* in NW marsh; *Da*^{2}, *D. angustifolia* in SW marsh. *Cl*, *C. lasiocarpa*; *Cp*, *C. pseudocuraic*.

Table 3. Correlation coefficient between nutrient concentrations and growth time.

Nutrients	*Da*[1]			*Da*[2]			*Cl*		*Cp*	
	Root	Stem	Leaf	Root	Stem	Leaf	root	Leaf/stem	root	Leaf/stem
TOC	0.86**	0.88**	−0.88**	0.80**	0.74**	−0.92**	0.73**	0.81**	0.77**	0.84**
TN	0.74**	−0.82**	−0.93**	0.82**	−0.82**	−0.92**	0.47**	−0.92**	0.36*	−0.80**
TP	0.97**	−0.92**	−0.95**	0.90**	−0.97**	−0.95**	0.83**	−0.88**	0.72**	−0.89**

Da[1], *D. angustifolia* in NW marsh; *Da*[2], *D. angustifolia* in SW marsh. *Cl*, *C. lasiocarpa*; *Cp*, *C. pseudocuraic*.
* Significant at the 0.05 level.
** Significant at the 0.01 level.

reported that woolgrass (*Scirpus cyperinus*) had the same trend for N and P accumulation.

Seasonal trends of nutrients in wetland plant organs have been reported, factors discussed to explain such trends include: competition for nutrients between plant tissues, degree of nutrient stress, growth dilution, vegetation flushing, soil temperature, and nutrient mobility [9, 26, 38, 39]. We observed that there were significant seasonal variations in the nutrient concentration of the three wetland species (Tab. 3). The TOC concentration increased from early growth phase and was relatively stable after late July when the plants had matured, except in leaves where the TOC concentration decreased gradually during the growth period (Fig. 4). The main reason of the phenomenon is that the photosynthesis of plants is weakened after the middle of August because of temperature decline

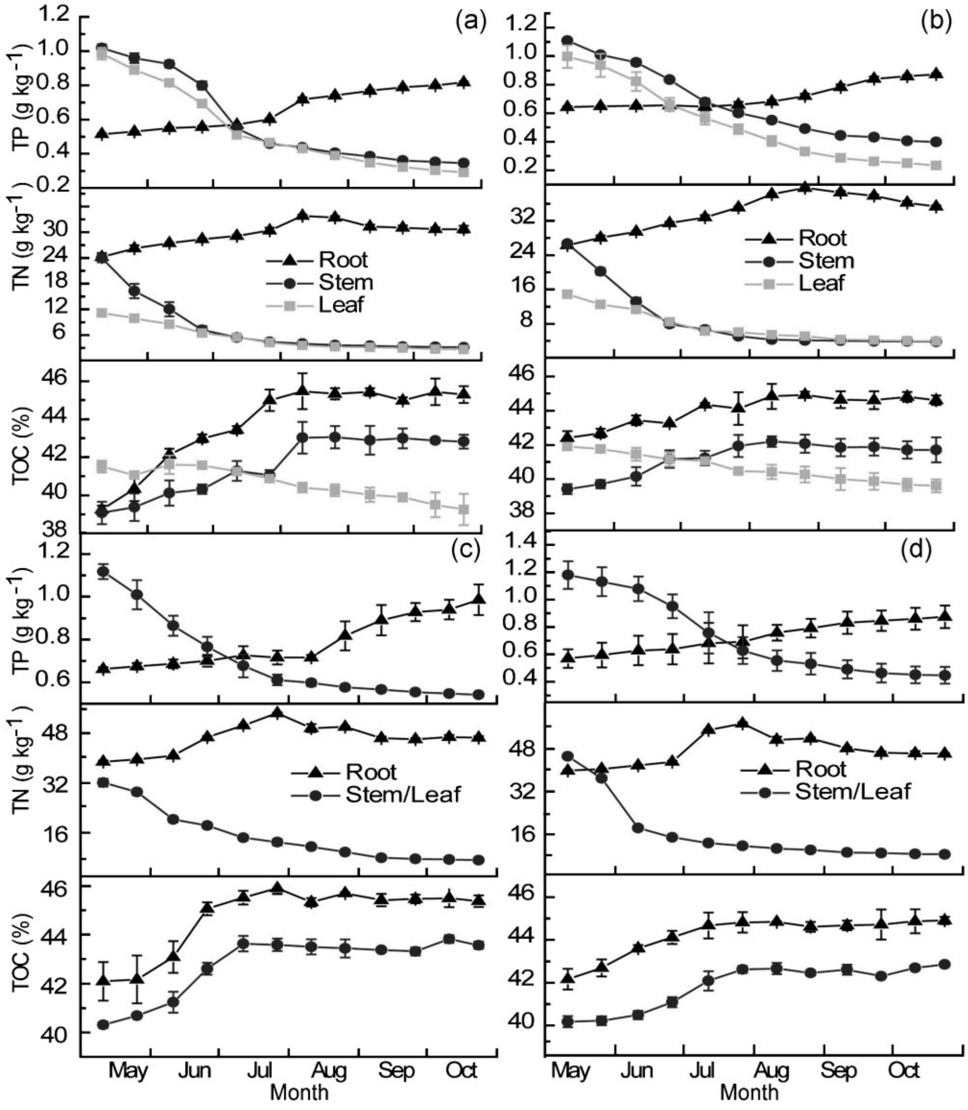

Figure 4. The seasonal variations in TOC, TN, and TP concentrations in different organs of marsh macrophytes in 2002–2004. Data presented are mean concentration and vertical bar stands for standard deviation. (a) *Da*[1], (b) *Da*[2], (c) *Cl*, and (d) *Cp*.

Table 4. Nutrient bioaccumulations in plants in freshwater marsh.

	Da^1	Da^2	*Cl*	*Cp*
TOC stock (g m^{-2} year^{-1})				
Aboveground	538.93 ± 9.93	399.70 ± 3.42	309.72 ± 2.66	229.15 ±2.11
Belowground	532.40 ± 8.60	475.38 ± 12.05	814.71 ±5.96	650.17 ± 6.54
Total	1071.33 ± 15.91	875.08 ± 12.00	1124.43 ± 6.43	879.32 ± 7.07
TN stock (g m^{-2} year^{-1})				
Aboveground	9.02 ± 0.17	8.02 ± 0.07	10.79 ± 0.09	8.94 ± 0.08
Belowground	36.19 ± 58	36.81 ± 0.93	84.50 ± 0.62	69.61 ± 0.70
Total	45.17 ± 0.68	44.83 ± 0.93	95.28 ± 0.62	78.55 ± 0.71
TP stock (g m^{-2} year^{-1})				
Aboveground	0.74 ± 0.01	0.60 ± 0.01	0.51 ± 0.01	0.39 ± 0.01
Belowground	0.80 ± 0.01	0.78 ± 0.02	1.44 ± 0.01	1.07 ± 0.01
Total	1.55 ± 0.02	1.38 ± 0.02	1.95 ± 0.01	1.47 ± 0.01

Da^1, *D. angustifolia* in NW marsh; Da^2, *D. angustifolia* in SW marsh. *Cl*, *C. lasiocarpa*; *Cp*, *C. pseudocuraic*.

(Fig. 2c). The concentrations of N and P in the aboveground parts of all three species were higher at the start of the growing season and decreased gradually until late July, and then were relatively stable during the following months. On the contrary, both N and P concentrations in the roots were lower during the early growing stages and increased slowly during the growing season (Fig. 4). That may be due to growth dilution effects [38] and being translocated to new sinks, such as the root, in which the TN and TP concentrations increased at same time (Fig. 4).

3.3 The nutrient stocks in plants

As shown in Tab. 4, the nutrient stock in different marsh plants was calculated based on nutrient concentrations and NPP, which were monitored from 2002 to 2004. When all the three marsh species were grouped, the nutrient stocks in plants ranged from 875.08 to 1124.43 g m^{-2} year^{-1} for TOC, 44.83 to 95.28 g m^{-2} year^{-1} for TN, and 1.38 to 1.95 g m^{-2} year^{-1} for TP. Comparing these three species, the maximum nutrient stocks of TN, TP, and TOC was in *Cl*, because of its high BNPP and high nutrient concentrations (Tabs. 1 and 2). The nutrients in *Cl* and *Cp*, both of which were located in waterlogged areas, were mainly stored in the belowground parts, whereas the nutrient stocks in above- and belowground parts were similar in *D. angustifolia*, which were located in non- or SW areas.

The total areas of NW *D. angustifolia* marsh, SW *D. angustifolia* marsh, *Cl* marsh, and *Cp* marsh in Sanjiang plain are about 2543, 1040, 5928, and 790 km^2, respectively [20]. We estimated that the annual nutrient bioaccumulations in NW *D. angustifolia* marsh, SW *D. angustifolia* marsh, *Cl* marsh, and *Cp* marsh were about 2.72×10^6, 0.91×10^6, 6.67×10^6, and 0.70×10^6 t for TOC, about 114.87×10^3, 46.62×10^3, 564.82×10^3, and 62.06×10^4 t for TN, about 3.94×10^3, 1.44×10^3, 11.56×10^3, and 1.16×10^3 t for TP, respectively. The calculated results show that the annual bioaccumulations of TOC, N, and P were about 10.99×10^6, 788.36×10^3, and 18.10×10^3 t, respectively, in the three species, which cover 80% of the sedge and grass covered marsh of Sanjiang plain.

4 Concluding remarks

Our data suggest that *Cl* had the greatest nutrient bioaccumulation capacity for belowground biomass of the three species, so the nutrient stocks in the marsh were greatly affected by changes in area occupied by this species. The land-use of Sanjiang plain has changed intensively in the past 45 years because of large scale reclamation. The depth of standing water in the marsh decreased because of agricultural drainage. We believe that the nutrient stocks in the Sanjiang plain marsh have been greatly reduced because some of the area occupied by *Cl* was replaced by *D. angustifolia* as a result of succession caused by the changes of water table.

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