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Nitrogen and phosphorus stoichiometry of common reed (*Phragmites australis*) and its relationship to nutrient availability in northern China

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ABSTRACT

Common reed (*Phragmites australis* (Cav.) Trin. ex Steud.) is a key wetland species with cosmopolitan distribution. In this study, we examined nitrogen (N) and phosphorus (P) stoichiometry in reed organs, using data of 28 samples from Wuliangsuhai Lake and 17 samples from the wetlands of the city of Zhangye, both located in northern China. Our results showed that the average N and P contents and N:P ratio of the whole plant (geometric mean of mass ± standard deviation) were $14.1 \pm 5.3\,\mathrm{mg\,g^{-1}}$, $0.95 \pm 0.54\,\mathrm{mg\,g^{-1}}$, and 16 ± 5, respectively. These values exhibited significant differences among the organs of reed, including the flowers, leaves, stems, roots, and rhizomes, ranging on average from 6.4 ± 4.2 (stem) to $31.4 \pm 5.2\,\mathrm{mg\,N\,g^{-1}}$ (leaf), from 0.652 ± 0.647 (stem) to $2.05 \pm 0.33\,\mathrm{mg\,P\,g^{-1}}$ (flower), and from 10 ± 6 (stem) to 24 ± 4 (leaf) on N:P ratio. The N content closely co-varied with P content within and across organs, and interestingly, P content was more variable than N content. The N and P contents of the whole reed plant, stems, and rhizomes were positively correlated with the availability of these nutrients in water and sediment, but were relatively stable in leaves and flowers. Structural organs probably perform a buffering function of storing N and P in plants. All such stoichiometric patterns can influence the reed bed stand structures such as stem density, stem height, and basal diameter, and may contribute to the wide distributions of reed species in various environments. Our findings are applicable to the management of reed-dominated wetlands.

1. Introduction

Plant nitrogen (N) and phosphorous (P) contents not only strongly influence the growth and reproduction of individual plants, but also regulate material and energy cycles of whole ecosystems, plant species interactions, community composition, and plant species diversity (Sterner and Elser, 2002; Kerkhoff et al., 2005, 2006). Variation in plant stoichiometry may also influence the activities of herbivores, parasites, pathogens, and decomposers in the ecosystems (Güsewell, 2004). The mineral demands of plants tend to be greatest for N which in turn is frequently the growth-limiting nutrient in both agricultural and natural systems (Chapin et al., 1987). P is also limited in most ecosystems (Chen et al., 2013).

Plant N and P contents are considered important indicators of the adaption of plants to the environments. In addition, the N:P ratio is used as an indicator of nutrient limitation in wetlands (Koerselman and Meuleman, 1996). Nutrient allocation patterns largely reflect the ability of plants to capture resources (Poorter et al., 1990). Plants in low-nutrient environments tend to allocate proportionally more resources to roots in order to increase their uptake capacity of the limited soil resources (Müller et al., 2000). Variation in plant tissue nutrient contents is similar in magnitude to variation in nutrient availability (Kerkhoff et al., 2006). A large variation in leaf traits, including N and P concentrations has been observed across geographical ranges, ecosystems, climatic regimes, as well as microhabitats (Reich and Oleksyn, 2004; Wright et al.,

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2004; Han et al., 2005, 2011; He et al., 2006, 2008; Anderson and Lockaby, 2011). Responses of plants to N and P supply could cause up to 50-fold variation in biomass N:P ratios, associated with differences in root allocation, nutrient uptake, biomass turnover and reproductive output (Güsewell, 2004). In contrast, Bowman et al. (2003) found that there were no significant relationships between soil nutrient supply and foliar nutrient concentrations because of the buffering effect of belowground nutrient storage in plants. These contrasting results highlight that further studies are needed to understand how nutrient availability influences plant nutrient contents.

Common reed (*Phragmites australis* (Cav.) Trin. ex Steud.) is widely distributed throughout the world and is one of the dominant emergent species in wetlands of northern China. It provides ecosystem services, e.g., water purification, biodiversity maintenance, and is a biomass resource for energy production (Brix, 1999; Thevs et al., 2007; Baratieri et al., 2011; Zerbe and Thevs, 2011). In this study, we analyzed the nutrient allocation patterns among five organs of reed from two sites in northern China, i.e. Wuliangsuhai Lake and wetlands in the city of Zhangye, with 11-fold N availability differences and 5-fold P availability differences in the sediment. Our objectives were to (1) determine the variation in N and P stoichiometry within and across reed flower, leaf, fine root (root hereafter), stem, and rhizome; (2) explore the relationship between reed N and P stoichiometry and water/sediment characteristics; and (3) describe the impact of reed N and P stoichiometry on stand structure.

2. Methods

2.1. Study sites

Wuliangsuhai Lake and the city of Zhangye are both located in northern China (Fig. S1 in the Appendix). Wuliangsuhai Lake is an important lake in the Urad Front Banner of the Bayannaoer Prefecture of the Inner Mongolia Autonomous Region. The average elevation of the lake is 1018.5 m, with an area of about 293 km^2 and a water capacity of 250–300 million m^3 (Fejes et al., 2008). It has a maximum depth of less than 4 m, while the average depth is only about 1 m. It lies downstream of the Hetao irrigation catchment and receives almost all the drainage water from the irrigation area. Hetao Irrigation District is an important crop production region in China. The annual crop production has increased from 0.6 million tons in 1985 and 1.5 million tons in 1998 to 2.7 million tons in 2008 (Xi, 2010). Accordingly, more and more fertilizers were used in this region leading to serious eutrophication (Duan et al., 2004). With the high evapotranspiration and low precipitation of this region, the salinization is also becoming a serious problem in Wuliangsuhai Lake (Duan et al., 2004).

Zhangye city is located in the oasis of the Heihe river basin in Gansu Province. There are large areas of reed remaining in and around the city, which forms the dominant emergent plant species in the national wetland park of Zhangye. The wetlands experience increasing pollution and exploitation from the local industries (Zhang et al., 2005; Ding et al., 2009). Environment characteristics differ between the two sites, for example, the mean water and sediment electric conductivity (EC, ms cm^{-1}) were 6.7 and 1.5, respectively in Wuliangsuhai Lake, and were 1.2 and 0.7, respectively in wetlands in Zhangye (this study, Table 1). For more information about these two sites, see Table 1.

Table 1
Characteristics of the two study sites: the Wuliangsuhai Lake and the wetlands of Zhangye. Altitude above sea level (a.s.l.) is the arithmetic mean value of the 45 sampling plots. Mean annual temperature (MAT), mean annual precipitation (MAP) and potential evapotranspiration (PET) are decade arithmetic mean values. EC/pH of sediment/water are geometric mean values ± standard deviation of this study.

	Wuliangsuhai Lake	Wetlands in Zhangye
Region	Hetao Irrigation Area, Inner Mongolia	Hexi corridor, Gansu
Watershed	Yellow River	Heihe River
Latitude (°N)	40.7–41.1	38.9–39.1
Longitude (°E)	108.7–109.0	100.3–100.6
Altitude (a.s.l., m)	1020	1455
MAT (°C)	7 (Duan et al., 2004)	7 (Ding et al., 2009)
MAP (mm)	216 (Duan et al., 2004)	129 (Ding et al., 2009)
PET (mm)	2300 (Xi, 2010)	2050 (Ding et al., 2009)
Water EC (ms cm^{-1})	6.7 ± 9.0	1.2 ± 0.4
Sediment EC (ms cm^{-1})	1.5 ± 1.0	0.7 ± 0.4
Water pH	8.7 ± 0.5	7.8 ± 0.2
Sediment pH	7.5 ± 0.2	7.3 ± 0.1

2.2. Field sampling and laboratory analyses

In Wuliangsuhai Lake and the wetlands of Zhangye, we sampled reed in August 2011 when reed was at its peak biomass of the year, in 45 water bodies (plots) covering a wide range of water pollution and salinization levels (Fig. S1 in the Appendix). The plots were 0.5 m × 0.5 m. Mean plant height (m) and basal diameter (cm) from the sediment surface were measured and the stem numbers were counted. Two to five cloned plant individuals were sampled on each plot. Roots and rhizomes were sampled 30 cm below the sediment surface. We divided each individual into five parts (organs), i.e. flowers, leaves, stems, roots, and rhizomes. The five organs were weighed immediately on site. Additionally, water and sediment were sampled at root depths near the plants at the same time as sample collection.

In the laboratory, we determined the dry matter content (DMC), total carbon (C, mg g^{-1}), total nitrogen (N, mg g^{-1}), and total phosphorous (P, mg g^{-1}) contents of reed flowers, leaves, stems, roots, and rhizomes. All samples were oven dried at 60 °C for 72 h for subsequent nutrient content analyses. C and N were measured using an elemental analyser (2400 II CHN Elemental Analyzer, Perkin–Elmer, USA) with a combustion temperature of 950 °C and a reduction temperature of 640 °C (He et al., 2006, 2008). P was measured following the molybdate stannous chloride method (He et al., 2008).

Both water EC and pH were measured on site with a Multi340i handheld meter (WTW, Germany). Other analyses were performed in the laboratory. N and P of water samples were measured as soon as possible after sampling. Sediment EC and pH were determined with a DDS-11A digital display conductivity meter (CSDIHO, China) and PH-3C (INESA, China). Sediment samples were then oven dried for further analysis of N and P. N (both sediment and water samples) was measured according to the alkaline potassium persulfate digestion-UV spectrophotometric method. P (both sediment and water samples) was measured in the same way as that in reed.

2.3. Data analyses

We pooled the data from the two sites during the data analyses. We log$_{10}$-transformed all the data before statistical analyses to meet normality of variance requirements. The data were sufficiently close to normal distributions after the log-transformation (see Table S1 in the Appendix). Geometric means were calculated for all values, unless otherwise stated. One-way ANOVA and Bonferroni post hoc tests were carried out to assess the differences in N and P contents within and across reed organs. Standardized major axis (SMA) slopes with 95% confidence intervals were used to examine N and P relationships within reed organs (Wright et al., 2004). Ordinary least square (OLS) regressions were performed to test the relationships of plant nutrient contents and water and sediment characteristics. Analysis of covariance (ANCOVA) was used to test the differences between regression slopes (Townend, 2002).