THE RESPONSE OF FUNCTIONAL TRAITS AND ABOVEGROUND BIOMASS OF *PHRAGMITES AUSTRALIS* TO HABITAT CHANGES IN THE YELLOW RIVER DELTA, CHINA

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Abstract. Plant functional traits and biomass allocation can reflect the adaptive strategies of plants to environmental changes. However, little is known about how plant functional traits and biomass allocation respond to habitat changes in the Yellow River Delta, China. The dominant species, *Phragmites australis* (Cav.) Trin. ex Steud (common reed), was chosen to investigate the response of functional traits and aboveground biomass allocation to different habitats (grassland and river bank) with different soil water content. The results showed that plant height and number of leaves of *P. australis* were lower in grassland compared with river bank, while leaf thickness showed the opposite trend. It suggests that a conservative strategy in grassland was adopted by *P. australis*. The stem biomass and aboveground biomass were higher in river bank compared with grassland. Plant height was positively correlated with number of leaves, individual leaf dry weight and stem diameter, while it was negatively correlated with leaf thickness. Aboveground biomass was positively correlated with plant height, number of leaves, individual leaf dry weight and stem diameter, and the strongest correlation was found between plant height and aboveground biomass (R^2 = 0.75). The adaptation of *P. australis* to habitat changes through manipulating key functional traits and biomass allocation was observed.
Keywords: *common reed, perennial grass, functional traits, ecological adaptation, biomass allocation*

Introduction

Plant functional traits are the features (such as plant height, leaf area, and dispersal syndrome, etc.) that reflect how plants respond to environmental changes, and can also affect ecosystem function (Díaz and Cabido, 2001). The advantages of plant functional traits lie in that some key traits are easy to measure (Collins et al., 2016), and they can reflect the adaptation of plants to environmental changes well (Ahrens et al., 2020; Prentice, 2024). For example, plant height is an indicator of plant size (Cayssials and Rodríguez, 2012). When water is scarce, the main way that plants cope with this change is by decreasing their height (Akram et al., 2023). As a result, it has received a considerable amount of attention from scholars. In recent years, many previous studies focused on changes in functional traits in frostland, grassland and wetland (Collins et al., 2016; Cao et al., 2020; Pan et al., 2020; Yue et al., 2019), and these results revealed how plant functional traits respond to climate and environmental change.

Plant biomass is the accumulation of matter and energy, which is important for the study of ecosystem structure and function (Li et al., 2021; Frolov et al., 2022). Understanding of biomass allocation patterns is an important aspect in plant ecology, and it reflects how plants adapt to their environments (Liu and Su, 2016). Moreover,

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biomass partitioning for plants was different under different environmental conditions. For example, *Suaeda salsa* regulates biomass allocation to adapt to different intertidal and supratidal habitats (Mao et al., 2011). Differences in branch and leaf biomass were found in *Nitraria tangutorum* under different precipitation conditions (He et al., 2016). Plants allocate more biomass to aboveground parts in environments with better water conditions (Hossain and Beierkuhnlein, 2018); however, more plant biomass is allocated to roots to adapt to harsh environmental conditions (Li et al., 2021). This reflects the optimal partitioning theory which predicts that plants allocate biomass to the organ that uses the resource that most limits their growth (Iyer and Walters, 2010). Changes in biomass allocation are influenced not only by the environment, but also by differences among species (Zhou et al., 2013; Fan et al., 2019). Recently, little attention has been paid to the biomass allocation of *Phragmites australis* (common reed) under different habitats (Yang and Li, 2003).

As one of the three major estuary deltas in China, Yellow River Delta, plays a vital role in maintaining biodiversity, especially for wild birds (Wang et al., 2012). *P. australis* is a perennial grass, which plays an important role in river bank protection and soil purification, etc. (Zhang et al., 2018a). Moreover, it can adapt to different environmental conditions (Yang and Li, 2003). The Yellow River Delta is an important area for the distribution of *P. australis*, and it is widely distributed in grassland and river bank in the study area. In recent years, most previous studies mainly focused on photosynthetic characteristics (An et al., 2020; Guo et al., 2018), Physiology (Tshapa et al., 2021; Khalilzadeh et al., 2022) and community dynamic of *P. australis* (Cho et al., 2017). However, little research has been conducted on the functional traits and biomass allocation of *P. australis* under different habitats in the Yellow River Delta. In order to provide a theoretical basis for the elucidation of plant adaptation strategies to habitat changes, *P. australis* was chosen as the study object. The objectives of this study were to (1) examine variations in functional traits and biomass allocation, (2) identify the relationship between functional traits and aboveground biomass.

Materials and methods

Study area

The study was conducted in the Binzhou Beihai Park (37°25′28″N, 117°59′58″E), in the Yellow River Delta, China (*Fig. 1*). The climate of the region is temperate continental monsoon climate with an average annual temperature of 12.5℃ (Wang et al., 2021). The annual mean precipitation is about 537 mm, and approximately 76% of the annual precipitation falling in June-September (Cai and Ren, 2014). The natural vegetation is mainly dominant by *P. australis*, *Cynodon dactylon*, *Sonchus arvensis* and *Setaria viridis*.

Experiment design and sampling

We selected sampling sites in grassland and river bank in the Yellow River Delta, and there was a distance of 60 m between the two habitats. 3 m × 3 m plots were randomly arranged, with six replicates for each habitat (*Table 1*). Natural plant stands were surveyed in the study area. In August of 2021, a quadrat (1 m × 1 m) was randomly setup in each plot. We chose *P. australis* as the study object, and sampling of

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functional traits and aboveground portion was carried out. According to standard protocols (Cornelissen et al., 2003), ten fully expanded and healthy leaves were randomly collected from five to ten individuals in each plot. Six individuals were randomly collected in each plot, and the aboveground portion of *P. australis* was harvested.

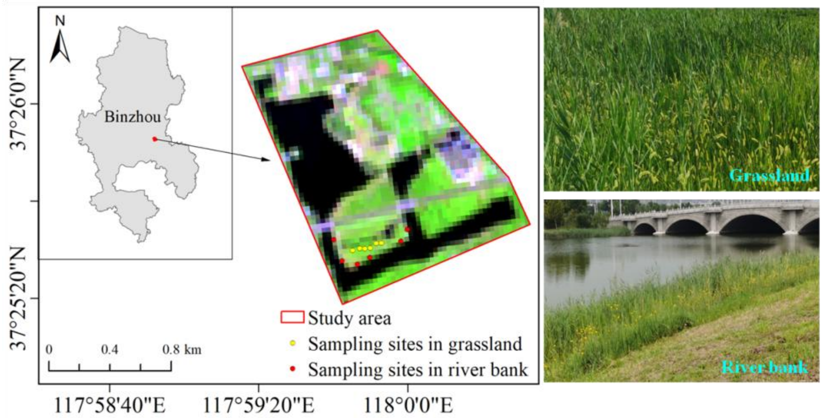

Figure 1. *Location of the study area, sampling sites and habitats*

Table 1. *Characteristics of different habitats in the Yellow River Delta*

Habitats	Altitude (m)	Soil water content (%)	Dominant species
Grassland	12	37.58 ± 1.88b	*P. australis*
River bank	11	50.86 ± 5.57a	*P. australis*

Different letters indicate differences at $P < 0.05$

Measurement of functional traits and biomass

Plant height was measured using tape, and stem diameter was measured using vernier calipers. Leaf thickness was measured using vernier calipers, avoiding main veins. The number of leaves was counted. Leaves and stems were dried for 48 h at 70°C, and then leaf dry mass and stem biomass were weighted. Biomass allocation was calculated as follows: leaf mass fraction as the ratio of leaf biomass to aboveground biomass, and stem mass fraction as the ratio of stem biomass to aboveground biomass.

Data analysis

Independent samples t-test was used to compare the difference between grassland and river bank for functional traits (plant height, number of leaves, leaf thickness, individual leaf dry weight and stem diameter) and aboveground biomass (leaf biomass, stem biomass, aboveground biomass, leaf mass fraction and stem mass fraction). Pearson correlation analysis was applied to examine relationships between functional traits. Linear regression analysis was use to determine relationships between functional traits and aboveground biomass. All tests were conducted at a significance level of $P < 0.05$. All statistical analyses were performed using SPSS software. Scatter plot was generated using Sigma plot software. A correlation map was generated using R software.

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Results

Variation in functional traits of P. australis under different habitats

Significant differences in plant height, number of leaves and leaf thickness were found between grassland and river bank ($P < 0.05$, *Table 2*), while there was no significant difference in individual leaf dry weight and stem diameter between grassland and river bank. Plant height and number of leaves in grassland were significantly lower than in river bank, while leaf thickness in grassland was significantly higher than that in river bank ($P < 0.05$).

Table 2. *Independent samples t-test for functional traits of P. australis under different habitats in the Yellow River Delta*

Functional traits	Grassland	River bank
Plant height (cm)	0.98 ± 0.04b	1.35 ± 0.06a
Number of leaves	10.47 ± 0.49b	12.42 ± 0.65a
Leaf thickness (mm)	0.15 ± 0.003a	0.13 ± 0.002b
Individual leaf dry weight (g)	0.14 ± 0.01a	0.14 ± 0.01a
Stem diameter (mm)	3.47 ± 0.20a	3.91 ± 0.16a

Different letters indicate significances between habitats ($P < 0.05$)

Biomass allocation of P. australis under different habitats

Table 3 shows the biomass allocation of *Phragmites australis*. Stem biomass, aboveground biomass, leaf mass fraction and stem mass fraction were significant different between grassland and river bank ($P < 0.05$). In contrast, there was no significant difference in leaf biomass between grassland and river bank. Stem biomass and aboveground biomass in river bank were 1.78 and 1.57 times higher than that in grassland, respectively.

Table 3. *Independent samples t-test for aboveground biomass allocation of P. australis under different habitats in the Yellow River Delta*

Biomass allocation	Grassland	River bank
Leaf biomass (g)	1.47 ± 0.13a	1.79 ± 0.20a
Stem biomass (g)	2.57 ± 0.28b	4.57 ± 0.53a
Aboveground biomass (g)	4.04 ± 0.40b	6.36 ± 0.68a
Leaf mass fraction	0.38 ± 0.01a	0.29 ± 0.01b
Stem mass fraction	0.62 ± 1.24b	0.71 ± 0.01a

Different letters indicate significances between habitats ($P < 0.05$)

Relationships between functional traits of P. australis

Plant height was significantly and positively correlated with number of leaves ($P < 0.05$), and a highly significant positive correlation was found between plant height and individual leaf dry weight and stem diameter ($P < 0.01$, *Fig. 2*). Plant height was significantly and negatively correlated with leaf thickness, while it was significantly and positively correlated with leaf thickness ($P < 0.01$). A significant positive correlation was found between individual leaf dry weight and stem diameter ($P < 0.01$).

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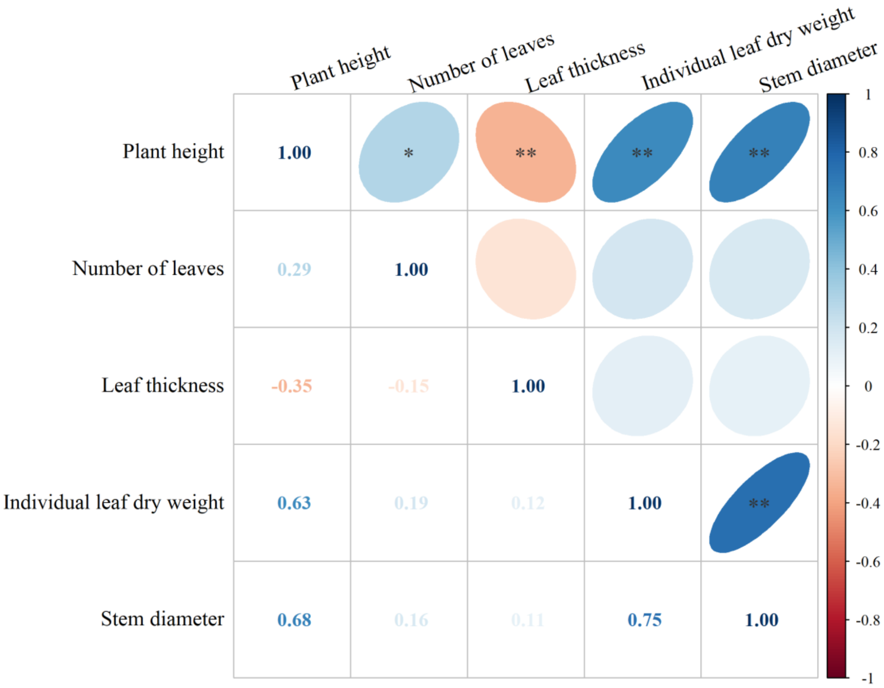

***Figure 2.** Relationships between functional traits of P. australis in the Yellow River Delta*

Correlations between functional traits and aboveground biomass of P. australis

Significant positive correlations were observed between plant height, number of leaves, individual leaf dry weight, stem diameter and aboveground biomass of *P. australis* in the Yellow River Delta ($P < 0.01$, *Fig. 3*). There was no significant correlation between leaf thickness and aboveground biomass ($P > 0.05$). The highest correlation coefficient was found between plant height and aboveground biomass ($R^2 = 0.75$, *Fig. 3a*), followed by individual leaf dry weight ($R^2 = 0.65$, *Fig. 3d*).

Discussion

Leaves are the photosynthetic organs of plants which are more sensitive to changes in the environment (Wang et al., 2017). In order to decrease water loss through transpiration from leaves, plants with thick leaves under water stressed conditions (Segura-Monroy et al., 2015). Thick leaves reflect a conservative strategy for plants to survive in harsh environmental conditions (Wei et al., 2021). In this study, leaf thickness is thicker in grassland compared to river bank, suggesting that a conservation strategy for *P. australis* to adapt to grassland in the Yellow River Delta. Moreover, the number of leaves of *P. australis* was less in grassland than that in river bank. Less leaf number helps to reduce water loss through leaf transpiration. It is a strategy for plants to adapt to changes in soil moisture. Our result is consistent with previous studies (Cirillo et al., 2015; Gorai et al., 2010). Plant height is an indicator of plant size, and changes in plant height reflect the adaptation of plants to environmental change (Price et al., 2017). In addition, plant height is an important part of plant ecological strategy, which is related to light competition (Moles et al., 2009). Water is one of the important factors limiting plant growth, and plant growth is inhibited under water deficient conditions (Baghalian et al., 2011). A similar result has been reported by previous studies, and they

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found that plant height of *P. australis* decreased as soil water content decreased (Zhang et al., 2018b). In this study, plant height was lower in grassland than that in river bank, indicating that plant size was sensitive to changes in soil moisture conditions. Water is sufficient in river bank, and humid environment is favorable for plant growth. In order to compete for light and space, *P. australis* allocated more matter to the stem (Yang and Li, 2003). Soil moisture is low in grassland compared to river bank, and a change in plant size is a strategy for *P. australis* to adapt to habitat changes.

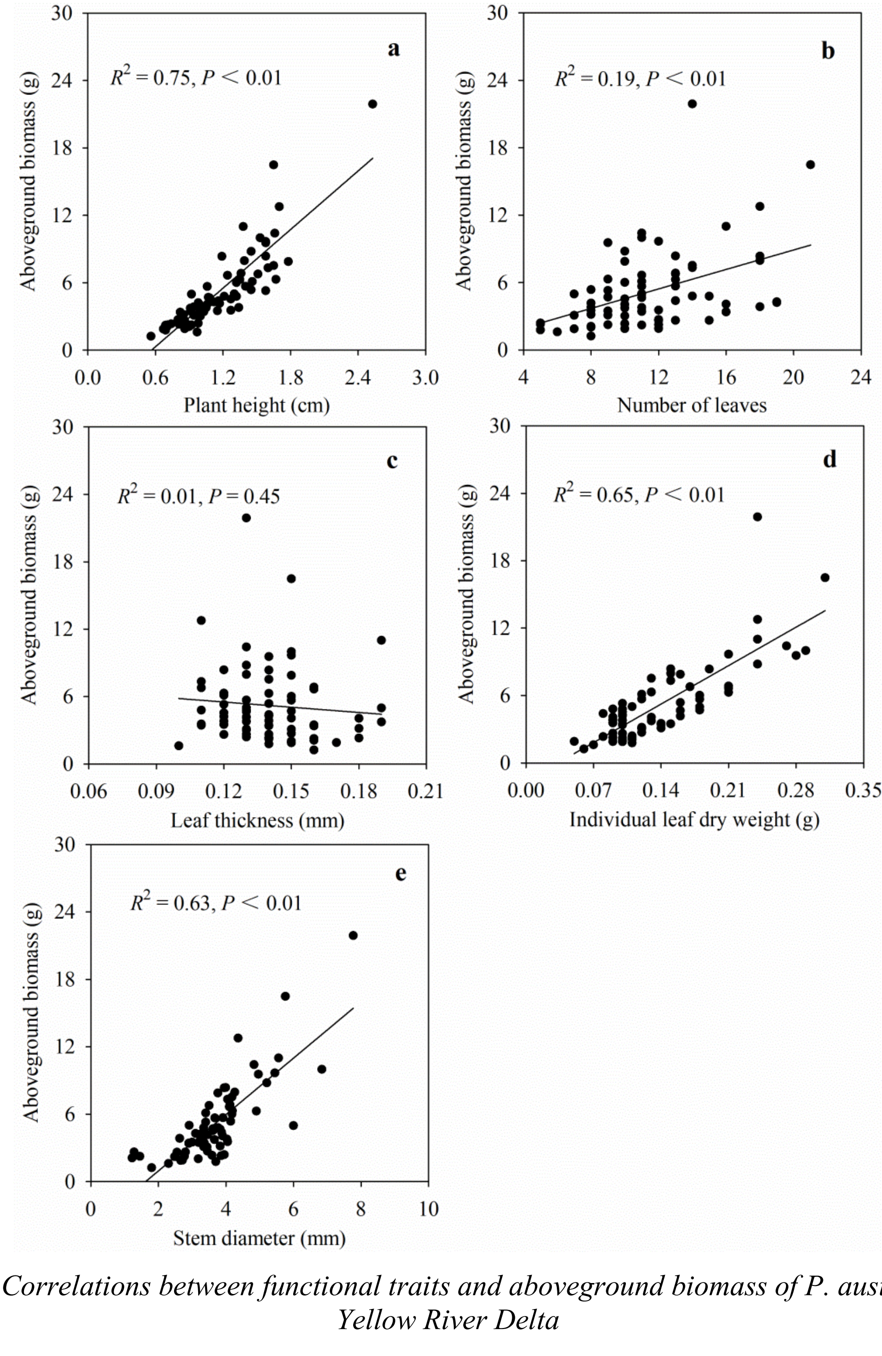

Figure 3. *Correlations between functional traits and aboveground biomass of P. australis in the Yellow River Delta*

Adaptation of plants to environmental changes is not only observed in changes in a single functional trait. There are also correlations between the functional traits, such as

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trade-offs and coordination (Yin et al., 2019). Additionally, quantifying the relationships between functional traits is one of the most important aspects of plant functional ecology (He et al., 2006). In this study, plant height showed a significant negative correlation with leaf thickness. In contrast, plant height was significantly and positively correlated with number of leaves, individual leaf dry weight and stem diameter. This reflects a trade-off or coordination between plant size and leaf traits. Leaf thickness is a morphological trait that reflects the adaptation of plants to their environment, which affects how leaves store and use water (Vile et al., 2005). Leaves are thicker and plant growth is inhibited under water stressed conditions. However, plants grow faster under humid conditions. In order to capture more light, leaves are relatively thin and large in humid environment. Thus, a trade-off between plant height and leaf thickness was observed, and it is a strategy for plants to adapt to environmental changes. Moreover, a significant positive correlation was found between plant height and individual leaf dry weight, indicating there is coordination between plant size and leaf dry matter content. Similar findings have been reported by previous studies that found plant height and leaf dry weight were significantly positively correlated (Chen et al., 2023; Chai, 2008).

Biomass allocation reflects the adaptive strategy of plants to adapt to environmental changes (Biehl et al., 2023). Biomass allocation pattern varies in different organs, which due to changes in environmental factors such as light, nutrients and water (Liu and Su, 2016). For example, Du et al. (2020) showed that the allocation to stem biomass is higher than that of leaf biomass in Hexi Corridor, China. However, a previous study found that the allocation to stem biomass is less than to leaf biomass in the Songnen plains of China (Yang and Li, 2003). A great biomass allocated to stem can ensure plants to grow high (Modrzynski et al., 2015). In this study, the allocation to stem biomass is higher in river bank than that in grassland. It is mainly because soil water content varies in different habitats in the study area, and soil water content was high in river bank compared to grassland. The more allocation of stem biomass helps *P. australis* to compete for more space and light resources (Yang and Li, 2003). Moreover, *P. australis* allocated more biomass to leaf in grassland than that in river bank, which supported the optimal partitioning theory (Iyer and Walters, 2010). *P. australis* prioritize the allocation of biomass to the organ that utilizes the resource most restricting its growth, and the leaves have the most priority under low soil water condition. Leaf biomass of *P. australis* showed no significant difference between grassland and river bank, it is mainly due to changes in leaf thickness and leaf number. *P. australis* with less and thick leaves in grassland, while the reversed result was observed in river bank.

Aboveground biomass is an important indicator of ecosystem productivity (Ding and Zang, 2021). Changes in aboveground biomass can be predicted by plant functional traits (Pontes et al., 2007). In this study, except for leaf thickness, number of leaves, stem diameter, individual leaf dry weight and plant height were significantly and positively correlated with aboveground biomass. It suggests that the influence of different functional traits on aboveground biomass varied, and plants can affect ecosystem function through a combination of function traits. The relationships between plant height, number of leaves, stem diameter and aboveground biomass is in consistent with Li et al. (2017), who reported that plant height, number of leaves, stem diameter were significantly and positively related to aboveground biomass. Moreover, plant height explained most of the aboveground biomass in this study, suggesting that functional traits associated with competitive ability (i.e. plant size) were key functional traits that affected aboveground biomass.

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Conclusions

The adaptation of *P. australis* to habitat changes mainly through key functional traits in the Yellow River Delta. *P. australis* adopts a conservative strategy in grassland, such as with small plant size, less number of leaves and thicker leaves. It can improve the ability of *P. australis* to utilize resources, and further enhance its adaptability to harsh environments. *P. australis* adjusts biomass allocation to adapt to habitat changes. In order to compete for more light and space, it invests more biomass to the stem in river bank. Importantly, the combination of functional traits helps *P. australis* well to adapt to habitat changes, and there is a trade-off between plant height and leaf thickness. Aboveground biomass is affected by functional traits, and key functional traits such as plant height can well reflect variation in aboveground biomass.

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Conflict of interests. The authors declare no conflict of interests.

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