RHIZOME DYNAMICS AND AGE STRUCTURE OF *PHRAGMITES AUSTRALIS* POPULATIONS IN HETEROGENEOUS HABITATS OF NORTHEAST GRASSLANDS IN CHINA

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Abstract

Rhizomes are important for both reproductive organs and nutrient storage; thus, rhizomes have the functions for vegetative propagation and expansion of population as well as for physiological integration of clonal family channels. Using soil samples excavated from Northeast meadow steppe, five rhizomes of single dominant rhizome species (*Phragmites australis*) from meadow soil habitat and saline-alkali soil habitat were investigated and compared within a growing season on growing period length, biomass and dry storage with the amount of seasonal variation. The results showed that: rhizome length, biomass and dry storage of the species from the meadow soil habitat are significantly greater than the species from the saline-alkali soil habitat. Over the entire growth period, rhizome length gradually increased to a maximum at the 3rd, while at the 6th the smallest rhizome biomass occurred. Dry material storage, after an initial decline, increased to the largest biomass at the 3rd and was the minimum at the 1st year. Maximum dry matter storage occurred at the 5th, and was the lowest for the 1st year. Among age classes, the relationship was significant between rhizome length and age spectrum month fitting a straight line. A quadratic function was found to fit the relationship between amount of months and the biomass of the age spectrum. Further, there is also a significant relationship between the five growth stages and age class of the rhizome dry storage defined by quadratic functions. Rhizome length, biomass and dry storage and soil moisture, soil organic matter, and soil available nitrogen content were significantly positively correlated with soil pH, while soil available phosphorus content was significantly negatively correlated with soil pH. All of the rhizome dynamics have the same seasonal variation; the rhizome life span of different age classes is closely related to nutrient output depletion and nutrient input compensation. Over the entire growth period, the impact of habitat heterogeneity on rhizome age structure dynamics is evident with the relatively stable differences.

Key words: *Phragmaites australis*; Rhizome; Age spectrum; Meadow soil; Saline-alkali soil.

Introduction

Rhizomes of plants are not only important for reproductive organs, but also important for nutrient storage organs; therefore, they have other functions in addition to that of vegetative propagation of roots and expanding populations (Klimes *et al*., 1999; Asaeda *et al*., 2006a; Yang *et al*., 1998), as well as that of the physiological integration of clonal family channels (Yang *et al*., 2005). Rhizomes are persistent in the soil; their growth and breeding require large amounts of nutrient. They are not only associated with the consumption and nutrient output, but also closely related to the nutrient storage ability (Hong *et al*., 2014; Yang *et al*., 1997; Li & Yang, 2004). Different ecological environments or phenomena, such as flooding, grazing, mowing, and leisure use will all have some impact on rhizomes (Hong *et al*., 2014; Li & Yang, 2004). In coastal wetlands invaded by reeds, rhizomes plunge deeper into the soil to absorb water and nutrients, in order to increase their competitiveness for survival (Moore *et al*., 2012). Low nutrient supply adversely affects rhizome expansion space, and high nutrient supply is beneficial to roots and branches (Dong *et al*., 1997), while high moisture and nutrient supply are conducive to the accumulation of sand-whip rhizome growth and biomass, having no significant effect on the corresponding rhizome internode length (Dong & Alaten, 1999).

For perennials, in addition to the population, measurement of the age in years can obtain the information of productivity, sexual and asexual reproduction and other life activities, which can objectively reflect the life status of each age class member, as well as the information of the ecological life (Yang *et al*., 2001). Therefore, the study of clonal plant population age structures not only can objectively estimate the population dynamics, but also can reveal the growth and reproductive strategies of clonal plants, revealing the secret of longevity and length of plant life (Meng *et al*., 2011).

Reed (*Phragmites australis*) is a typical long rhizome clonal plant, with natural populations relying mainly on nutritional supplements to promote propagation (Yang *et al*., 1998). *P. australis* is a widely distributed species in the world (Chen & Jia, 2002), with a wide range of ecological adaptability, and can be found in wetlands, calcinated/basic soil, saline-alkali soil, meadow soil and sandy soils. Although there has been a considerable amount of research undertaken on reed (Engloner, 2009), a quantitative and detailed study of the life cycle and fecundity of reed rhizomes, especially for heterogeneous rhizome length, biomass and seasonal variation of dry storage habitats is lacking, and a systematic study of plant life cycle strategies of adaptation mechanisms has yet to be thoroughly explored.

P. australis populations of two habitats, Northeast meadow steppe meadow soil and saline-alkali soil, were studied for five growth periods, comparing seasonal variations in different age classes, rhizome length, biomass and dry storage, and populations, to determine the basis of rhizome longevity and age classes, rhizome material storage and consumption. This research will also provide a scientific basis (Yang *et al.*, 2008) for further studies on rhizome longevity and reproductive adaptation mechanisms.

Materials and Methods

Site description and sample description: Sampling experiments were performed from June to October 2012, in the northern part of the buffer zone in the Songnen Plain, Zhalong National Nature Reserve (47°20'45" N, 123°59'22" E). This location is in a region of temperate continental monsoon climate, with average annual temperature of 3.5°C, average annual precipitation of 402.7 mm, average annual evaporation of 1506.2 mm, accumulated temperature is 2 600 ~ 3 000°C, and average frost-free period of 128 d (Anon., 1997). Plots located in a *L. chinensis* (*Leymus chinenis*) meadow, were designated as meadow soil plots (H1). In this location, the soil is meadow soil with relatively low-lying terrain, and the annual dry season has 7-8 months without water or water for only a very short time. Thus, there can often form the local micro-topographic centers of *P. communis* within *L. chinensis,* containing tens to hundreds of square meters for a single dominant species of *P. communis* reed plants with average height of 140-160 cm density of 320-350 plants m^{-2}. Other lower abundant associated communities include Siberia Polygonum (*Polygonum sibiricum* Laxm), needle rush (*Eleocharis congesta* D.Don ssp. *Japonica* (Miq.) *T. Koyama*), Korea Puccinellia (*Puccinellia chinampoensis*), flat straw bulrush (*Scirpus planiculmis* Fr. Schmidt), and Potentilla (*Potentilla aiscolor* Bunge).

For the saline-alkaline soil plots (designated as H2), the soil is saline-alkaline, with no natural water from precipitation throughout the year. The soil surface has been completely eroded, with clear saline spots, soil compaction and poor permeability. The reeds are mostly scattered in these plots; some alkali spots may contain a single dominant species population of reed with reed plant heights of 120-140 cm and a density of 280-320 plants • m^{-2}, possibly together with a lower abundance species, such as Suaeda (*Suaeda corniculata*), alkali kochia (*Kochia sieveriana*), and wild barley (*Hordeum brevisubulatum*). Every year in early August, the fields with the residual stems dormant, are mowed using hay mowing equipment.

Methods: Rhizomes were sampled from populations of the single dominant species *P. communis* of five different growth periods: the early vegetative growth stage, the vigorous vegetative growth period, the early reproductive growth period, the prolific reproductive growth period, and the period of dormancy. Triplicate sets of samples were obtained using sampling plots of 1 m^3 size, digging up the complete rhizome system, to the oldest rhizomes of the death point (Yang *et al.*, 2005). The rhizomes were divided into age classes according to their life limit.

Rhizomes formed in the current year were designated as the first (one) age-class rhizomes, those rhizomes formed in the previous years, were designated as the second (two) age-class rhizomes, while the crop plants or withered rhizomes from the previous year being directly connected to the rhizomes of the year were designated as third (three) age-class rhizomes (Yang *et al.*, 1998). To determine the age class of reed rhizomes, some apparent differences were utilized, including the darkening color occurring with increasing age and the rhizome diameter being formed over different years. For each age class of rhizomes, the cumulative length was measured, and the samples were then dried to constant weight at 80℃, which is defined as the biomass content of the rhizomes. Every sampling point was drilled to a soil sampling depth of 1 m, and after mixing the samples into bags, they were taken back to the lab. After sifting the samples, soil moisture content was measured by the dry weight method. The soil pH was determined by the potentiometric method, while organic matter content was measured using potassium dichromate and heating. Available nitrogen content was measured by the alkaline hydrolysis/diffusion method, while available phosphorous content was determined by molybdenum-antimony colorimetry (Lu, 2000; Luo *et al.*, 2002).

Data processing: Visual observations of rhizome length, and biomass were performed on storage root dry matter for 100 cm unit length of rhizome biomass. Age class, rhizome length, and the total length of the observed biomass, represent the proportion of the total biomass of the age spectrum. Microsoft Excel 2007 was used to handle all the data and graphing. SPSS19.0 statistical software was used for data analysis, to determine the correlations between rhizome length, biomass, and the proportion of sampling month and rhizome dry storage and age class which were used in the fittings equation and to perform significance tests. The T- test method was used to analyze the differences between two habitats, and the differences of different months were determined using analysis of variance. The Pearson correlation analysis method was used for the over sampling of the two habitats and over sampling of rhizomes. Dynamic numerical indicators of soil physical and chemical characteristics were obtained for analysis. The data in the charts are presented as the mean ± standard deviation.

Results

Comparisons of rhizome length: In Fig. 1A, for the time period of 6-10 months, the rhizome length of native meadow habitat was significantly higher than the length from the saline native habitat. For the two habitats, the rhizome length gradually increased, with no significant difference between July and August. For the two habitats, six years was the highest age for the reed rhizomes (Fig. 1B); within the plots, reed rhizomes can survive for up to six years. Rhizome length according to age class followed the descending order: 3a> 2a> 4a> 1a> 5a> 6a. For the rhizomes from saline-alkali soil samples 1a and 5a, there was no significant difference. The longest rhizomes were from 3a, while those from 6a had the shortest length.

Between each age class of rhizomes from the two habitats, those from meadow soil were generally higher than those from the saline-alkali soil, except for those from 5a and 6a, for which there was no significant difference (NSD) between these two age classes.

The rhizome length between age classes had an optimal correlation with the month as the linear relationship was: $y = a + bx$ (Table 1), where: y is rhizome length, x is the number of months, a is the intercept, and b is the slope. For equation 1-3a, b is positive, so that the slope decreased with the increasing of rhizome length; for equation 6a, b is negative, indicating that with the decreasing of rhizome length, the slope decreased. For reed rhizome length throughout the growth period, 1a had the maximum rate of increase, 3a increased the minimum, 4a was reduced to the maximum rate, and 6a was reduced to a minimum.

Age structure and rhizome length: In Fig. 2, the proportion of rhizome length gradually increased in 1-3a, while the proportion gradually decreased in 4-6a. The proportion of native meadow habitats for 1a-3a are

significantly higher than those from saline-alkali soil, but significantly lower than the saline-alkali soil for 4a-6a. The highest proportion is from 3a, with minimum proportion at 6a. Rhizomes from the two habitats after the fourth year started to die; therefore, they reached the highest proportion at 3a and there was only a small proportion at 6a.

From Table 2, Equation 1a, for 4a-6a, the relationship between rhizome length age spectrum and month was linear for $y = a + bx$ (Table 2), where: y is the length of rhizome age spectrum, x is the month, a is the intercept, and b is the slope of the line. For 1a native meadow habitat, equation b was positive, while for other age classes b was negative. For saline native habitat, the equation was positive for 1a-3a, for 4a-6a, b was negative. For meadow soil 2a and saline-alkali soil 3a, there was no significant linear relationship between rhizome length and the month of the age spectrum. A common feature was the significant increase in the proportion of rhizome length for 1a, while the proportion for 2a-3a was relatively stable, and for 4a-6a the proportion was significantly reduced.
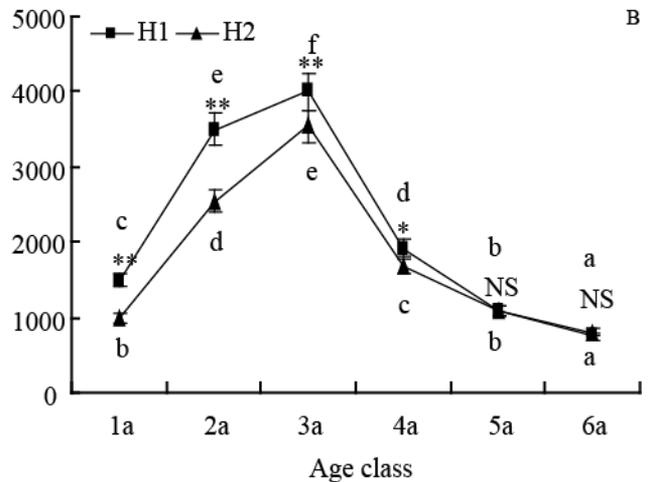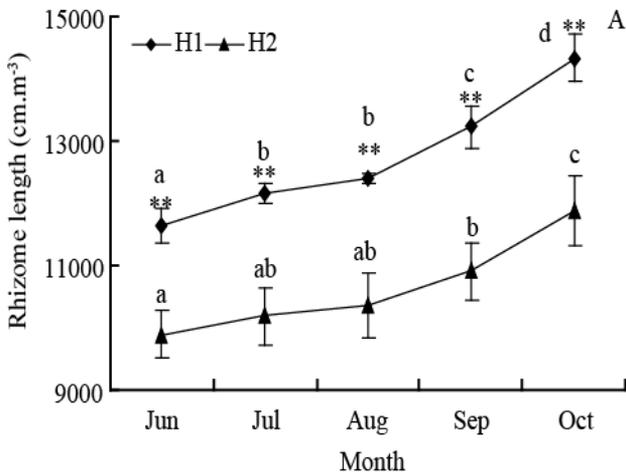
Fig. 1 Changes of rhizome length of *Phragmites australis* populations in heterogeneous habitats
H1, Meadow soil; H2, Saline-alkali soil. NS ($p > 0.05$); *$p<0.05$; **$p<0.01$. Different letters above and below particular points represent a significant difference between different months and different age classes at the 0.05 level.
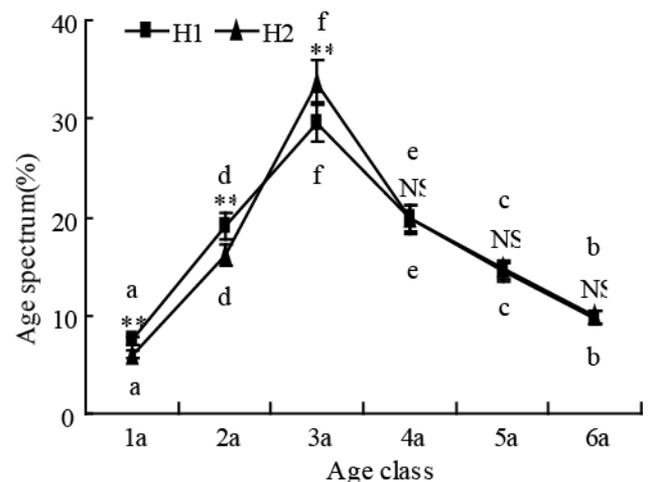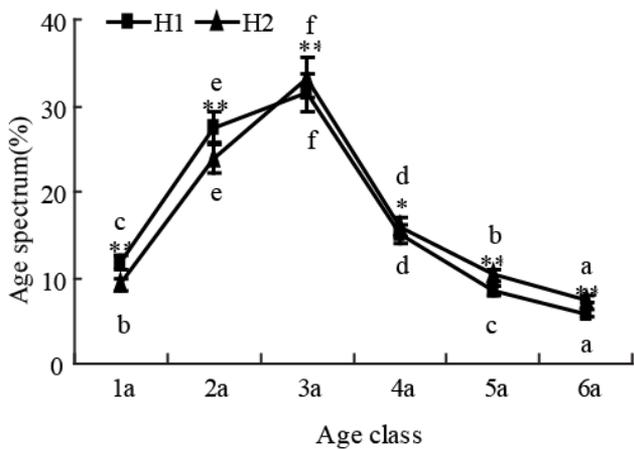
Fig. 2. Age spectrum of rhizome length of *Phragmites australis* populations in heterogeneous habitats. The description of the symbols and letters above and below data points is the same as that of Fig. 1.

Fig. 4. Age spectrum of rhizome biomass of *Phragmites australis* populations in heterogeneous habitats.
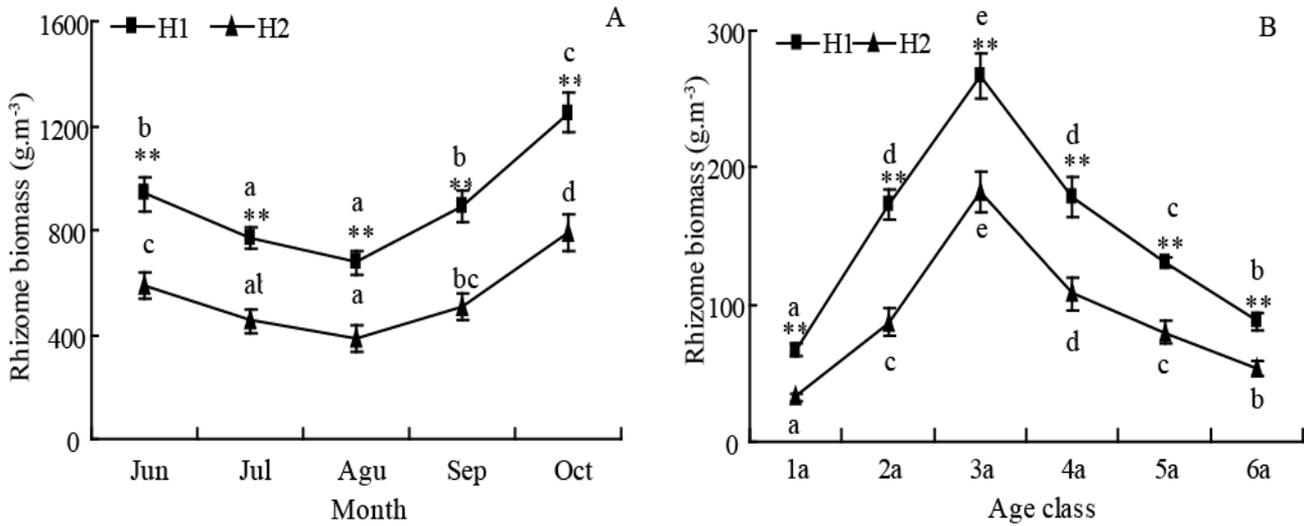
Fig. 3. Changes of rhizome biomass of *Phragmites australis* populations in heterogeneous habitats.
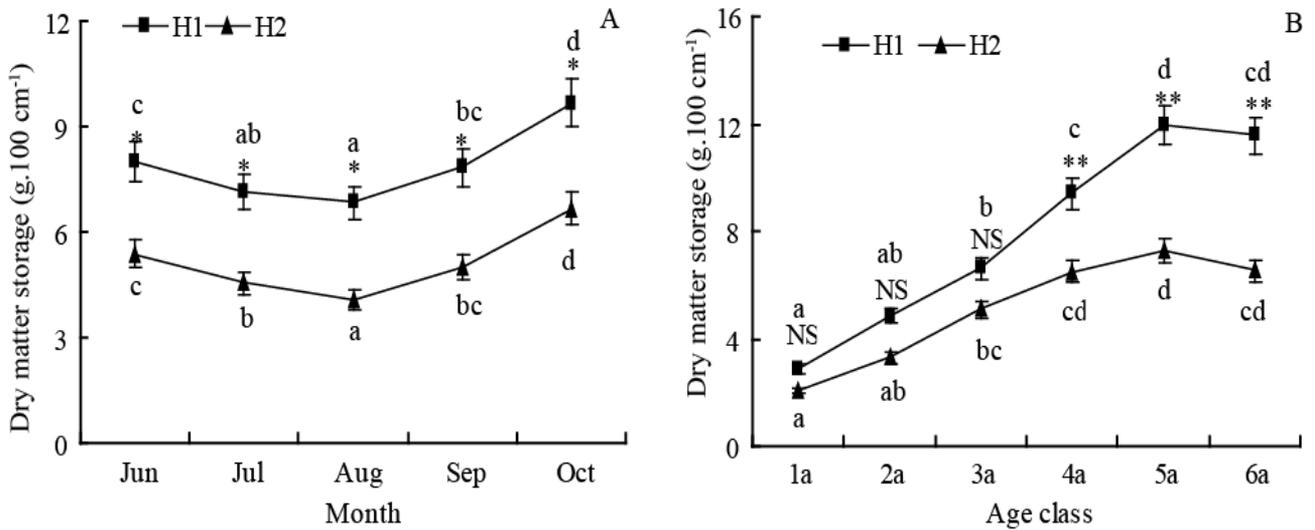
Fig. 5. Changes of rhizome dry matter storage of *Phragmites australis* populations in heterogeneous habitats.

Table 1. Simulated equations and significance tests between the rhizome length (*y*) and month (*x*) for
***Phragmites australis* population in heterogeneous habitats.**

Age class	H1			H2		
	Equation	r	P	Equation	r	P
1a	y=-4830.7 +790.8x	0.986	<0.05	y=-3597.7 + 571.9x	0.980	<0.05
2a	y= 2121.9 +172.6x	0.992	<0.05	y=1175.7 + 171.7x	0.948	<0.05
3a	y=3154.0 +106.2x	0.981	<0.05	y=2275.1 + 157.7x	0.984	<0.05
4a	y=3766.6 - 231.8x	0.982	<0.05	y=3626.3 - 242.5x	0.993	<0.05
5a	y =2111.9 - 127.7x	0.963	<0.05	y =2074.4 - 122.3x	0.983	<0.05
6a	y=1265.5 - 64.8 x	0.916	<0.05	y=1356.9 - 69.5 x	0.990	<0.05

Table 2. Simulated equations and significance tests between the age spectrum of rhizome length (*y*) and month
(*x*) of *Phragmites australis* populations in heterogeneous habitats.

Age class	H1			H2		
	Equation	r	P	Equation	r	P
1a	y=-33.1 + 5.5x	0.995	<0.05	y=-30.3 + 4.9x	0.990	<0.05
2a	y= 27.6 - 0.01x	0.022	>0.05	y=19.5 + 0.5x	0.953	<0.05
3a	y=37.4 - 0.7x	0.928	<0.05	y=32.9 + 0.03x	0.144	>0.05
4a	y=35.7 - 2.6x	0.993	<0.05	y=39.5 - 2.9x	0.994	<0.05
5a	y =20.1 - 1.4x	0.983	<0.05	y =23.0 - 1.6x	0.987	<0.05
6a	y=12.4 - 0.8 x	0.958	<0.05	y=15.3 - 0.9x	0.993	<0.05

Table 3. Simulated equations and significance tests between the rhizome biomass (*y*) and month (*x*) of *Phragmites australis* populations in heterogeneous habitats.

Age class	H1			H2		
	Equation	r	*P*	Equation	r	*P*
1a	$y=14.8x^2-192.2x + 626.9$	0.988	<0.05	$y=10.0x^2-135.8x + 457.3$	0.992	<0.05
2a	$y= 25.4x^2-371.4x + 1465.2$	0.997	<0.05	$y=20.8x^2-309.2x + 1186.8$	0.993	<0.05
3a	$y=35.3x^2-522.6x + 2122.2$	0.989	<0.05	$y=29.0x^2-434.1x + 1739.7$	0.994	<0.05
4a	$y=11.3x^2-198.5x + 1023.4$	0.987	<0.05	$y=8.1x^2-141.8x + 710.9$	0.991	<0.05
5a	$y =5.9x^2-109.5x + 616.9$	0.952	<0.05	$y =4.2x^2-77.1x + 416.6$	0.997	<0.05
6a	$y=4.5x^2-86.4x + 483.4$	0.987	<0.05	$y=0.9x^2-25.0x + 194.9$	0.999	<0.05

Table 4. Simulated equations and significance tests between age spectra of rhizome biomass (*y*) and month (*x*) of *Phragmites australis* populations in heterogeneous habitats.

Age class	H1			H2		
	Equation	r	*P*	Equation	r	*P*
1a	$y=3.8x - 23.4$	0.982	<0.05	$y=3.4x - 21.8$	0.962	<0.05
2a	$y= 2.0x + 2.2$	0.942	<0.05	$y=2.5x - 4.6$	0.878	<0.05
3a	$y=1.9x + 13.8$	0.936	<0.05	$y=2.3x + 14.1$	0.885	<0.05
4a	$y=46.0 - 3.2x$	0.954	<0.05	$y=47.9 - 3.4x$	0.948	<0.05
5a	$y =34.4 - 2.4x$	0.942	<0.05	$y =35.0 - 2.4x$	0.930	<0.05
6a	$y=26.9 - 2.1x$	0.952	<0.05	$y=29.4 - 2.3x$	0.899	<0.05

Comparison of rhizome biomass: The changing of rhizome biomass from June to October was showed in Fig. 3A. The native meadow habitat rhizome biomass was significantly higher than that of the saline native habitat. The rhizome biomass of the two habitats increased after an initial reduction, with the lowest biomass in August and the highest amount in October for both habitats. Between the different age classes, for each habitat, (Fig. 3B) the rhizome biomass had a maximum value for 3a, and a minimum for 1a. Between the two habitats, meadow soil biomass from each age class was significantly higher than that from the saline-alkali soil.

Among the age classes of rhizome biomass, there was generally a relationship between rhizome biomass and month as defined by the quadratic function $y = a + bx + cx^2$ (Table 3), where: y is the rhizome biomass, x is the month, a is the intercept, b is slope for the first power of x, and c is the slope of the second power. Parameters b and c were positive or negative, reflecting the direction of an upwards or downwards curve, respectively. The size of the absolute value was reflected in the change in speed rate. For the six age classes, all had negative values of b, while positive values of c. For 1a-3a, the absolute value gradually increased, while for 4a-6a, the absolute value of the biomass decreased .Over the entire growing period of the reed rhizomes, both habitats exhibited the same variation. For 3a, the rhizome biomass increasing or decreasing rate was the highest, while the biomass of the roots of 6a was minimized.

Rhizome biomass age structure: As shown in Fig. 4, for 1a-3a, the rhizome biomass proportion gradually increased, while for 4a-6a it gradually decreased. The biomass of the native meadow habitat for 1a-2a was significantly higher than the proportion in the native saline environment, but significantly lower than that of the saline 3a native habitat. For age classes 4a-6a, there was no significant difference between habitats. The highest proportion of rhizomes occurred at 3a, while the 1a roots had the lowest proportion of rhizomes.

For the biomass age classes of the rhizomes, the relationship between biomass age spectrum and month obeyed the linear relationship $y = a + bx$ (Table 4), where: y is the rhizome biomass age spectrum, x is the month, a is the intercept, and b is the slope. For the two different habitats, for age classes 1a-3a, b was positive, and rhizome biomass proportion increased with seasonal changes. For 4a-6a, b was negative, and the rhizome biomass proportion decreases with seasonal changes. For 1a, the rhizome biomass proportion of the rate increased to the maximum, while 3a had the smallest roots. The reducing rate of 4a rhizome biomass proportion was the maximum rate, while that of 6a rhizomes was the minimum rate.

Reed rhizome dry storage population change: As shown in Fig. 5A, from June to October, rhizome dry matter storage form the native meadow habitat was significantly higher than that from the saline native habitat. For the two habitats, rhizome dry storage reduced for the first three months, and then increased. The lowest values for both habitats were in August, and the highest occured in October. For age class, 1a had the lowest rhizome dry storage, while it gradually increased from 1a-5a, with the highest value of 5a, while 6a experienced a decline from 5a. Age class rhizomes dry storage for the meadow habitat was higher than that for the saline native habitat. For 1a-3a there was no significant difference between the two habitats, while there were significant differences between them from 4a to 6a.

For the two habitats at different growth stages, the relationship between rhizome dry matter storage reserve and age class had better compliance with a quadratic function as defined by $y = a + bx + cx^2$ (Table 5), where: y is the dry storage content of the roots; x is age class; a is the intercept; b is the slope of the single power of x, and c is the slope of the second power of x. Parameters b and c represented the positive or negative direction of the curve, upwards or downwards, respectively, which was reflected in the size of the absolute value of the rate of changing speed. In Table 5, 5 b values were representative of a positive growth period, while all c values were negative. For 1a-3a the absolute value decreased, while for 4a-6a the absolute value gradually increased in biomass. Over the entire reed growth period, the rhizomes showed the same variation. In each age class, the increasing or decreasing rates of rhizomes dry storage were the maximum in October and minimum in August.

Discussion

Rhizome growth: Reeds have typical long clonal plant roots, so the length of the roots contains important information concerning plant growth and survival (Yang *et al.*, 1998). Rhizome length for meadow soil and saline soil increased to annual values of 2, 691 cm and 2, 109 cm, respectively. For 1a, rhizome formation from July to October had lengths of 3 334 cm and 2 306 cm, respectively. Meanwhile, for 2a and 3a, roots had only a small increase in length over the whole growth period, while for 4a, rhizome length significantly reduced, thereby also reduced slowly for 5a and 6a. Therefore, the increase of rhizomes length in the plots throughout the growing period is primarily due to gradual 1a rhizome formation and elongation. For the various growth stages, 1a rhizomes are the youngest in grade of growth stage; 2a, 3a roots maintain a relatively stable stage, while 4a-6a rhizomes are at the aging stage of death. For age classes, rhizome length and proportion are in the descending order: 3a> 2a> 4a> 1a> 5a> 6a, and there are significant differences between age classes. If a change in the proportion of each age class has a dynamic population age composition for the year, then for the entire growth period, reed rhizome 1a population had the greatest increasing proportion (23% increasing in meadow soils, 19% increasing in saline soil). The 2a proportion of the rhizomes was the most stable (meadow soil accounts for 26-28%, saline soil accounts for 22-25%); the 3a proportion roots are more stable (meadow soil accounts for 29-32%; saline soil accounts for 32-33%), and in 4a-6a, rhizomes gradually reduced in proportion (meadow soils decreased by 19%, saline soil decreased by 22%). Therefore, the population of young grade reed rhizomes grows rapidly in favor of populations occupying or extending horizontally into niche spaces [19], forming a relatively stable age class structure in favor of stable roots. Year after year, the rhizome level gradually reduced and eventually disappeared because of death and decay.

Rhizome nutrient storage: Rhizome biomass can characterize the nutrient storage of roots (Yang *et al.*, 1998). In the early growing season, from June to July, with small reed leaves, photosynthesis is weak and the ground plant must consume nutrients underground through rhizomes for growth. Especially in August,

nutrient consumption for reproductive growth is the largest. In the late growing season from September to October, the reed population will have ground transport of nutrients to the roots (Asaeda *et al.*, 2006b; Karunaratne *et al.*, 2004), and therefore, for the whole growth period, the reed rhizome biomass population will decrease after first showing of an increasing trend. The lowest reproductive growth occurs in August, and the highest end of growing season occurs in October. With increasing biomass accumulation over many years, although the roots are aging, the rhizome bud germination and growth is bound to consume the old rhizome nutrients (Yang *et al.*, 2008). There is a considerable loss of length, and the biomass from 4a level increases with age after a significant decline. Rhizomes had the largest proportion of biomass in 3a, and the smallest proportion in 1a. From 1a-3a, the biomass proportion gradually increased, while over 4a-6a, the proportion gradually reduced. If the number of unit volume deemed vegetative propagation rhizome length, is regarded as the biomass nutrient storage capacity (Yang *et al.*, 2004), the population levels of rhizome biomass for 1a-3a have a rhizome length reduction of 11-14%, while an increase of 11-14% for 4-6a over the rhizome length. Material inputs population aging elongation weak roots level remains at a high level, in order to ensure that aging roots level can still produce rhizomes to supply and update the population (Asaeda *et al.*, 2006).

Rhizome material basis for longevity: Rhizome dry storage is a measure of the main indicators of clonal plant root nutrient storage and consumption (Yang *et al.*, 2008), and it is also the main basis for the determination of rhizome longevity. The physical performance of the storage capacity of short-lived natural roots increases with decreasing age class trend (Li & Yang, 2004; Yang & Zheng, 2000; Yang *et al.*, 1997; Yang *et al.*, 1997). The roots with super compensatory physical storage capacity have more dry matter stored in the late growing season than in the early growing season with its consumption of dry matter (Yang *et al.*, 2008). Since 1a was the year of the newly formed roots, the dry matter storage had a linear upward trend, so that in the sampling survey, it reached the maximum in October. From 2a-5a, the roots dry matter storage dropped after the first increase, but in a sample survey in October, the indicated storage was also significantly higher than in June. From June-August the decline of dry storage substance was considered as consumption, while the increase from August to October in the dry storage of the substance was considered as storage; thus, 1a-5a rhizomes dry storage were present as compensatory storage, while for dry storage for 6a rhizomes over the whole growth period there was a linear downward trend. The 1a reed populations have young grade class roots and rhizomes, super mature rhizomes of the 2a, 3a populations have higher compensation, the smaller class roots of the super-aging 4a and 5a no longer compensate for the roots of 6a. All of these are material transport and storage strategies and tips during the reed nutrition reproductive process.

Rhizomes in response to heterogeneous habitats: In plants, there is often significant heterogeneity in the necessary resources and environmental conditions required for plant growth and reproduction (Dong, 1996a). Environmental heterogeneity is a selective pressure, so that plants can often obtain the necessary resources to create effective ecological adaptation strategies (Dong, 1996b; Dong *et al*., 2002). In reed rhizome locations in soil, soil heterogeneity can affect rhizome elongation, biomass accumulation and dry storage. The two habitats examined in this study have large differences in their soil physical and chemical properties (Table 6). The relationships between rhizome dynamics parameters and soil physical and chemical properties were investigated by means of correlation analysis (Table 7). As shown in Table 7, the rhizome length, root biomass and root storage dry matter are significantly positively correlated with soil moisture content, organic matter, and available nitrogen content, while they are significantly negatively correlated with soil pH and available phosphorus content. For the entire growth period from June to October, the populations per unit volume within reed rhizome length, rhizome biomass and dry storage from meadow soil were significantly higher than those from saline-alkaline soil. The environmental conditions in the former are relatively better than those of the latter, being more conducive to the growth of the roots, ultimately leading to more beneficial nutrient accumulation and storage.

Table 5. Simulated equations and significance tests between dry matter storage of rhizomes (y) and age class (x) of *Phragmites australis* populations in heterogeneous habitats.

Sampling time	H1			H2		
	Equation	r	*P*	Equation	r	*P*
June	$y=-0.264x^2+4.297x-4.089$	0.995	<0.05	$y=-0.353x^2+3.906x-3.637$	0.999	<0.05
July	$y=-0.107x^2+2.382x-0.959$	0.991	<0.05	$y=-0.108x^2+2.025x-0.915$	0.988	<0.05
August	$y=-0.016x^2+1.071x+1.295$	0.966	<0.05	$y=-0.0004x^2+1.121x+0.157$	0.973	<0.05
September	$y=-0.161x^2+2.711x+0.780$	0.960	<0.05	$y=-0.25x^2+2.527x-0.058$	0.942	<0.05
October	$y=-0.449x^2+4.563x+1.543$	0.948	<0.05	$y=-0.526x^2+4.175x-0.726$	0.948	<0.05
Mean	$y=-0.154x^2+3.005x-0.286$	0.983	<0.05	$y=-0.247x^2+2.750x-0.745$	0.983	<0.05

Table 6. Soil physical and chemical characteristics for two habitats.

Month	Habitat	Moisture (%)	pH	Organic matter (g·kg⁻¹)	Available nitrogen (mg·kg⁻¹)	Available phosphorus (mg·kg⁻¹)
June	H1	18.4 ± 2.3a	8.53 ± 0.10b	66.76 ± 2.59a	166.54 ± 5.62a	2.41 ± 0.42b
	H2	13.0 ± 1.4b	10.35 ± 0.32a	29.69 ± 2.06b	95.44 ± 4.78b	7.63 ± 0.48a
July	H1	26.9 ± 3.6a	7.48 ± 0.08b	58.09 ± 4.63a	157.17 ± 3.08a	2.12 ± 0.13b
	H2	16.1 ± 2.6b	10.07 ± 0.14a	24.17 ± 3.56/b	84.39 ± 3.22b	6.89 ± 0.23a
August	H1	32.4 ± 3.0a	7.30 ± 0.06b	47.08 ± 1.30a	150.23 ± 5.06a	1.98 ± 0.18b
	H2	22.2 ± 3.8b	9.34 ± 0.20a	16.36 ± 1.34b	83.05 ± 3.48b	6.35 ± 0.16a
September	H1	25.7 ± 0.7a	8.42 ± 0.07b	44.13 ± 2.65a	133.72 ± 8.09a	1.73 ± 0.10b
	H2	18.6 ± 1.9b	10.05 ± 0.20a	14.92 ± 1.45b	74.27 ± 4.69b	6.16 ± 0.29a
October	H1	19.8 ± 1.4a	9.73 ± 0.10/b	37.52 ± 3.47a	122.40 ± 6.86a	1.61 ± 0.04b
	H2	15.4 ± 1.2b	10.94 ± 0.07a	13.33 ± 1.05b	67.84 ± 6.90b	5.68± 0.26a

Table 7. Correlation coefficients between bud bank, bud flow and soil physical and chemical characteristics in two habitats.

Variable	Month	Moisture	pH	Organic matter	Available nitrogen	Available phosphorus
Length	June	0.952**	-0.984**	0.977**	0.981**	-0.907*
	July	0.963**	-0.989**	0.983**	0.977**	-0.944**
	August	0.958**	-0.984**	0.969**	0.972**	-0.941**
	September	0.994**	-0.989**	0.982**	0.988**	-0.910**
	October	0.980**	-0.979**	0.978**	0.993**	-0.933**
Biomass	June	0.952**	-0.979**	0.985**	0.989**	-0.926**
	July	0.973**	-0.985**	0.9994**	0.987**	-0.960**
	August	0.969**	-0.986**	0.979**	0.986**	-0.948**
	September	0.986**	-0.991**	0.991**	0.995**	-0.955**
	October	0.979**	-0.990**	0.989**	0.998**	-0.952**
Dry matter Storage	June	0.827*	-0.979**	0.977**	0.974**	-0.978**
	July	0.913*	-0.980**	0.961**	0.988**	-0.981**
	August	0.867*	-0.981**	0.982**	0.974**	-0.979**
	September	0.955**	-0.986**	0.975**	0.962**	-0.981**
	October	0.878*	-0.973**	0.956**	0.960**	-0.975**

*$p<0.05$; **$p<0.01$.

Plant growth stages are inherent to the rhythm of growth and development, and will also present regular changes from year to year. The observed seasonal volatilities in rhizome length, biomass and dry storage changes are largely determined by genetic factors, but also by inherent species-specific properties that are very difficult to change in normal circumstances. The length and the proportion of the roots and rhizome biomass, the proportion of the month between the roots dry storage and age class were optimally fit to equations used to describe these relationships. At the same time, for both the habitats, the native meadow habitats and the saline habitats, the heterogeneity of the rhizomes and age structure dynamics had a significant impact on the rhizomes. The overall impact caused by the differences over the whole growth period is also relatively stable, reflecting in the fact of a widely distributed species of reed population level divergence embodied in adaptation to its environment. Whether or not the data fitting equations for the growing season information are a true reflection of changes in the fundamental properties of rhizomes which requires further confirmation. In addition, clone of above ground plant is a one-year-old Coorong, the rhizome is endless. The relationship between the underground rhizomes and the above ground plant biomass density requires further study, as does the relationship between the length of the rhizomes of each age class, the biomass and the dry inter-annual variations in the storage material.

Acknowledgements

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