JOURNAL OF
ECOLOGY AND ENVIRONMENT
http://www.jecoenv.org

Research Paper

J. Ecol. Environ. 38(1): 57-65, 2015

Distribution properties of *Phragmites australis* and *Phacelurus latifoilus* in the tidal-flat of Suncheon Bay

Byeong-Mee Min*

Department of Science Education, Dankook University, Yongin 448-701, Korea

Abstract

A natural mixed stand of *Phragmites australis* and *Phacelurus latifolius* was studied to clarify the distribution properties in a microsite in a tidal flat of Suncheon Bay. The height, density, and biomass of the shoots, as well as the biomass of the root system, were monitored for both species along with the altitude on a mound from June 2010 to October 2013. Firstly, the mean height and dry weight of both species were similar during the growth season. However, individual variations of the sizes of plants in the same species were noticeable. Secondly, the density and dry weight per unit area of *P. latifolius* increased, but that of *P. australis* decreased with the altitude on the mound. Thirdly, the root system (rhizomes and roots) of *P. latifolius* was mostly located in the upper layer (up to 20 cm depth), while that of *P. australis* was in the lower layer (over 70 cm depth) of the sediment. The roots of *P. australis* penetrated to the lower parts of the water table, while the roots of *P. latifolius* did not make contact with free water of the sediment. Fourthly, the removal of the shoot in the early growth season led to a visible reduction of biomass in the late growth season. The reduction rate was larger in *P. latifolius* than in *P. australis*. Lastly, in the area where the mound was removed, the density of *P. australis* increased in the first two years (2010-2011) and was highly sustained inthe last two years (2012-2013). However, the density of *P. latifolius* was low, and this plant was distributed at the edge of the mound only.

Key words: altitude, biomass, density, *Phacelurus latifolius*, *Phragmites australis*, root system, sediment, Suncheon Bay, tidal flat

INTRODUCTION

In an ecosystem, a niche overlap gives rise to competition. In a plant community, intra- or interspecific competition for resources usually occurs. Many studies of this theme have been carried out (Aerts 1999, Maina et al. 2002, Kisdi and Geritz 2003, Bittebiere et al. 2012). According to these studies, the root systems compete for nutrients or water, and the shoot systems compete for sunlight (McPhee and Aarssen 2001). Moreover, basedon the game theoretical model, plants growing alone should rapidly grow their roots until the marginal return and the cost of new roots is equal to each other (Gersani et al. 2001). Beside the game model, other diverse models predicting the result of competition between two populations have been proposed (Hara 1993, Damgaard 1998, 2003, Hamidi et al. 2012). These models revealed that the asymmetric competition of shoot systems for sunlight could be estimated based on the plant sizes; but the symmetric one could not (Hara 1992, Nevai and Vance 2007, 2008). The plant competition can also be estimated by non-destructive pin-point data (Damgaard et al. 2009). Because the competition for sunlight forces the plant to invest more energy into the shoot system, the shoot sizes of plants

http://dx.doi.org/10.5141/ecoenv.2015.006

Received 05 January 2014, **Accepted** 31 December 2014

***Corresponding Author**
E-mail: bmeemin@hanmail.net
Tel: +82-31-8005-3843

pISSN: 2287-8327 eISSN: 2288-1220

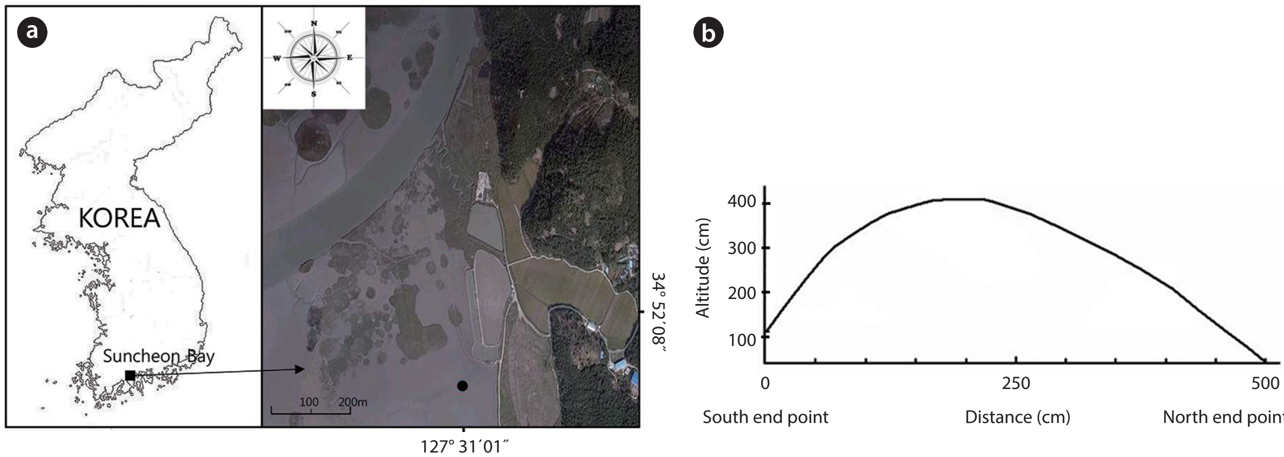

Fig. 1. Location of study area (a) and topography of mound (b).

growing under competition and the ones growing alone are similar (Firbank et al. 1993, Law et al. 1993, Berendse and Möller 2009). For this reason, the competition of root systems between individual plants is defined as a mathematical function of the biomass while the competition of the shoot systems is a function of the density (De Kroon 1993, Just and Nevai 2008). At the same time, microenvironments as well as individual's competitive ability affect the outcome of competition. Therefore, to exactly understand the cause and effect of competition between individuals, abiotic and biotic data are needed. Wetlands or salt marshes show unique physical environments unlike terrestrial environments. Thus, salt concentration and water content greater than those of terrestrial settings can alter a competition regime between the two species (Bertness and Shumway 1993, Dickinson and Miller 1998, Giblin et al. 2010).

In Korea, the area of tidal flat is broad and various studies of the coastal ecosystem have been carried out. Suncheon Bay is one of the coastal ecosystems with large area, high species diversity, and beautiful landscape. On these merits, Suncheon Bay was designated as conservation district by several institutions. The Ramsar Convention designated it as Wetlands of International Importance in 2006; the Cultural Heritage Administration as a Beauty Spot; the Ministry of Ocean and Fisheries as Wetlands Conservation Area (Jang and Cheong 2010, Seo et al. 2012). Moreover, the area in which *P. australis* is distributed is estimated to be about 5.4 km^2 and increases every year (Lee et al. 2008). However, a field survey showed that *P. australis* is being replaced by *P. latifolius* in high altitude. The two species in the same area compete for sunlight, water, and nutrients, and this interspecific competition for the deficient resources forces one species to disappear. In Korea, the *P. australis* (*P. longivalis* or *P. communis*) have been studied extensively (Lee et al. 2008). However, there are only few studies of *P. latifolius* available. Moreover, Suncheon Bay is well-known as a large and beautiful area of *P. australis*.

The aim of this study was to clarify the cause of coexistence of small *P. latifolius* patch in the large *P. australis* patch. For this purpose, mean sizes of plants, densities with altitude, and effects of mound removal were monitored in a mixed stand of *P. australis* and *P. latifolius* for 4 years on a tidal flat in Suncheon Bay.

MATERIALS AND METHODS

The study area was located on a tidal flat in the Suncheon Bay, Nongju-ri, Byeolryang-myeon, Suncheon-city, Jeonnam Province, Korea (34°51′59.04″ N, 127°31′02.26″ E) (Fig. 1). At the time of full moon on a tide table on May 28, 2010 (http:/www.khoa.go.kr/info/tide/YEOSU), a 50-cm ruler was set at the dug area and height was checked at the maximum and the minimum. The highest altitude of the mound was 41 cm from the peripheral natural tidal flat. The tidal flat was inundated at the time of 110 cm tide level. The mound studied over 37 cm in height was not inundated at the time of ordinary full moon. This mound was an artificially constructed tidal flat for using as a saltpan in the past. The mound was divided into three districts as follows. In the first district, three quadrats (50 cm × 50 cm) were randomly located and the shoots of the two species were sampled monthly. The shoots in each unit area were cut to measure the plant size (its height and dry

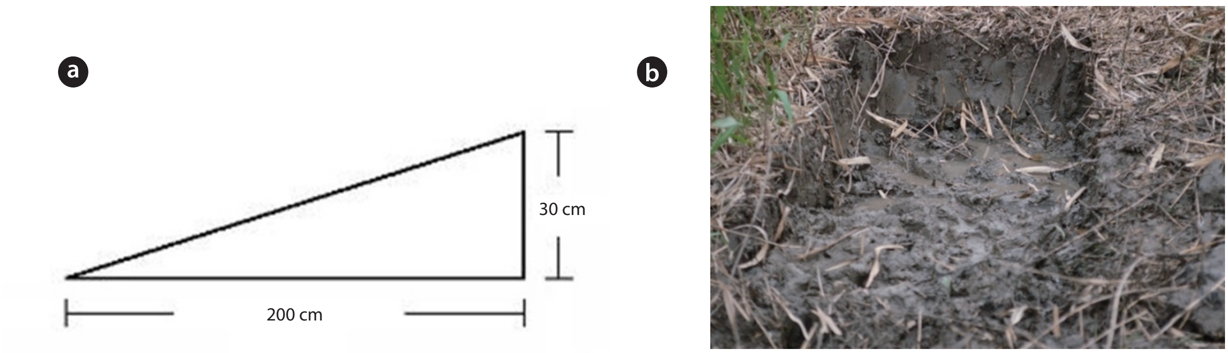

Fig. 2. Schematic diagram of experiment site which mound was removed to the level of tidal flat surface (a) and its photograph (b).

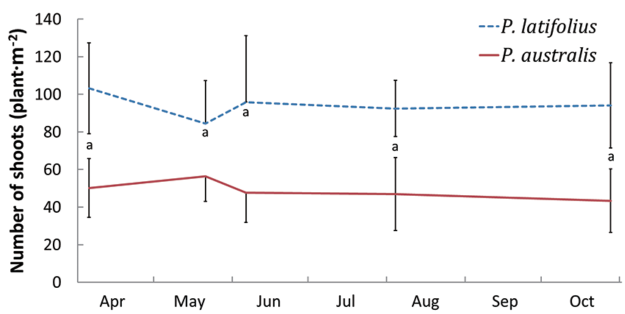

Fig. 3. Change of densities of *Phacelurus latifolius* and *Phragmites australis* along the growth season in 2011 at undisturbed area. Vertical bars represent standard deviation and the letter "a" indicates the 0.01 level of significance.

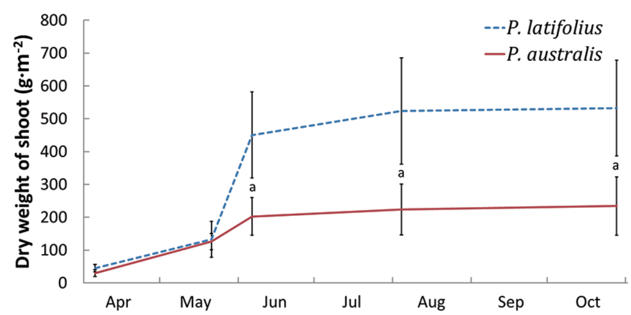

Fig. 4. Change of the dry weight per unit area in *Phacelurus latifolius* and *Phragmites australis* along the growth season in 2011 at undisturbed area. Vertical bars represent standard deviation and the letter "a" indicates the 0.01 level of significance.

weight) during the growth season. To check the biomass of the root system (rhizomes and roots) along the sediment depth, three quadrats (50 cm × 50 cm) were located at the highest site and at the lowest site; root system was dug out in 10 cm interval from the sediment surface to 80 cm in depth of the sediment. In the second district, density and biomass were periodically checked along the altitude of the mound. Permanent quadrat of 1 m × 5 m was located crossing the mound from a starting point in the south to the ending point in the north section. The permanent quadrat was divided into ten 1 m × 50 cm subquadrats along the distance (50 cm interval) from the south starting point. In these subquadrats, all shoots of the two species counted monthly and cut at the end of the growth season annually. Of the ten subquadrats, the first and the last one were the lowest and the fifth one was the highest in altitude. The lowest subquadrat was inundated by seawater at a 110 cm tide level twice a day. The highest subquadrat was at a 410 cm tide level and not inundated by seawater. In the third district, the mound was removed to the level of tidal flat on May 5, 2010, to create the experimental site (Fig. 2). The dimensions of this site were 1 m wide, 1.4 m long, and 30 cm high at the maximum. The shoots of the two species were monitored for 4 years. Height and dry weight of all shoots were measured per plant. The root system was washed by tap water, then dried at 80°C in a dry oven, and weighed.

RESULTS

Size and density of the two species

The mean density of *P. latifolius* was higher than that of *P. australis* during the growth season (Fig. 3). The density difference between the quadrats was large in the early growth season but decreased with time elapsed. The dry weight per unit area ($g{\cdot}m^{-2}$) increased with time elapsed and at the end of the growth season (October) was 532.851 ± 145.642 for *P. latifolius* and 234.023 ± 88.334 for *P. australis* (Fig. 4). However, the growth of both species was mostly over by June. The maximum height (cm)

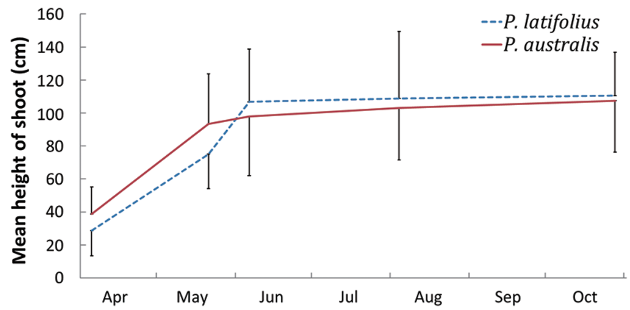

Fig. 5. Change of the heights of *Phacelurus latifolius* and *Phragmites australis* along the growth season in 2011 at undisturbed area. Vertical bars represent standard deviation.

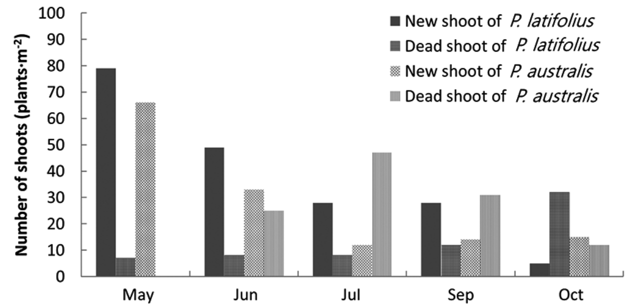

Fig. 8. The number of new shoots of the two species and dead one along the growth season on mound (shoots/subquadrat) in 2011. Subquadrat size is 50 cm x 100 cm.

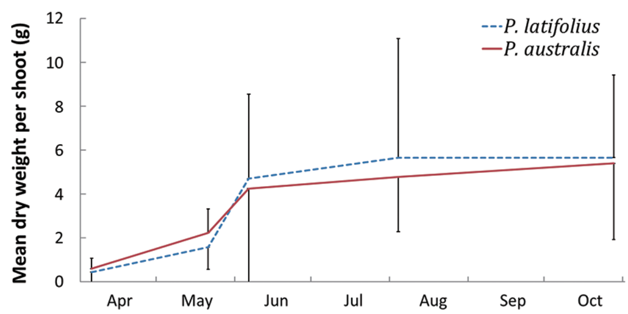

Fig. 6. Change of dry weight per shoot of the two species along the growth season in 2011 at undisturbed area. Vertical bars represent standard deviation.

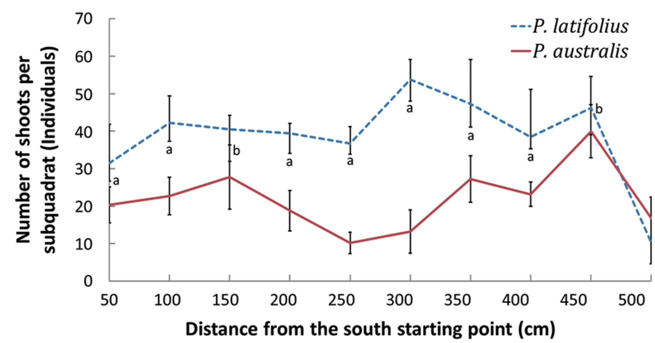

Fig. 9. The number of the two species along the altitude of mound in 2011. Vertical bars represent standard deviation; the letter "a" indicates the 0.01 level of significance and "b" indicates the 0.05 level of significance.

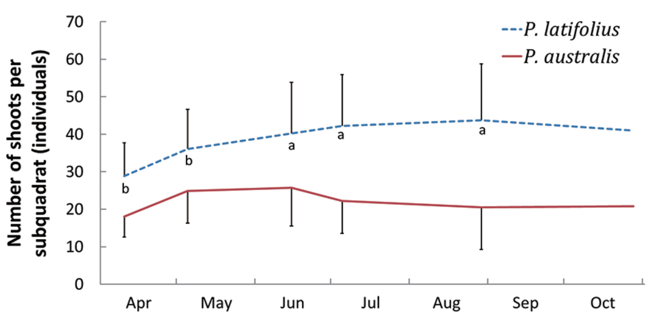

Fig. 7. The number of the two species along the growth season on mound (shoots/subquadrat) in 2011. Subquadrat size is 50 cm x 100 cm. Vertical bars represent standard deviation; the letter "a" indicates the 0.01 level of significance and "b" indicates the 0.05 level of significance.

was 110.56 ± 26.14 for *P. latifolius* and 107.48 ± 31.13 for *P. australis* (Fig. 5). The latter grew faster into late May than the former, but thereafter the growth rate reversed. However, the height difference between the two species was not significant. The dry weight per plant of *P. australis* was larger than that of *P. latifolius* in the early growth season (from March to June). However, at the end of the growth season, the dry weight per plant (g) was similar between the two species (5.659 ± 3.773 for *P. latifolius* and 5.401 ± 3.471 for *P. australis*) (Fig. 6). The differences between the plants were substantial.

Distribution of the two species along the altitude and cutting effect of shoots

The densities of the two species ona mound changed with time elapsed. Maximum density (individuals per 100 cm × 50 cm subquadrat) was 43.7 ± 15.1 on August 29, 2010, for *P. latifolius* and 25.7 ± 10.2 on June 15, 2010, for *P. australis* (Fig. 7). The mean density was higher for *P. latifolius* than for *P. australis* during the entire growth season. The number of shoots alive from the early growth season to the late growth season was larger for *P. latifolius* than for *P. australis*. Moreover, during all growth season, there were more newly germinated or prematurely dead shoots for *P. australis* than those alive. The mean density was higher for *P. latifolius* than for *P. australis* in the most subquadrats (Fig. 8). The density of both species was generally proportioned to the altitude, although inversely to each other, where the density of *P. latifolius* was the highest in the center subquadrats while that of *P. australis* it was the lowest in the same subquadrats (Fig. 9).

The cutting of the shoot sat the end of the growth season affected the next year's biomass of the two species (Table 1). Total densities (shoots/quadrat), mean heights (cm), and total dry weights (g) of *P. latifolius* in the 1 m × 5 m of permanent quadrat were 410, 100.16 ± 31.77, and 2,329.222, respectively, on October 28, 2010; and 421, 100.87 ± 19.65, and 2,226.154, respectively, on October 3, 2011. Those of *P. australis* were 208, 106.11 ± 23.38, and 1,128.728, respectively, on October 28, 2010; and 203, 100.74 ± 24.64, and 983.236, respectively, on October 3, 2011. However, in the third year (October 5, 2012) after all shoots had been cut two years in a row, these values were 413, 81.77 ± 19.61, and 1,374.154, for *P. latifolius*; and 214, 77.74 ± 22.97, and 652.236 for *P. australis*, respectively.

Distribution of root system with the sediment depth

The lowest level that the root systems penetrated was different between the two species (Fig. 10). The root systems of *P. australis* and *P. latifolius* penetrated 70 cm and 40 cm deep, respectively. Moreover, *P. latifolius*' root system at the low altitude distributed 20 cm deep into the sediment. The biomass of the root system of *P. latifolius* was distributed more at the high altitude than at the low one, and it was concentrated in the upper layer of the sediment (0-10 cm). However, the biomass of the root system of *P. australis* was distributed more at the low altitude and did not penetrate more than 30% into the sediment.

Germination of the two species at the new experimental site

In the area where the mound was removed on May 5, 2010, the number of shoots was higher for *P. australis* than for *P. latifolius* (Fig. 11). *Phragmites australis* had 36 plants on June 25, 2010; 62 plants on October 5, 2010; 92 plants on October 15, 2011; 196 plants on September 26, 2012; and 112 plants on October 3, 2013. *Phacelurus latifolius* had 0 plant on June 25, 2010; 0 plants on October 5, 2010; 7 plants on October 15, 2011; 83 plants September 26, 2012; and 117 plants on October3, 2013. The shoots of *P. latifolius* were distributed on the borders of the experimental site from 2010 to 2012, and its rhizome did not make contact with the sediment surface. However, a significant amount of mud particles was being piled up at the experimental site and its altitude rose by about 20 cm by 2013.

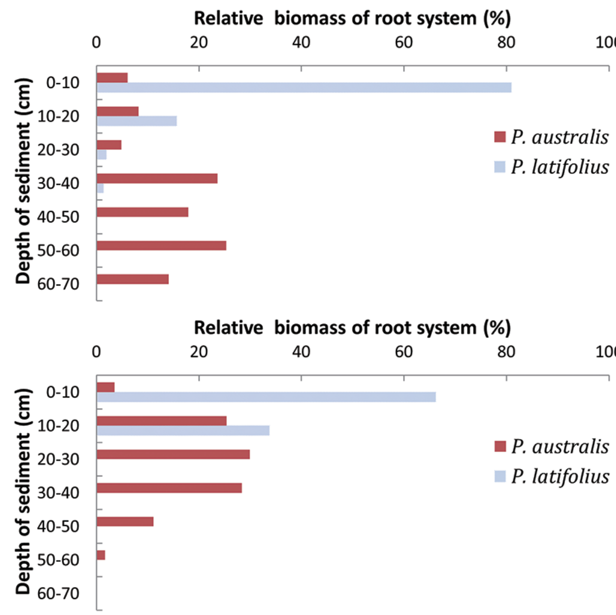

Fig. 10. Relative biomasses of the root system of the two species along the sediment depth (a) at 410 high tide level (30-cm high altitude), (b) at 110 cm high tide level (tidal flat).

Table 1. After cutting, total shoot number, mean height and dry weight of the two species at all permanent quadrats (1 m × 5 m)

Date	*Phacelurus latifolius*			*Phragmites australis*		
	Shoot number	Mean height (cm)	Dry weight (g)	Shoot number	Mean height (cm)	Dry weight (g)
Oct 28, 2010[a]	410	100.16 ± 31.77	2,329.222	208	106.61 ± 23.38	1,128.728
Apr 30,2011[b]	396	19.39 ± 8.04	93.905	176	27.70 ± 9.53	63.596
Jul 4, 2011[c]	377	67.37 ± 21.02	644.072	177	60.29 ± 21.55	243.684
Oct 5, 2012[d]	413	81.77 ± 19.61	1,374.154	214	77.74 ± 22.97	652.236
Oct 3, 2013[e]	421	100.87 ± 19.65	2,226.154	203	100.74 ± 24.64	983.236

[a]October 28, 2010 : the first year's late growth season.
[b]April 30, 2011 : the second year's early growth season.
[c]July 4, 2011 : the second year's middle growth season.
[d]October 5, 2012 : the third year's early growth season.
[e]October 3, 2013 : the third year's late growth season.

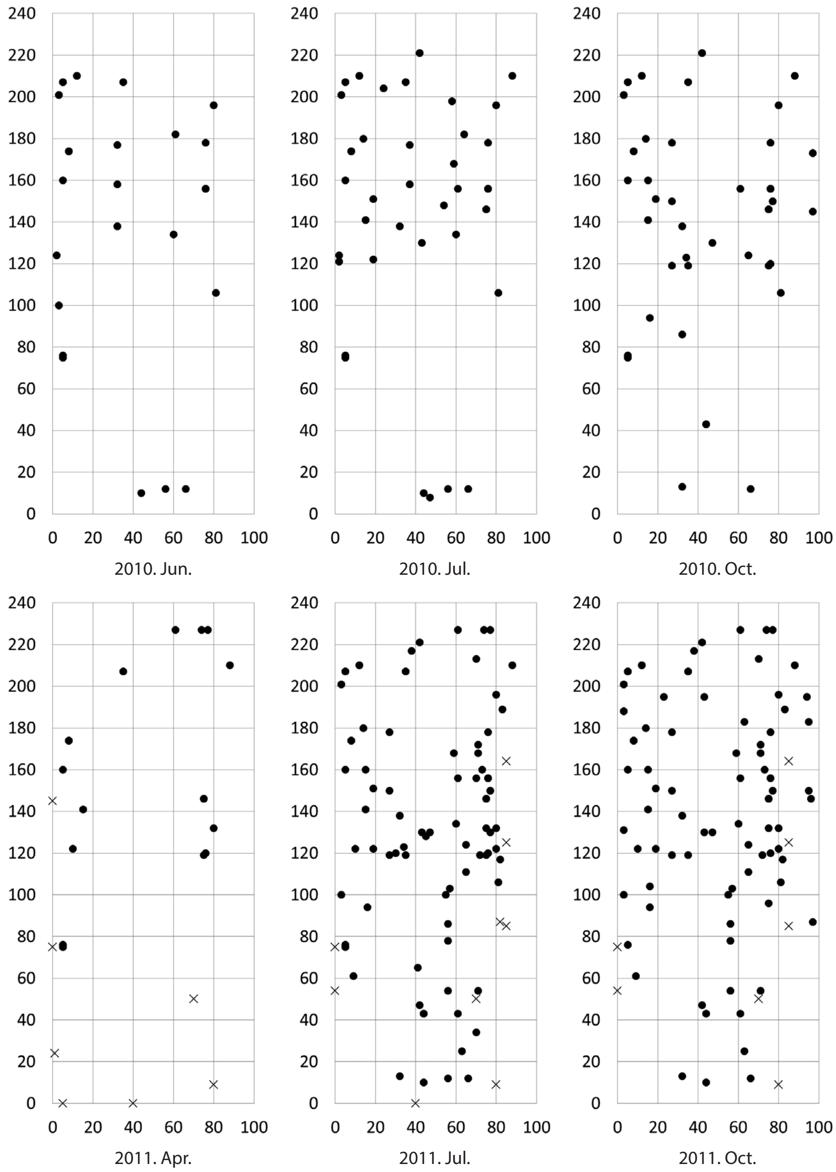

Fig. 11. Distribution of the shoots of the two species at experimental site for 4 years. A rectangle represents dug quadrat (1 m x 5 m) of Fig 2. Up, the North margin; down, the South margin.

DISCUSSION

The following conclusions can be made based on the above results. Firstly, since the mean heights and dry weights of the two species were similar, the two species competed for the sunlight but one was not superior to the other. Generally, competition for sunlight between two perennial herbs results in similar height, so that vegetation forms one layer (De Kroon 1993, Hara 1993). Next, the competition between two species can be assessed by dry weight (Connolly et al. 2001, Connolly and Wayne 2005, Laird and Aarssen 2005). However, the mean dry weight of *P. latifolius* per plant was similar to that of *P. australis*. Therefore, the competition between these two species can be best assessed by dry weight per unit area or density. The dry weight per unit area and density were higher for *P. latifolius* than for *P. australis*, making the former superior to the latter on the mound.

Secondly, in the permanent subquadrat, the density was predominantly higher for *P. latifoilus* than for *P. australis*. The density of *P. latifolius* was three times higher than that of *P. australis* in the central subquadrat, which

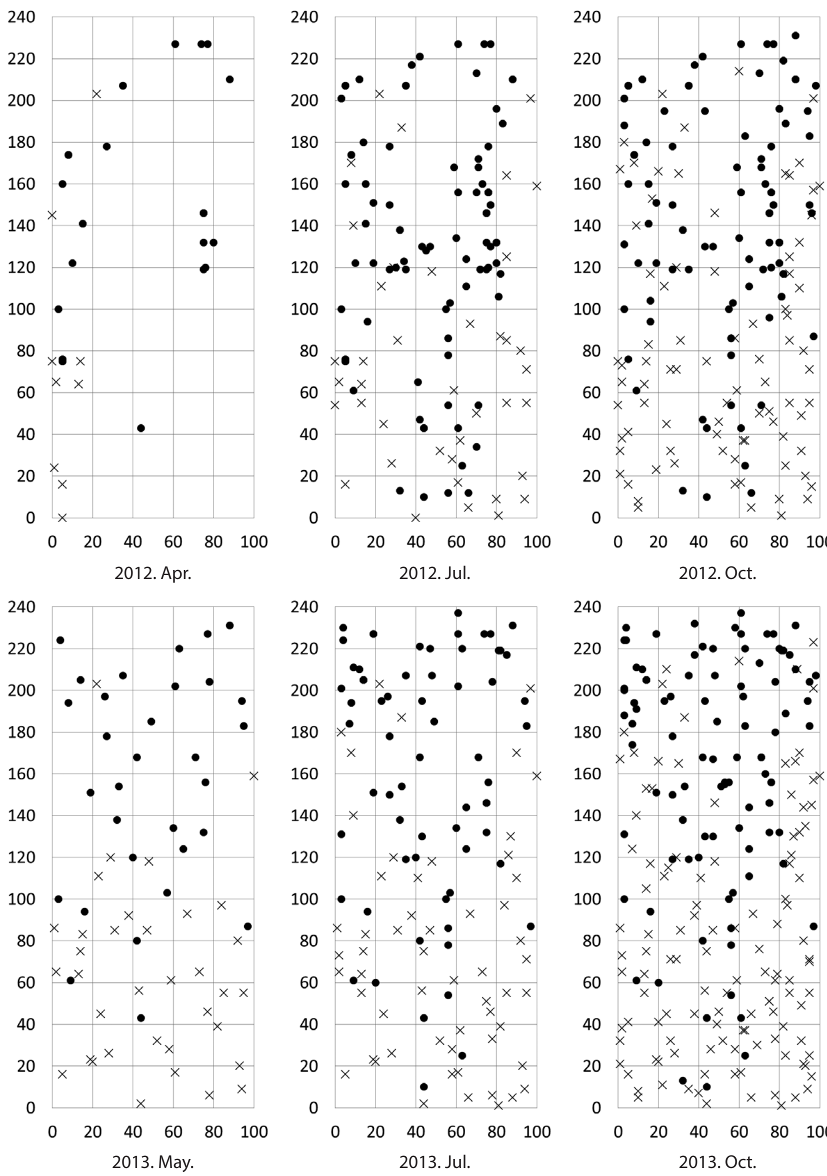

Fig. 11. Continued.

altitude was the highest. However, the densities of the two species at the two lower ends were similar to each other, making *P. australis* a predominant species at the low altitude and *P. latifolius* at the high altitude, respectively. Halophytes in tidal flat are sensitive to altitude and vegetation forms an evident zonation (Emerry et al. 2001, La Peyre et al. 2001). Many shoots of the two species germinated and died during the whole growth season and the size difference between large shoots and small ones was obvious, indicating that the new shoots died before they had time to grow to their average size. It appeared that a small shoot was unfavorable in the competition with other large shoots regardless of species.

Thirdly, cutting of the shoots in the early growth season affected the biomass of the root system in the late growth season as well as in the next year, showing that a lot of the photosynthetic energy was allocated to the root system and then transported to the shoots in the next growth season. Typically, perennial herb species allocate more energy to their root systems. However, our results indicated that the biomasses of the two species were affected by cutting of the shoots as well.

Fourthly, the root system of *P. latifolius* was distributed in the upper layer of sediment and that of *P. australis* in the lower level. Moreover, the latter penetrated deep into the sediment and was submerged in the soil water, while the former was not submerged in the soil water, indicating that the root systems of the two species did not overlap and did not compete with each other for resources. It appeared that *P. australis* grew vigorously in areas where water table was high or at low altitudes. On the other hand, *P. latifolius* grew better in dry areas or at higher altitudes. Consequently, there was no competition between the root systems of the two species. Generally, the competition between root systems for water or nutrients arises (Kadmon 1995, Casper and Jackson 1997, Levine et al. 1998, Rebele 2000, Fransen et al. 2001, Kennedy et al. 2003, Cahill and Lamb 2007, Luo et al. 2010). However, the root systems of the two species in this study were vertically isolated.

Lastly, the density was higher for *P. australis* than for *P. latifolius* at the new experimental site during the three years. The rhizome of *P. latifolius* was a guerrilla type and that of *P. australis* was a phalanx type. The rhizome of *P. latifolius* grew up to the dry area rather than remaining in the wet sediment. Therefore, *P. latifolius* grew up fast and migrated long distance in short time compared to *P. australis*. In the last year when the sediment piled up to 30 cm in height from the level of the removed mound, the densities of the two species were reversed, revealing that the altitude had the greater effect on distribution of *P. latifolius* and *P. australis*, rather than competition between the two species.

ACKNOWLEDGMENTS

This work was supported by the LTER Program of the Ministry of Environment from 2010 to 2013.

LITERATURE CITED

Aerts R. 1999. Interspecific competition in natural plant communities: mechanism, trade-offs and plant-soil feedbacks. J Exp Bot 50: 29-37.

Berendse F, Möller F. 2009. Effects of competition on root-shoot allocation in *Plantago lanceolata* L.: adaptive plasticity or ontogenetic drift? Plant Ecol 201: 567-573.

Bertness MD, Shumway SW. 1993. Competition and facilitation in marsh plants. Am Nat 142: 718-724.

Bittebiere AK, Mony C, Clement B, Garbey M. 2012. Modeling competition between plants using an individual based model: methods and effects on the growth of two species with contrasted growth forms. Ecol Model 234: 38-50.

Cahill JF, Lamb EG. 2007. Interactions between root and shoot competition and plant traits. HortScience 42: 1110-1112.

Casper BB, Jackson RB. 1997. Plant competition underground. Annu Rev Ecol Syst 28: 545-570.

Connolly J, Wayne P. 2005. Assessing determinants of community biomass composition in two-species plant competition studies. Oecologia 142: 450-457.

Connolly J, Wayne P, Bazzaz FA. 2001. Interspecific competition in plants: how well do current methods answer fundamental questions? Am Nat 157: 107-125.

Damgaard C. 1998. Plant competition experiments: testing hypotheses and estimating the probability of coexistence. Ecology 79: 1760-1767.

Damgaard C. 2003. Modeling plant competition along an environmental gradient. Ecol Model 170: 45-53.

Damgaard C, Riis-Nielsen T, Schmidt IK. 2009. Estimating plant competition coefficients and predicting community dynamics from non-destructive pin-point data: a case study with *Calluna vulgaris* and *Deschampsia flexuosa*. Plant Ecol 201: 687-697.

De Kroon H. 1993. Competition between shoots in stands of clonal plants. Plant Spec Biol 8: 85-94.

Dickinson MB, Miller TE. 1998. Competition among small, free-floating, aquatic plants. Am Midland Nat 140: 55-67.

Emery NC, Ewanchuk PJ, Bertness MD. 2001. Competition and salt-marsh plant zonation: stress tolerators may be dominant competitors. Ecology 82: 2471-2485.

Firbank LG, Lintell-Smith G, McCloskey M, Smith JM, Webb DJ. 1993. Scale experimental design and the detection of interspecific competition within plant communities. Plant Spec Biol 8: 159-166.

Fransen B, De Kroon H, Berendse F. 2001. Soil nutrient heterogeneity alters competition between two perennial grass species. Ecology 82: 2534-2546.

Gersani M, Brown JS, O'Brien EE, Maina GM, Abramsky Z. 2001. Tragedy of the commons as a result of root competition. J Ecol 89: 660-669.

Giblin AE, Weston NB, Banta GT, Tucker J, Hopkinson CS. 2010. The effects of salinity on nitrogen loses from an oligohaline estuarine sediment. Estuar Coasts 33: 1054-1068.

Hamidi AE, Garbey M, Ali N. 2012. A PDE model of clonal plant competition with nonlinear diffusion. Ecol Model 234: 83-92.

Hara T. 1992. Growth and competition in clonal plants - persistence of shoot populations and species diversity. Folia Geobot Phytotax 29: 181-202.

Hara T. 1993. Mode of competition and size-structure dynamics in plant communities. Plant Spec Biol 8: 75-84.

Jang SG, Cheong CJ. 2010. Characteristics of grain size and organic matters in the tidal flat sediments of the Suncheon Bay. J Mar Environ Eng 13: 198-205.

Just W, Nevai AL. 2008. A Kolmogorov-type competition model with multiple coexixtence states and its applications to plant competition for sunlight. J Math Anal Appl 348: 620-636.

Kadmon R. 1995. Plant competition along soil moisture gradients: a field experiment with the desert annual *Stipa capensis*. J Ecol 83: 253-262.

Kennedy MP, Milne JM, Murphy KJ. 2003. Experimental growth responses to groundwater level variation and competition in five British wetland plant species. Wetlands Ecol Manag 11: 383-396.

Kisdi E, Geritz SAH. 2003. On the coexistence of perennial plants by the competition-colonization trade-off. Am Nat 161: 350-354.

La Peyre MKG, Grace JB, Hahn E, Mendelssohn IA. 2001. The importance of competition in regulating plant species abundance along a salinity gradient. Ecology 82: 62-69.

Laird RA, Aarssen LW. 2005. Size inequality and the tragedy of the commons phenomenon in plant competition. Plant Ecol 179: 127-131.

Law R, McLellan A, Mahdi AKS. 1993. Spatio-temporal processes in a calcareous grassland. Plant Spec Biol 8: 175-193.

Lee YG, KimS, Lee HW, Min BM. 2008. Chemical properties of sediment and increase of reed (*Phragmites australis*) stands at Suncheon Bay. J Wetlands Res 10: 9-26.

Levine JM, Brewer JS, Bertness MD. 1998. Nutrients, competition and plant zonation in a New England salt marsh. J Ecol 86: 285-292.

Luo W, Xie Y, Chen X, Li F, Qin X. 2010. Competition and facilitation in three marsh plants in response to a water-level gradient. Wetlands 30: 525-530.

Maina GG, Brown JS, Gersani M. 2002. Intra-plant versus inter-plant root competition in beans: avoidance, resource matching or tragedy of the commons. Plant Ecol 160: 235-247.

McPhee CS, Aarssen LW. 2001. The separation of above- and below-ground competition in plants. A review and critique of methodology. Plant Ecol 152: 119-136.

Nevai AL, Vance RR. 2007. Plant interspecies competition for sunlight: a mathematical model of canopy partitioning. J Math Biol 55: 105-145.

Nevai AL, Vance RR. 2008. The role of leaf height in plant competition for sunlight: analysis of a canopy partitioning model. Math Biosci Eng 5: 101-124.

Rebele F. 2000. Competition and coexistence of rhizomatous perennial plants along a nutrient gradient. Plant Ecol 147: 77-94.

Seo Y, You YH, Yoon H, Kang SM, Kim H, Kim M, Kim C, Lee IJ, Kim JG. 2012. Gibberellin A4 produced by *Fusarium solani* isolated from the roots of *Suaeda japonica* Makino. J Life Sci 22: 1718-1723.