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Soil factors determining the distribution of *Phragmites australis* and *Phacelurus latifolius* in upper tidal zone

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Abstract

To assess the environmental factors determining the zonation between *Phacelurus latifolius* and *Phragmites australis*, vegetation survey and soil analysis were performed at a tidal marsh. The vegetation of the tidal marsh was classified into *P. latifolius* and *Suaeda japonica* dominated quadrats, *P. latifolius* and *P. australis* dominated quadrats, *P. australis* dominated quadrats, and *P. australis* and other land plants dominated quadrats. The density of *P. latifolius* (83.7 ± 5.5 shoots m^{-2}) was higher than that of *P. australis* (79.3 ± 12.1 shoots m^{-2}) in each dominated quadrat but height of two species were similar. Soil environmental characteristics of *P. latifolius* dominated quadrats appeared to be affected by tide based on higher soil electric conductivity (EC_{PL} = 1530 ± 152 μS cm^{-1}; EC_{PA+PL} = 689 ± 578 μS cm^{-1}; EC_{PA} = 689 ± 578 μS cm^{-1}) and lower pH (pH_{PL} = 5.96 ± 0.16; pH_{PA+PL} = 6.28 ± 0.31; pH_{PA} = 6.38 ± 0.22). In redundancy analysis, environmental characteristics of *P. latifolius* dominated quadrats and *P. australis* dominated quadrats were clearly separated and those of *P. latifolius* and *P. australis* co-dominated quadrats were similar to *P. australis* dominated quadrats. From our investigation, *P. latifolius* showed relatively high competitiveness when compared to *P. australis* in lower tidal zone rather than upper tidal zone. Zonation of *P. latifolius* and *P. australis* seems to be a transitional zone between halophytes and land plant species.

Keywords: Common reed, Halophytes, Redundancy analysis, Soil salinity, Tidal channel

Background

Tidal marshes, showing high primary productivity, usually function as buffer zone, water purifier, and habitat for wildlife (Moeller et al. 1996; Wolters et al. 2005; Bang et al. 2018). Many ecological functions of tidal marsh are based on the growth of plant species. Since salinity and water flooding act as a selective pressure in tidal marsh, only a few plant species could inhabit in tidal marsh when compared to other types of wetland (Ihm et al. 2006; Isacch et al. 2006). Thus, adaptive mechanisms to the saline and frequently inundated soil such as salt excretion are necessary to plant species for inhabiting in tidal marsh.

Due to seawater flooding regime causing heterogeneous environments in tidal marsh, zonation patterns of vegetation often occur depending on soil environments particularly in rhizosphere (Armstrong et al. 1985; Ihm et al. 2006; Bang et al. 2018). Grass species mainly occur in the temperate zone of tidal marsh (Ihm et al. 2001, 2006). In upper tidal zone, for example, common reed (*Phragmites australis* (Cav.) Trin. ex Steud.) is the most common and dominant species that contributes to productivity and landscape. *Suaeda* spp. such as *Suaeda glauca* (Bunge) Bunge and *Suaeda japonica* Makino are common halophytes, which inhabit only at lower part of tidal zone in East Asia (Lee et al. 2016).

In tidal marsh of East Asia, *Phacelurus latifolius* (Steud.) Ohwi has also occurred with *P. australis* (Yokoyama et al. 2003; Min 2015). Both species show high standing crop and similar stand in tidal marsh (Lee 2003). *P. latifolius* is classified as halophytes, while *P. australis* is classified as salt-tolerant species (Lissner and Schierup 1997; Yokoyama et al. 2003). According to salinity ranges, two species have shown the zonation pattern in tidal marsh (Yokoyama et al. 2003; Bang et al. 2018). Despite different niche in the salinity range of *P.*

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latifolius and *P. australis*, those species occasionally co-occur in an area (Min 2015).

Quantitative analyses on soil physicochemical properties are important for understanding the environmental ranges of individual species in tidal marsh. Nevertheless, only a few studies have been performed about the co-existence of *P. australis* and *P. latifolius* in tidal marsh focusing on the environmental distribution range of two species only in elevation and physical properties of soil (Yokoyama et al. 2003; Min 2015). To investigate the soil environmental factors determining the zonation between *P. australis* and *P. latifolius* in tidal marsh, distributional characteristics and soil physicochemical properties were surveyed.

Methods

Study site and vegetation survey

Field survey was conducted at a tidal marsh in the tidal channel of Siheung City, Gyeonggi Province, Republic of Korea (37° 24′ N 126° 45′ E) in July 2016, when the flowering bud of *P. latifolius* was emerged. Two or three quadrats in each of 11 transverse lines along the zonation of *P. latifolius* and *P. australis* were surveyed (total 31 quadrats; Fig. 1). Average height, density, and coverage of every species which emerged in the 1 m × 1 m quadrat were surveyed. Soil samples were collected in 30~40 cm depth (near the rhizosphere of *P. latifolius* or *P. australis*) at each quadrat at low tide.

Soil analysis

Soil samples were air-dried and passed through a 2-mm-mesh sieve. Soil moisture was measured by loss of mass after drying at 105 °C oven for 24 h (or 48 h), and organic matter content (OM) was calculated by the loss-on-ignition method at 550 °C furnace (Boyle 2004). Soil electric conductivity and pH were measured by the mixture of soil samples with distilled water at 1:5 ratio (conductivity meter: Corning Checkmate II, Corning, Lowell, MA; pH meter: AP63, Fisher, Hampton, USA). Soil NO_3-N and NH_4-N content were measured by hydrazine method and indophenol method from the extract using 2 M KCl solution at 1:5 ratio, respectively (Kamphake et al. 1967; Kim et al. 2004). Soil PO_4-P content was measured by a Bray No. 1 method (Bray and Kurtz 1945) from the extract with Bray No. 1 solution. Available cations (K^+, Ca^{2+}, Na^+, and Mg^{2+}) were extracted with 1 N ammonium acetate solution (Allen et al. 1974), and contents were measured by an atomic absorption spectrophotometer (AA240FS, Varian, Palo Alto, USA). Soil particle composition, sand, silt, and clay contents were examined by hydrometer method (Carter 1993).

Statistical analysis

TWINSPAN analysis for community ordination and redundancy analysis (RDA) were performed by R version 3.3.3 (R Core Team 2016) with “twinspanR” and “vegan” package, respectively. Vegetation cover was used in TWINSPAN analysis. Hellinger-transformated vegetation cover and raw soil environmental variables were used in RDA. Analysis of variance and Duncan’s post hoc test of soil environmental variables were also conducted using R with “agricolae” package.

Results

Phacelurus latifolius dominated quadrats were distributed in the relatively lower part of the tidal marsh than *P. australis* dominated quadrats. *P. latifolius* and *P. australis* co-dominated quadrats by two species were distributed between dominated areas of each two species. Average shoot height of *P. latifolius* and *P. australis* was similar as about 150 cm (Fig. 2a). Those two species grew about 2 m at the end of the growing season. Average density was slightly higher in *P. latifolius* dominated quadrats (Fig. 2b). In *P. latifolius* and *P. australis* dominated quadrats, density of two species was relatively low, while average height of each species was similar to the each dominated quadrat.

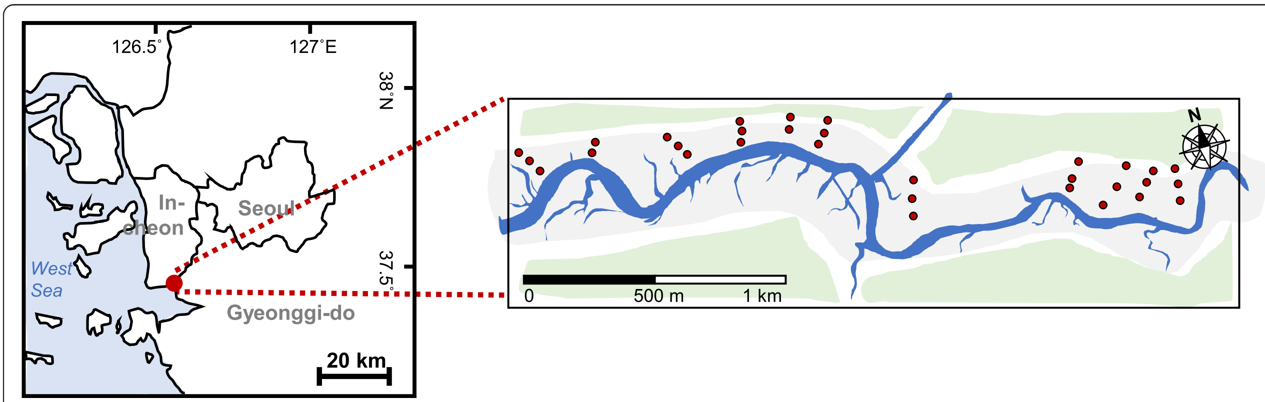

Fig. 1 Map of study site. Red closed circles indicate the location of quadrats

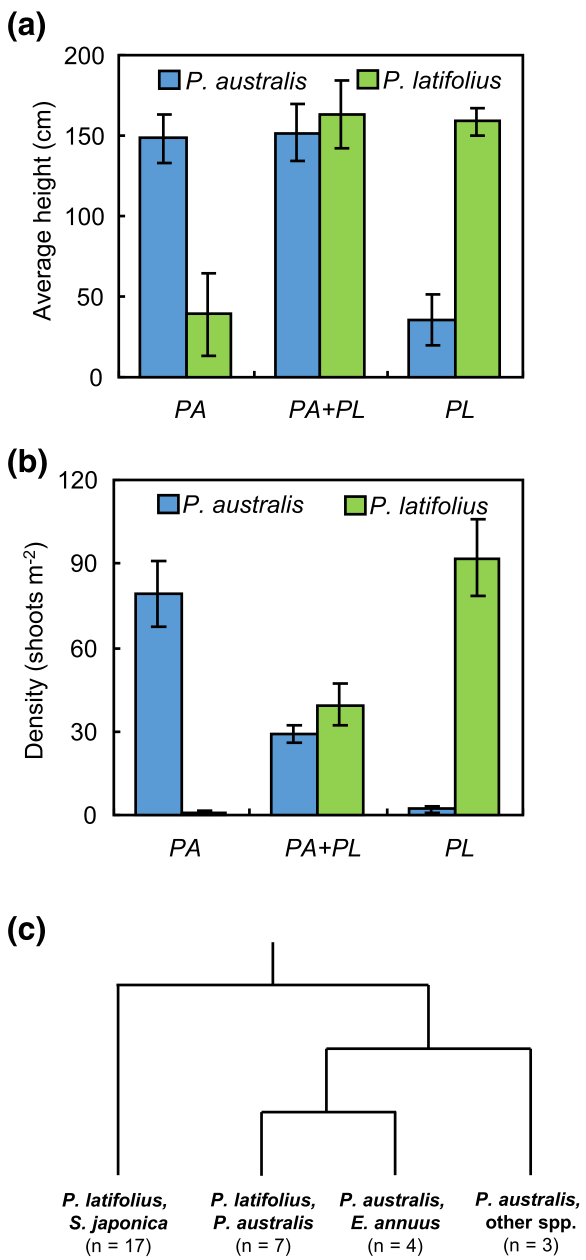

Fig. 2 Distribution characteristics of *Phacelurus latifolius* and *Phragmies australis* in a tidal marsh. **a** Average height in quadrat. **b** Shoot density. **c** Ordination based on species composition by TWINSPAN. *PA P. australis* dominated, *PL P. latifolius* dominated, *PA* + *PL P. australis* and *P. latifolius* co-dominated quadrats

As a result of TWINSPAN ordination, quadrats were classified into *P. latifolius* and *Suaeda japonica* community and other communities with *P. australis* (Fig. 2c). Major co-occurred species with *P. australis* was *P. latifolius* or *Erigeron annuus* (L.) Pers. (daisy fleabane), mainly occurs in land ecosystem (Lee 2003). Species composition of *P. australis* and *E. annuus* community or *P. australis* and other species community were similar to the terrestrial ecosystem rather than tidal marsh.

In proximity to the seawater, physicochemical properties of *P. latifolius* dominated quadrats were similar to the seawater rather than *P. australis* dominated and *P. latifolius* and *P. australis* dominated quadrats. *P. latifolius* dominated quadrats had the highest electric conductivity (1530 ± 152 μS cm^{-1}) and the lowest pH (5.96 ± 0.16) rather than other two groups (Fig. 3A, B). Clay, silt, and sand contents were similar among the three groups (Fig. 3C).

Soil moisture content was also the highest in *P. latifolius* dominated quadrats (26.1 ± 1.7%), and *P. australis* dominated quadrats (24.0 ± 2.0%) and *P. latifolius* and *P. australis* co-dominated quadrats (20.8 ± 0.9%) were followed (Fig. 3D). Soil organic matter content was similar among the three groups. Soil PO_4-P content was the highest in *P. latifolius* dominated quadrats (PO_4-P_{PL} = 13.0 ± 1.7 mg kg^{-1}; PO_4-$P_{PA + PL}$ = 6.8 ± 0.6 mg kg^{-1}; PO_4-P_{PA} = 8.7 ± 1.3 mg kg^{-1}; Fig. 3E). Soil NH_4-N and NO_3-N content was similar among the three groups. Soil sodium content was the highest in *P. latifolius* dominated quadrats (PL = 2619 ± 230 mg kg^{-1}; PL + PA = 1219 ± 738 mg kg^{-1}; PA = 1301 ± 439 mg kg^{-1}), which showed similar pattern with soil electric conductivity (Fig. 3F). Other exchangeable cation contents (K^+, Ca^{2+}, Mg^{2+}) were similar among the three groups.

Redundancy analysis showed that soil environmental characteristics of *P. latifolius* dominated quadrats and *P. australis* dominated quadrats could be separated by ordination (Fig. 4a). *P. australis* dominated or *P. latifolius* and *P. australis* co-dominated quadrats showed the higher pH or calcium content than *P. latifolius* dominated quadrats, while they were characterized by the higher soil ion contents caused by saline water.

Discussion

From the results of the field survey and ordination, generalized zonation pattern could be described as [*S. japonica*] – [*P. latifolius*] – [*P. latifolius* and *P. australis*] – [*P. australis* and other land plants] from the relatively lower to upper tidal zone (Fig. 4b). Soil environmental characteristics of *P. latifolius* and *P. australis* dominated quadrats were similar to *P. australis* dominated quadrats rather than *P. latifolius* dominated quadrats, whereas the environmental characteristics of *P. latifolius* and *P. australis* co-dominated quadrats were varied. *P. latifolius* dominated quadrats showed higher electric conductivity, soil Na^+ and PO_4-P content and lower Ca^{2+} content than *P. australis* dominated or *P. latifolius* and *P. australis* co-dominated quadrats.

Soil environmental characteristics such as soil salinity, total nitrate, and clay content of *P. australis* in tidal marsh were significantly lower than the soil environment

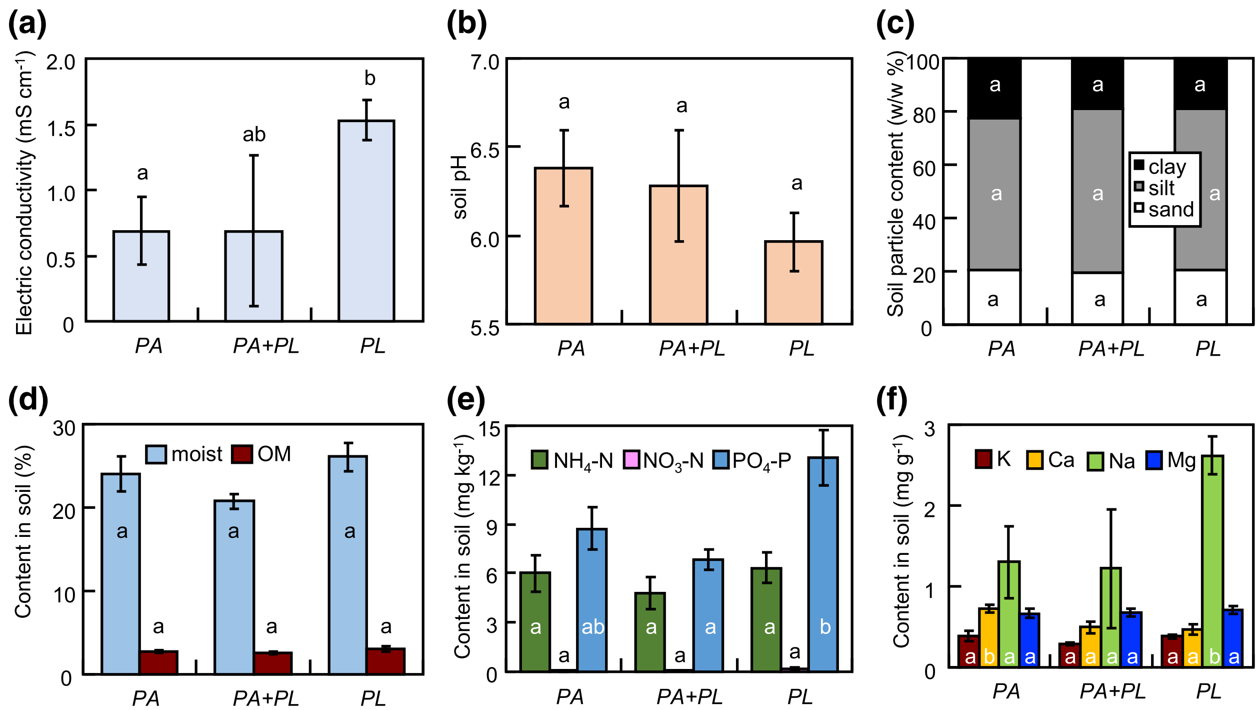

Fig. 3 Soil characteristics of *Phragmites australis* dominated (PA), *Phragmites latifolius* dominated (PL), and *P. latifolius* and *P. australis* co-dominated (PA + PL) quadrats in the tidal marsh. **A** Electric conductivity. **B** pH. **C** Soil texture. **D** Moisture and organic matter content (OM). **E** Major nutrient (NH_4-N, NO_3-N, PO_4-P). **F** Exchangeable cations (K^+, Ca^{2+}, Na^+, Mg^{2+}). Letters on the bar indicate statistically different sub-groups by Duncan's post hoc test in $p < 0.05$ significance range

of *Suaeda* community in lower area (Lee et al. 2016, 2018). Overall soil pH, electric conductivity, and other exchangeable cation concentrations were lower than the previous studies on the tidal marsh (Ihm et al. 2007; Lee et al. 2016). Plant community and soil of the studied tidal channel seemed to likely be classified as estuaries, which affected by seawater tide and freshwater output. Not only the tide affected the soil environment of zonation between *P. australis* and *P. latifolius*, but also the freshwater input seemed to affect the soil. In the present

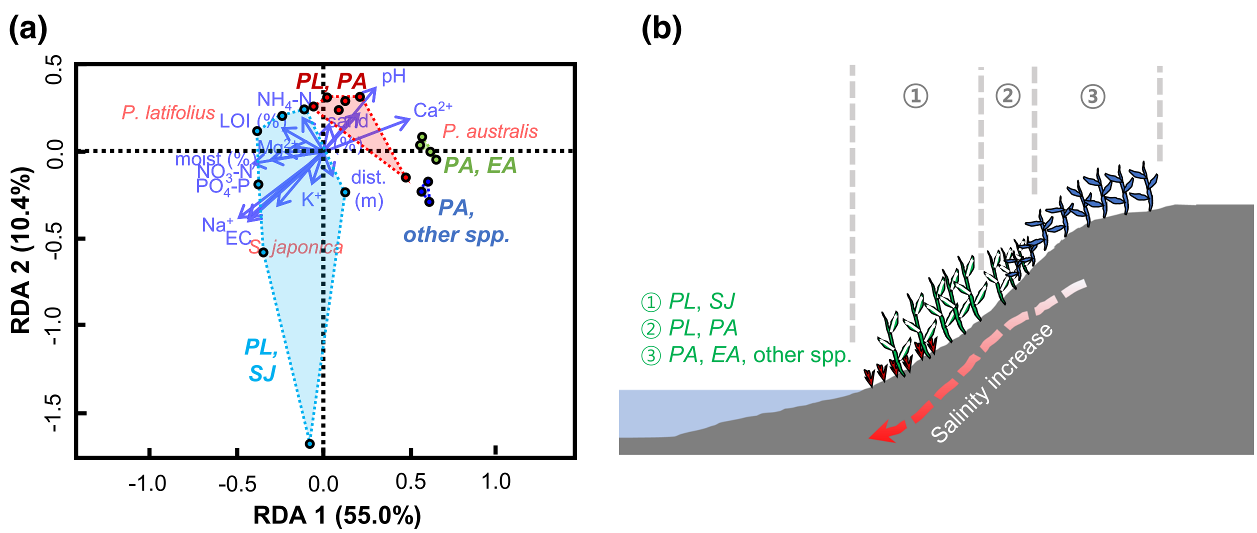

Fig. 4 a Ordination result based on the community structure and environmental characteristics using redundancy analysis (RDA). **b** Schematic diagram of the distribution between *Phacelurus latifolius* (PL) and *Phragmites australis* (PA) study, soil environmental characteristics of *P. australis* and *P. latifolius* did not show the difference in soil nitrate content or particle content. According to the narrower difference in soil environment, distribution range of *P. australis* and *P. latifolius* seemed to be restricted and almost overlapped only in the upper tidal marsh (Yokoyama et al. 2003; Bang et al. 2018).

Despite the overlapped distribution ranges by elevation of *P. australis* and *P. latifolius* (Bang et al. 2018), the co-existence range was narrower in this study. Min (2015) showed that *P. australis* and *P. latifolius* could co-exist in same tidal mound without the belowground competition by rhizome of *P. australis* which rooted deeper than *P. latifolius*. It has been reported that *P. australis* could inhabit in tidal marsh and even thrive when freshwater inflows (Lissner and Schierup 1997; Hong 2015). In spite of that, *P. latifolius* could exist in the more upper tidal zone than *P. australis* (Yokoyama et al. 2003; Bang et al. 2018); *P. latifolius* could not outcompete *P. australis* at the upper tidal zone in this study. Plant growth in the lower tidal zone is mainly restricted by saline soil than interspecific competition, whereas interspecific competition is major in the upper tidal zone by reduced environmental stress (Crain et al. 2004). Therefore, it could be supposed that competitiveness of *P. latifolius* is stronger in relatively lower tidal zone by active salt excretion mechanism, whereas *P. australis* is competitive only in the relatively upper zone where the effect of seawater is weak.

Soil salinity, which is represented by the electric conductivity, and soil pH were the key factors that determine the distribution of *P. australis* and *P. latifolius*. Regardless of that *P. latifolius* inhabited in the relative saline soil environment than *P. australis*, soil electric conductivity and pH range of *P. latifolius* dominated habitat were narrower than those of *P. australis* dominated. Considering that *P. australis* dominated habitat consists of terrestrial plant species, zonation of *P. latifolius* and *P. australis* seemed to be a transitional zone between halophytes and land plant species. Our result could provide information of the soil environmental range of large macrophyte vegetation in the salt marsh restoration.

Abbreviations

PA: *Phragmites australis*; PL: *Phacelurus latifolius*

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Availability of data and materials

The datasets during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Authors' contributions

BEN participated in the design of the study, field survey and sampling, environmental analysis experiment, and data analyses and wrote the manuscript draft. MGH participated in the design of the study, field survey, and data analyses and edited the manuscript draft. HJP participated in the field survey and sampling and environmental analysis experiment. JGK conceived the study, participated in the design of the study, edited the manuscript draft, and secured the funding. All authors read and approved the final manuscript.

Authors' information

Not applicable.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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