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# Spatial distribution of halophytes and environment factors in salt marshes along the eastern Yellow Sea

Jaesang Chung<sup>1†</sup>, Jae Hyun Kim<sup>2,3†</sup> and Eun Ju Lee<sup>4\*</sup>

## Abstract

**Background:** Salt marshes provide a variety of ecosystem services; however, they are vulnerable to human activity, water level fluctuations, and climate change. Analyses of the relationships between plant communities and environmental conditions in salt marshes are expected to provide useful information for the prediction of changes during climate change. In this study, relationships between the current vegetation structure and environmental factors were evaluated in the tidal flat at the southern tip of Ganghwa, Korea, where salt marshes are well-developed.

**Results:** The vegetation structure in Ganghwa salt marshes was divided into three groups by cluster analysis: group A, dominated by *Phragmites communis*; group B, dominated by *Suaeda japonica*; and group C, dominated by other taxa. As determined by PERMANOVA, the groups showed significant differences with respect to altitude, soil moisture, soil organic matter, salinity, sand, clay, and silt ratios. A canonical correspondence analysis based on the percent cover of each species in the quadrats showed that the proportion of sand increased as the altitude increased and *S. japonica* appeared in soil with a relatively high silt proportion, while *P. communis* was distributed in soil with low salinity.

**Conclusions:** The distributions of three halophyte groups differed depending on the altitude, soil moisture, salinity, and soil organic matter, sand, silt, and clay contents. Pioneer species, such as *S. japonica*, appeared in soil with a relatively high silt content. The *P. communis* community survived under a wider range of soil textures than previously reported in the literature; the species was distributed in soils with relatively low salinity, with a range expansion toward the sea in areas with freshwater influx. The observed spatial distribution patterns may provide a basis for conservation under declining salt marshes.

**Keywords:** *Phragmites communis*, *Suaeda japonica*, Pioneer species, Spatial distribution

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## Background

Coastal salt marshes are ecosystems that connect terrestrial and marine ecosystems. Halophytes in salt marshes tend to have a zonal distribution along an altitudinal gradient (Bang et al. 2018; Santelmann et al. 2019). This is because the altitude determines the inundation frequency (Santelmann et al. 2019). Inundation places great stress on plants, which are typically not tolerant to salinity. Thus, the distribution of halophytes is determined by the ability of taxa to withstand an oxygen-free, high-saline environment by excreting or avoiding salt (Colmer and Flowers 2008; Parida and Das 2005). Other factors determining halophyte distributions include soil texture (Brereton 1971; Ihm et al. 2007), salinity (Silvestri et al. 2005), herbivory (Olf et al. 1997), and interspecific competition (Bertness and Ellison 1987). In general, pioneer species are highly resistant to stress.

The Yellow Sea has well-developed salt marshes, providing important wetland habitats for diverse wildlife in East Asia (Ministry of Oceans and Fisheries 2020). However, factors such as development projects and industrial effluent (Newton et al. 2020) have resulted in declining salt marshes. For example, from the 1950s to 2000s, salt marshes along the Yellow Sea have decreased by 51.4% as a result of land reclamation. Additionally, 65.6% of the salt marshes in South Korea have disappeared (Murray et al. 2014). As of 2018, Ganghwa has vast tidal flats covering 256.1 km<sup>2</sup>, accounting for about 10% of the tidal flats in Korea (Ministry of Oceans and

Fisheries 2020); however, development projects in the 1990s altered the physical structure of the salt marsh near Ganghwa Island, resulting in extensive die-off of *Suaeda japonica* (Y.-K. Lee et al. 2014).

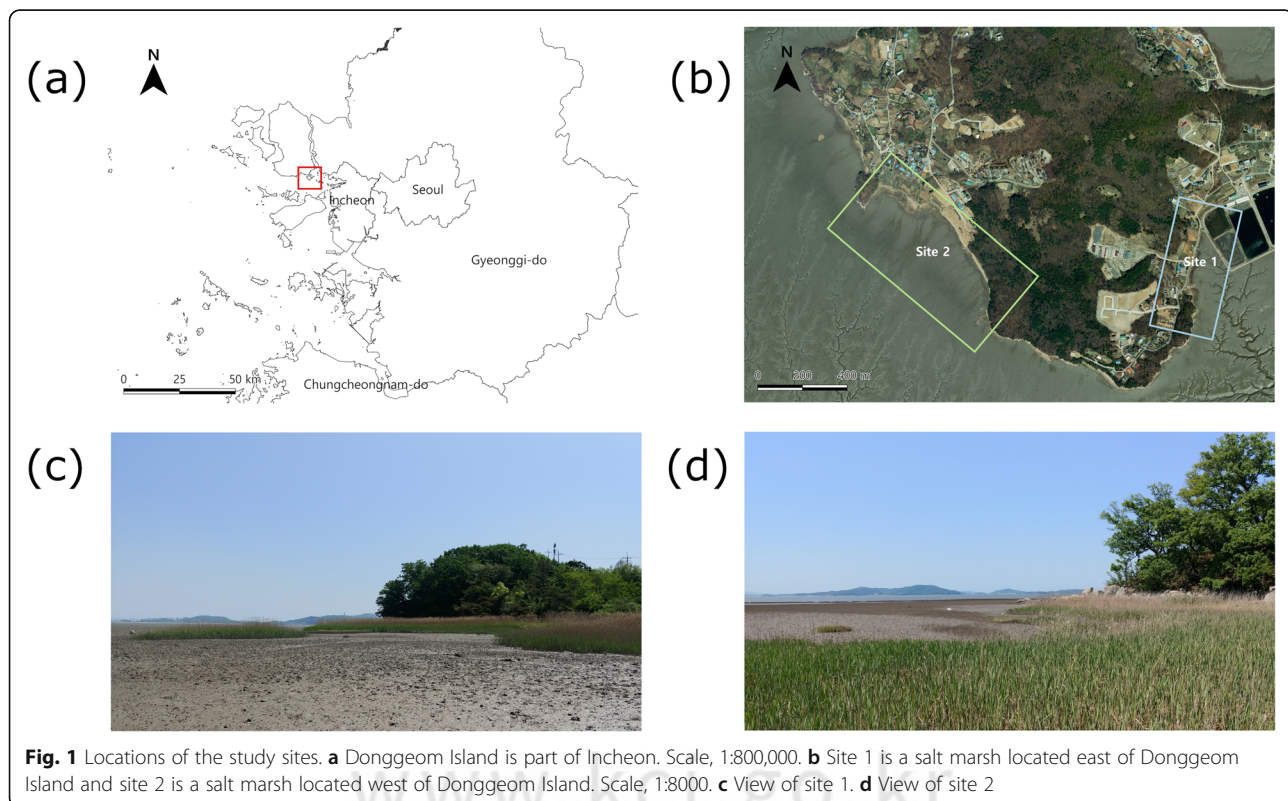
In Ganghwa Island's neighboring big cities, such as Seoul and Incheon, development projects and the discharge of industrial effluent are major issues. In a salt marsh of southern Ganghwa, the zonal distribution of halophytes is related to environmental factors such as salinity and exposure time, and the halophyte community is related to the organic matter content (H. G. Lee et al. 2006, 2016). Despite the size and importance of the Ganghwa Southern tidal flat in the Yellow Sea, few studies have evaluated the relationship between the halophyte community structure and spatial distribution of environmental factors in the tidal flat.

Thus, the objective of this study was to determine whether environmental factors influence the distribution of halophytes in salt marshes of the eastern Yellow Sea. Our results reveal the close relationship between vegetation in salt marshes and various environmental factors, especially soil texture.

## Materials and methods

### Study area

The study was conducted in the eastern (37° 35' 1.13" N, 126° 31' 8.17" E; site 1) and western (37° 35' 5.44" N, 126° 30' 33.59" E; site 2) salt marshes of Donggeom Island, southern Ganghwa, South Korea (Fig. 1). The research site



had an annual average temperature of 11.5 °C over the last 10 years and an average annual rainfall of 1169.9 mm (Korea Meteorological Administration 2020). The average tidal range, measured from 2016 to 2018 at the tide observation point of Yeongjong Bridge near the research site, was 6.4 m (Korea Hydrographic and Oceanographic Agency 2017, 2018, 2019).

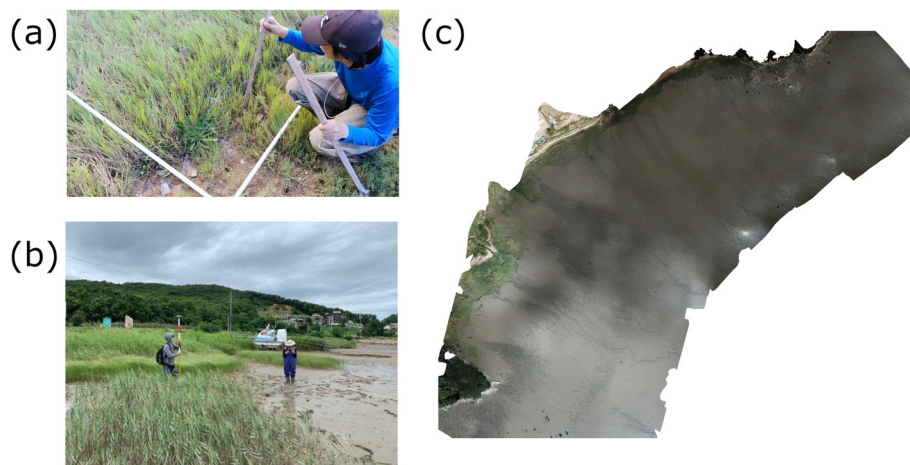
#### Field surveys and vegetation mapping

Vegetation was evaluated by field surveys conducted from July 2020 to October 2020. Scientific names were determined in accordance with the Korea Biodiversity Information System (<http://www.nature.go.kr/>), except for *Spartina anglica*, which was identified based on the biodiversity of the Korean Peninsula (<https://species.nibr.go.kr/>) of the National Institute of Biological Resources (NIBR). For a list of halophytes, the protocol of the National Marine Ecosystem Monitoring Program was followed (Ministry of Oceans and Fisheries/Korea Marine Environment Management Corporation 2019). Based on the area covered by each community (obtained using the network-RTK (Real Time Kinematic) connected to a mobile antenna), 2–25 random points were set in QGIS (Quantum GIS). Temporary quadrats, each measuring 1 × 1 m<sup>2</sup>, were installed at these random points. Coordinates, altitude, species and their coverage, bare ground coverage, and individual heights of each species repeated 5 times were recorded for each quadrat (Fig. 2a). Coverage was recorded in increments of 0.05% for less than 1% of coverage, 1% for 1% to 50%, and 5% for 50% or greater. During the low tide period, three soil samples around each quadrat were removed to a depth of 15 cm, placed in a zipper bag, transported to the laboratory, and refrigerated at 4 °C.

The GPS received from network-RTK (PX1122R; NavSpark 2020) was connected to a tablet (SM-T830; Samsung 2018) at the site. Using QField for GIS version 1.5.8 (OPENGIS.ch 2020), polygons representing the boundaries of each community were created at the site and an existing vegetation map was drawn (Fig. 2b). The *S. japonica* community at Site 2 was spread over a long distance, making it impossible to create polygons by walking the boundaries of the community with an RTK receiver. Thus, a drone (Mavic Pro; DJI Co. 2017) was used to draw a polygon of the *S. japonica* community. After obtaining images of the area of *S. japonica* with a drone, photos were merged and converted into a single TIFF file using DroneDeploy (<https://www.dronedeploy.com/>). A polygon of the *S. japonica* community was created manually based on the TIFF file (Fig. 2c). The existing vegetation map was completed by correcting errors in the laboratory.

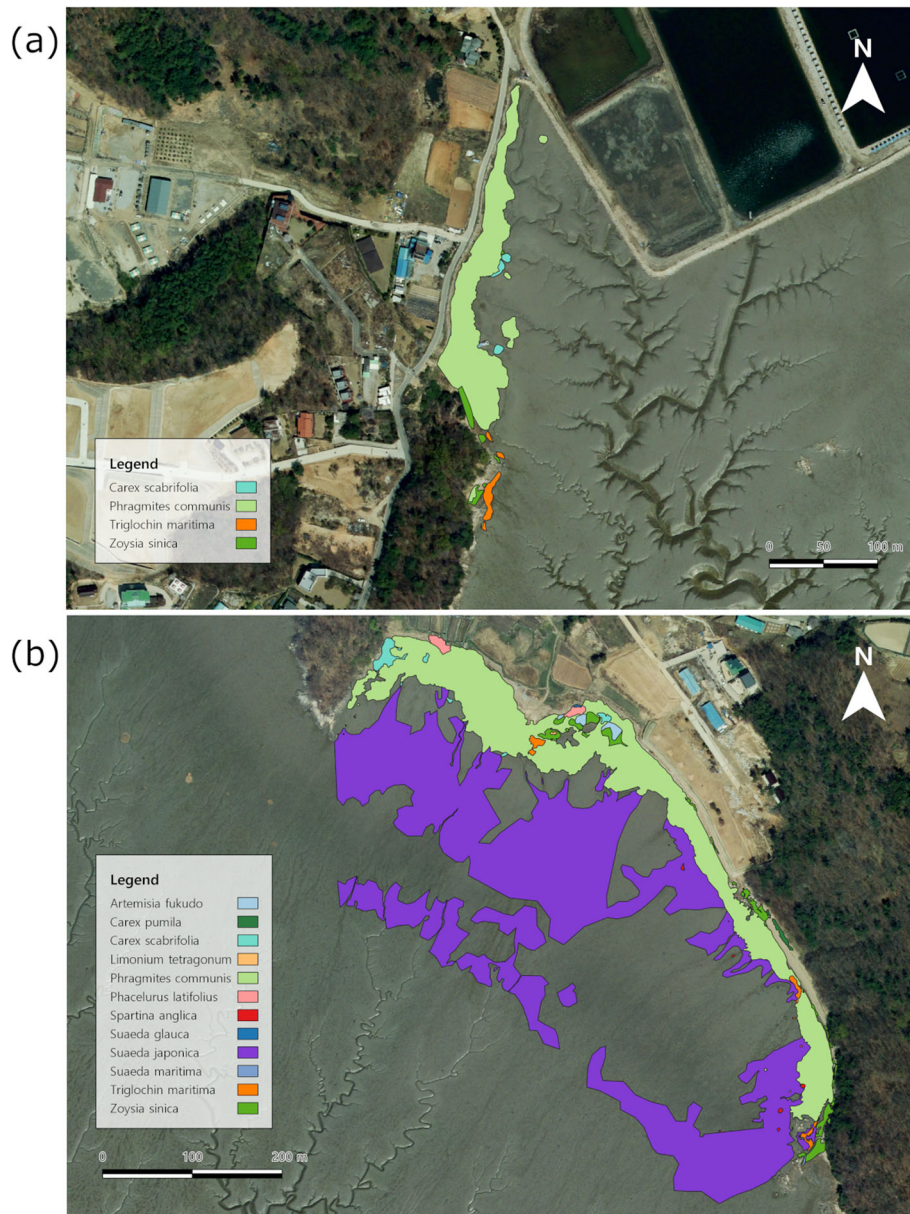
#### Soil analysis

The soil samples transported to the laboratory were filtered through a 2-mm sieve to remove gravel and any plant material. Soil texture was determined using a hydrometer and a texture triangle of the USDA (Carter and Gregorich 2007). Soil moisture (SM) was determined after drying samples at 105 °C in an oven for 24 h (Carter and Gregorich 2007). Soil organic matter (SOM) was analyzed by burning the dried samples at 550 °C for 4 h (Boyle 2004). Soil solutions were prepared by mixing 5 g of soil sample with 60 ml of distilled water in a 50-ml conical tube; pH and salinity were measured using a PC-2000 (THERMO EUTECH, Singapore).



**Fig. 2** Parts of the field survey. **a** Briefly, 1 × 1 m<sup>2</sup> quadrats were used to survey coverages and heights of species. **b** Vegetation maps were constructed with network-RTK GPS. **c** A map showing the *Suaeda japonica* distribution by merging images obtained by a drone. North is on the left



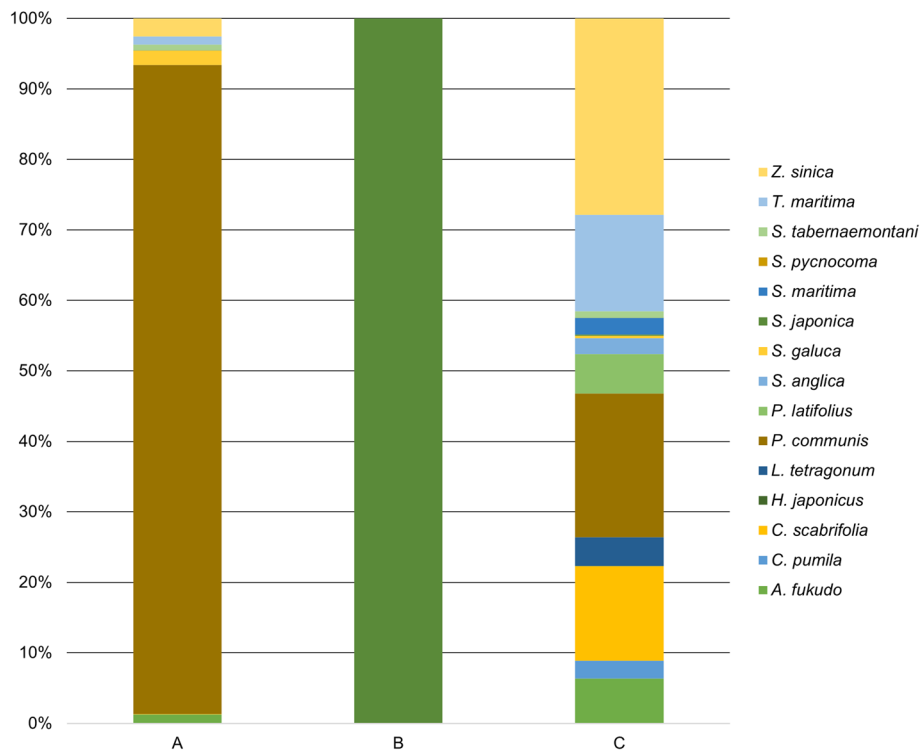


**Fig. 4** Vegetation map of the study sites surveyed in 2020. **a** Site 1. **b** Site 2

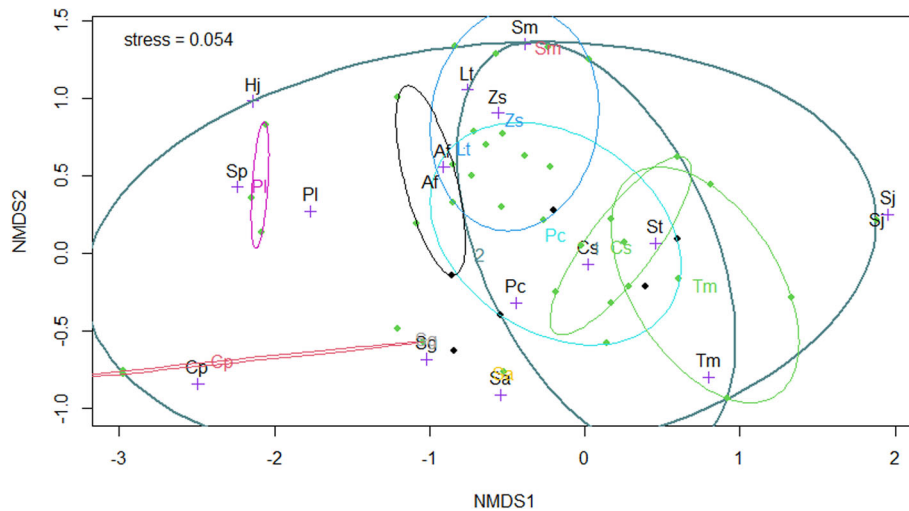
sand dune plants such as *C. pumila* formed a community. The salt marsh was very large and included a mixed community of various species. There were two composition types, one in which only *P. communis* was detected, and another in which *T. maritima*, *C. scabrifolia*, and *Schoenoplectus tabernaemontani* (C.C.Gmel.) Palla were found in the lower layer, despite a high *P. communis* cover of  $\geq 80\%$  in the upper layer. The *A. fukudo* community occurred together with *P. communis* and *Z. sinica*. The *C. scabrifolia* community appeared frequently with *P. communis* in the upper layer (Fig. 5). The *L. tetragonum* community co-existed with *Z. sinica* and *A. fukudo*. The *S. glauca*

community appeared with *P. latifolius* and *P. communis*. The *Z. sinica* community appeared with *P. communis*, *L. tetragonum*, *A. fukudo*, and *S. maritima*.

NMDS confirmed the species distribution of group B (Fig. 6). Group C was more broadly distributed than group A. *C. pumila* and *S. japonica* did not appear frequently with other plants. *A. fukudo*, *Z. sinica*, and *L. tetragonum* co-existed with *S. maritima*, and *C. scabrifolia* was found together with *P. communis* and *S. tabernaemontani*. Glycophytes, *Humulus japonicus* Siebold & Zucc., *Setaria*  $\times$  *pyncocoma* (Steud.) Henrard ex Nakai, and *P. latifolius* co-existed.



**Fig. 5** Average coverage of species in the three groups. Average coverage of each species in the quadrats for each group is presented as a proportion of the total area



**Fig. 6** NDMS ordination based on Bray-Curtis dissimilarity distances. Cross symbols show ordinations of species. Points show ordinations of quadrats. Black points are quadrats containing group A, and green points are quadrats containing group C. Ellipses show the species abundance and range of the study sites, and the dominant vegetation groups. Abbreviations are the same as those defined in Fig. 4

**Environmental conditions in the eastern Yellow Sea**

In addition to 128 quadrats with halophyte vegetation, 12 control quadrats were installed to analyze the SM, SOM content, pH, salinity, and soil texture (Table 1). Based on a soil texture analysis, in group B (containing only *S. japonica*), the silt content was the highest among the three soil elements. This group was mainly found in areas with silt (Z) and sandy silt (sZ) (Fig. 7). Group A was found in a relatively wide range of sand and silt conditions. Species in Group C were distributed in areas with a high proportion of silt, such as *T. maritima* and *C. scabrifolia*, and in areas with a high proportion of sand, such as *Z. sinica* and *C. pumila*. Thus, this group showed a wide range of soil textures. In the control areas lacking halophytes, sand (S) was predominant in quadrats installed near the *C. pumila* community, while sandy silt (sZ) or silt (Z) was predominant in quadrats installed near *S. japonica* and other halophytes.

We detected significant correlations between altitude ( $p < 0.05$ ) and all environmental variables examined (Fig. 8). Altitude was positively correlated ( $r = 0.53$ ) with the sand content and negatively correlated ( $r = -0.56$ ) with silt. SM was positively correlated with SOM and silt ( $r = 0.82$  and  $r = 0.81$ , respectively). SOM showed a negative correlation ( $r = -0.76$ ) with the sand content and positive correlations with clay and silt contents ( $r = 0.75$  and  $r = 0.72$ , respectively). There were no significant correlations between pH and other factors, except altitude. The sand content was negatively correlated with clay and silt contents ( $r = -0.86$  and  $r = -0.98$ , respectively).

PERMANOVA revealed significant differences among the three groups ( $p < 0.05$ ) with respect to altitude, SM, SOM, salinity, sand, silt, and clay contents (but not pH). Dunn’s test for environmental factors other than pH further revealed that parameter values typically differed between group B and groups A and

C. The altitude of group B, dominated by *S. japonica*, was lower than that of other groups. Furthermore, SOM content differed among groups (Table 1).

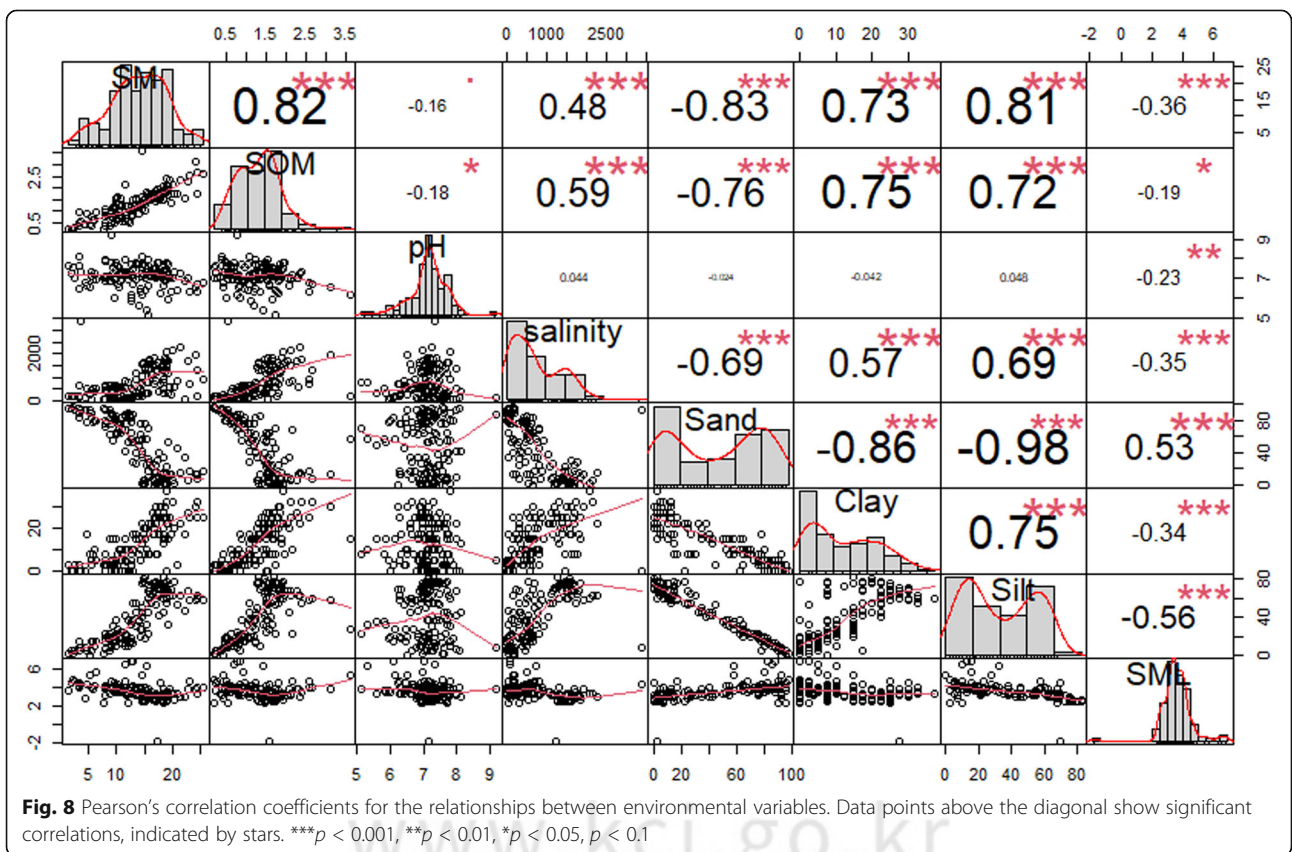
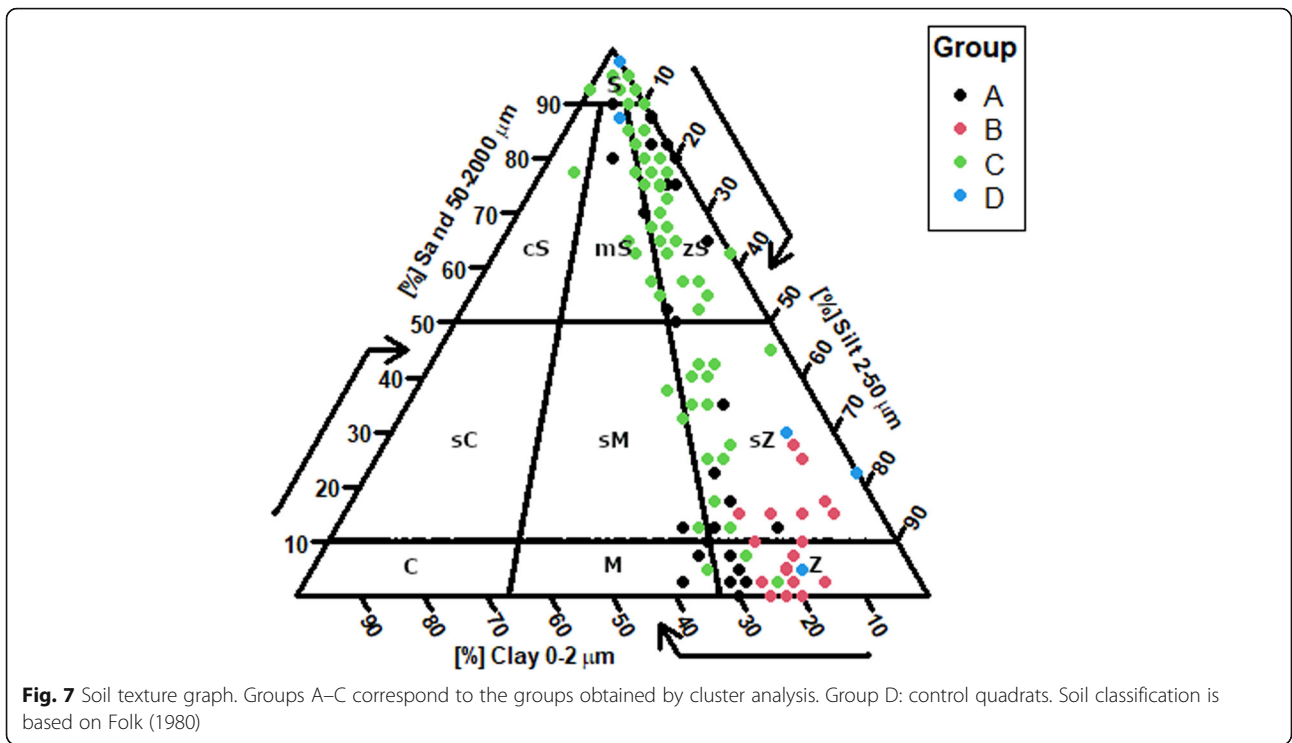
In a CCA of relationships between each group and environmental factors, CCA1 explained 8.8% of the total variance (eigenvalue 0.6850) and CCA2 explained 6.2% of the total variance (eigenvalue 0.4845) (Fig. 9). In the positive direction along CCA1, the silt and clay contents, SM, SOM content, and salinity tended to increase, while the altitude and sand content tended to decrease (silt, 0.79; clay, 0.40; soil moisture, 0.65; soil organic matter content, 0.31; salinity, 0.52; altitude, -0.47; sand, -0.70). Species best explained by CCA1 were glycopytes, as well as *Setaria × pycnocomma* (Sp) and *S. japonica* (Sj), the pioneer halophytes. In the positive direction along CCA2, SM and clay contents tended to increase and pH and salinity tended to decrease (SM, 0.40; clay, 0.31; pH, -0.31; salinity, -0.36). Species best explained by CCA2 were *S. glauca* (Sg), *Setaria × pycnocomma* (Sp), *S. maritima* (Sm), and *H. japonicus* (Hj). Group A was found at a wide range of altitudes and in areas with lower salinity than the average. *P. communis* tended to overlap with other taxa, while *S. japonica* was frequently found alone in areas with high salinity. The silt content, SOM content, SM, and clay content showed similar trends in the CCA.

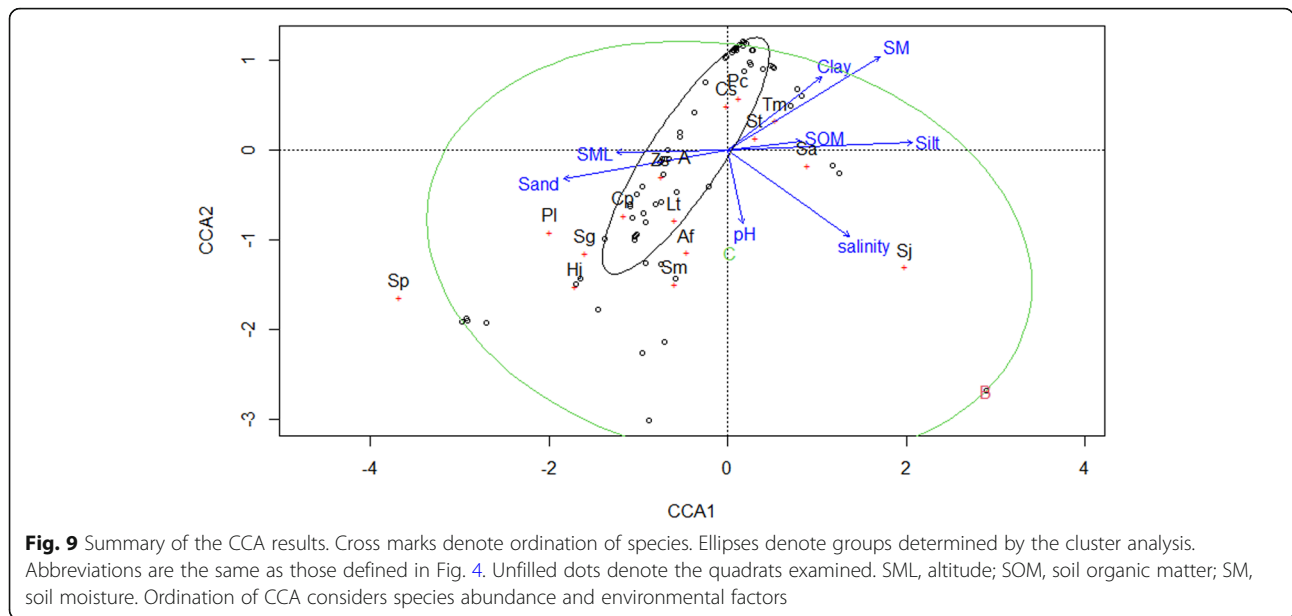
**Spatial distribution of environmental conditions**

To visualize variation in environmental factors at the study sites, kriging was used for spatial interpolation. Moran’s *I* revealed positive spatial autocorrelation for SM, pH, sand, clay, and silt at site 1. Site 2 had positive spatial autocorrelation for altitude, SM, SOM, sand, clay, silt, and salinity. Based on a semi-variogram for environmental factors, kriging showed spatial autocorrelation (Fig. 10). We observed that, in general, SM for group A was lower than that in other

**Table 1** Summary of environmental conditions for the three clusters (A, B, and C) and the control groups with means. Standard deviations are presented in parentheses. Superscript letters indicate significant differences between clusters based on Dunn’s test,  $p < 0.05$

	A	B	C	Control
Altitude (m)	3.71 (1.26) <sup>a</sup>	2.82 (0.23) <sup>b</sup>	3.89 (0.73) <sup>a</sup>	3.31 (0.69)
Soil moisture (%)	14.70 (5.03) <sup>a</sup>	17.51 (1.70) <sup>b</sup>	11.96 (5.29) <sup>c</sup>	13.54 (5.83)
Soil organic matter (%)	1.28 (0.62) <sup>a</sup>	1.70 (0.25) <sup>b</sup>	1.24 (0.67) <sup>a</sup>	1.33 (0.57)
pH	6.89 (0.54)	7.23 (0.17)	7.04 (0.59)	7.73 (0.49)
Salinity (ppm)	634.57 (620.74) <sup>a</sup>	1508.54 (367.09) <sup>b</sup>	564.33 (548.07) <sup>a</sup>	1036.58 (537.65)
Sand (%)	45.97 (35.33) <sup>a</sup>	8.71 (8.11) <sup>b</sup>	60.39 (26.31) <sup>a</sup>	35.64 (36.16)
Clay (%)	15.29 (12.33) <sup>a</sup>	17.73 (6.02) <sup>b</sup>	10.59 (8.40) <sup>a</sup>	12.91 (9.17)
Silt (%)	38.74 (23.74) <sup>a</sup>	73.55 (4.85) <sup>b</sup>	29.23 (19.00) <sup>a</sup>	51.45 (30.10)





areas (Fig. 10a, f). Additionally, the soil of group A had a lower silt content than those of other areas in the salt marsh (Fig. 10e, k). For some parameters, predictive power deteriorated, even if the distance from the quadrats was greater.

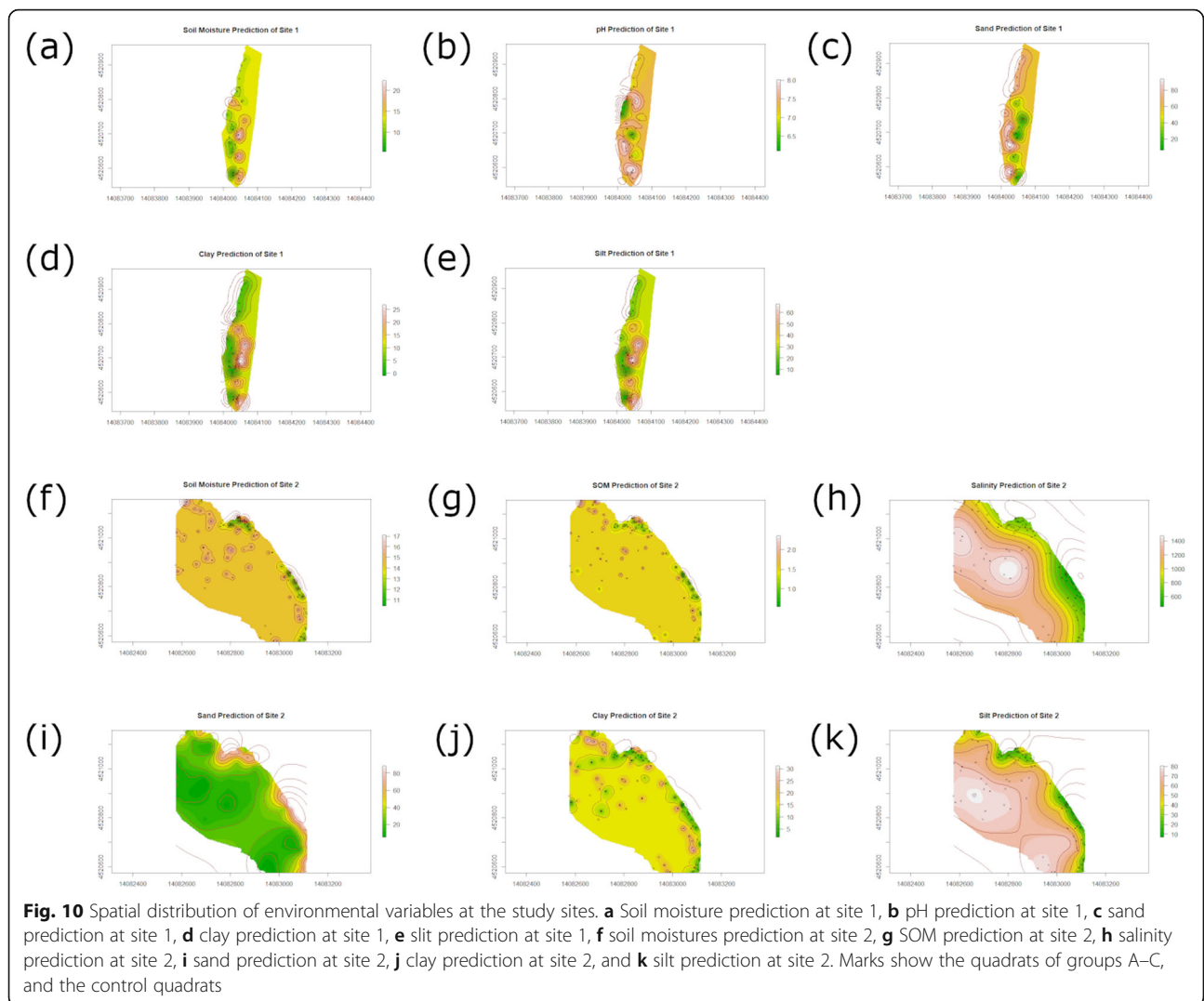
**Discussion**

Our results confirmed that the structure of the salt marsh community is closely related to the values and spatial distribution of environmental factors. The plant community in salt marshes in the southern region of Ganghwa could be divided into group A, dominated by *P. communis*; group B, dominated by *S. japonica*; and group C, dominated by halophytes other than *S. japonica* and *P. communis*. There were significant differences in SM, SOM, salinity, soil texture, and altitude among groups. In particular, environmental conditions associated with group B were significantly different from those of other groups. Pioneer species such as *S. japonica* can survive at lower altitudes due to their strong salt tolerance, and can emerge in soils with high silt ratios (van Regteren et al. 2020; Kim 2018a).

In a CCA of the major environmental factors influencing the distribution of halophytes, the proportion of sand increased as the altitude increased, while SM, silt, clay, and SOM contents, and salinity tended to decrease. Group A, dominated by *P. communis*, was found in areas with lower than average salinity, as observed previously in the Siheung salt marsh (Bang et al. 2018). By contrast, the salinity of *Phragmites* habitats is higher than that of *Carex* habitats in China (Cui et al. 2021).

In an analysis of 128 quadrats with halophyte vegetation and 12 control quadrats with no vegetation, mainly sand (S), silty sand (zS), sandy silt (sZ), and silt (Z) sedimentary facies were detected. These were similar to sedimentary facies in the tidal flat along the west coast determined by the National Marine Ecosystem Monitoring Program from 2015 to 2019 (Ministry of Oceans and Fisheries 2019). Contents of sand and silt for group A, where the *P. communis* community dominated, varied substantially, with average values of 45.97% and 15.29%, respectively. Previously reported contents of sand and clay in coastal salt marshes with *P. communis* were 82.81% and 4.85%, respectively, in southern Korea (Cho, Lee, and Kim 2017), and 2.0% and 44.8%, respectively, in Suncheon Bay (Jang et al. 2013), revealing large differences in soil texture among habitats. There were differences in SM, SOM, salinity, soil texture, and altitude between group B and other groups. Pioneer species such as *S. japonica* have strong salt tolerance and can survive at relatively low altitudes. They are likely to emerge in soils with a relatively high silt content, as the species shows better seeding settlement in soils with small grain sizes, such as silt or clay, than in sand (van Regteren et al. 2020; Kim 2018a).

Altitude correlated significantly with all measured environmental factors. The physical environment varies among altitudes, including variation in the time submerged in seawater and differences in size of sediment particles swept away by waves. Furthermore, different halophyte communities are associated with chemical differences in soil (Bart and Hartman 2000; Santelmann et al. 2019; van Regteren et al. 2020).



Regarding the halophyte community in southern Ganghwa, a higher altitude was associated with a higher sand content and lower SM, silt and clay contents, SOM content, and salinity. In the late 1990s, southern Ganghwa was primarily a silt-rich muddy tidal flat. However, due to large-scale development near Ganghwa Island in the 1990s, currents changed, resulting in continuous sedimentation in southern Ganghwa. The soil texture changed gradually to a sandy mud tidal flat because the sediment is largely sand (Woo 2013). These changes are consistent with the CCA results in the present study, showing that the higher the altitude, the higher the sand content. In this study, the salinity of group A (dominated by *P. communis*) was lower than the average salinity, similar to results for the Siheung salt marsh (Bang et al. 2018). Freshwater influx explains the appearance of *P. communis* in salt marshes, and the rapid range expansion (Bart and Hartman 2000). Site 1 also maintained a

relatively low salinity due to the presence of drainage holes for freshwater inflow. This appears to have become a source area allowing expansion toward oceans with high salinity (Hong 2015).

**Conclusion**

We characterized the halophyte composition in the tidal flats of southern Ganghwa and evaluated the spatial relationship between the distribution of halophytes and environmental factors. A cluster analysis revealed that the halophyte communities in the study area could be assigned to three groups: *P. communis*, *S. japonica*, and other halophyte communities. The *S. japonica* community was distributed in areas with a relatively high silt content. The *P. communis* community appeared in a wider range of soil textures than those reported in the literature. These results provide essential information about changes in spatial distribution in salt marshes, which may facilitate conservation or restoration.

**Appendix 1**

**Table 2** List of plant species observed at the study sites. Taxa marked with an asterisk are halophytes classified by KOEM (2019)

Family	Species
<b>Amaranthaceae</b>	<i>Achyranthes japonica</i> (Miq.) Nakai
	<i>Amaranthus retroflexus</i> L.
	<i>Portulaca oleracea</i> L.
<b>Cannabaceae</b>	<i>Humulus japonicus</i> Siebold & Zucc.
<b>Caryophyllaceae</b>	<i>Cucubalus baccifer</i> var. <i>japonicus</i> Miq. <i>Spergularia marina</i> (L.) Besser*
<b>Chenopodiaceae</b>	<i>Chenopodium album</i> var. <i>centrorubrum</i> Makino
	<i>Chenopodium ficifolium</i> Smith
	<i>Salsola komarovii</i> Iljin*
	<i>Suaeda glauca</i> (Bunge) Bunge*
	<i>Suaeda japonica</i> Makino
	<i>Suaeda maritima</i> (L.) Dumort*
<b>Commelinaceae</b>	<i>Commelina communis</i> L.
<b>Compositae</b>	<i>Ambrosia artemisiifolia</i> L.
	<i>Artemisia capillaris</i> Thunb.*
	<i>Artemisia fukudo</i> Makino*
	<i>Artemisia princeps</i> Pamp.
	<i>Bidens bipinnata</i> L.
	<i>Conyza canadensis</i> (L.) Cronquist
	<i>Conyza sumatrensis</i> E.Walker
	<i>Eclipta prostrata</i> (L.) L.
	<i>Erechtites hieracifolia</i> Raf.
	<i>Sigesbeckia pubescens</i> (Makino) Makino
	<i>Sonchus brachyotus</i> DC*
<b>Convolvulaceae</b>	<i>Calystegia soldanella</i> (L.) Roem. & Schult*
<b>Cruciferae</b>	<i>Capsella</i> sp.
<b>Cyperaceae</b>	<i>Bolboschoenus planiculmis</i> (F.Schmidt) T.V.Egorova*
	<i>Carex scabrifolia</i> Steud.*
	<i>Carex pumila</i> Thunb.*
	<i>Cyperus amuricus</i> Maxim.
	<i>Schoenoplectus tabernaemontani</i> (C.C.Gmel.) Palla
<b>Fagaceae</b>	<i>Castanea crenata</i> Siebold & Zucc.
	<i>Quercus acutissima</i> Carruth.
<b>Gramineae</b>	<i>Digitaria ciliaris</i> (Retz.) Koel.
	<i>Echinochloa crus-galli</i> (L.) P.Beauv.
	<i>Miscanthus sinensis</i> var. <i>purpurascens</i> (Andersson) Rendle
	<i>Panicum bisulcatum</i> Thunb.
	<i>Phacelurus latifolius</i> (Steud.) Ohwi*
	<i>Phragmites communis</i> Trin.*
	<i>Setaria faberii</i> Herrm.
	<i>Setaria viridis</i> (L.) P.Beauv.
	<i>Setaria x pycnocomma</i> (Steud.) Henrard ex Nakai
	<i>Spartina anglica</i> C.E.Hubb.*

**Table 2** List of plant species observed at the study sites. Taxa marked with an asterisk are halophytes classified by KOEM (2019) (Continued)

Family	Species
	<i>Themeda triandra</i> var. <i>japonica</i> (Willd.) Makino
	<i>Zoysia sinica</i> Hance*
<b>Juncaceae</b>	<i>Juncus haenkei</i> E.Mey.*
<b>Juncaginaceae</b>	<i>Triglochin maritima</i> L.*
<b>Labiatae</b>	<i>Leonurus japonicus</i> Houtt.
<b>Leguminosae</b>	<i>Amorpha fruticosa</i> L.
	<i>Pueraria lobata</i> (Willd.) Ohwi
	<i>Vigna angularis</i> var. <i>nipponensis</i> (Ohwi) Ohwi & H.Obashi
<b>Malvaceae</b>	<i>Abutilon theophrasti</i> Medicus
<b>Menispermaceae</b>	<i>Cocculus trilobus</i> (Thunb.) DC.
<b>Oxalidaceae</b>	<i>Oxalis stricta</i> L.
<b>Pinaceae</b>	<i>Pinus densiflora</i> Siebold & Zucc.
<b>Plumbaginaceae</b>	<i>Limonium tetragonum</i> (Thunb.) Bullock*
<b>Polygonaceae</b>	<i>Persicaria longiseta</i> (Brujin) Kitag.
	<i>Polygonum bellardii</i> All.* <i>Rumex crispus</i> L.
<b>Portulacaceae</b>	<i>Portulaca oleracea</i> L.
<b>Solanaceae</b>	<i>Datura meteloides</i> DC. ex Dunal
<b>Vitaceae</b>	<i>Parthenocissus tricuspidata</i> (Siebold & Zucc.) Planch.
<b>Number of species</b>	<b>61</b>

**Appendix 2**

**Table 3** Area of vegetation in each salt marsh (m<sup>2</sup>). Values in parentheses indicate the number of quadrats surveyed

Species	A	B	C
<i>Artemisia fukudo</i> Makino			222.6 (5)
<i>Carex pumila</i> Thunb.			100.3 (3)
<i>Carex scabrifolia</i> Steud.			573.1 (9)
<i>Limonium tetragonum</i> (Thunb.) Bullock			11.2 (2)
<i>Phragmites communis</i> Trin.	22,683.3 (46)		
<i>Phacelurus latifolius</i> (Steud.) Ohwi			280.4 (3)
<i>Spartina anglica</i> C.E.Hubb.			48.1 (2)
<i>Suaeda glauca</i> (Bunge) Bunge			12.3 (2)
<i>Suaeda japonica</i> Makino		45,236.3 (22)	
<i>Suaeda maritima</i> (L.) Dumort			15.2 (2)
<i>Triglochin maritima</i> L.			528.8 (12)
<i>Zoysia sinica</i> Hance			1344.7 (20)
<b>Total vegetated salt marsh area</b>	<b>22,683.3</b>	<b>45,236.3</b>	<b>3136.7</b>

### Abbreviations

CCA: Canonical correspondence analysis; NMDS: Non-metric multidimensional scaling; PERMANOVA: Permutational multivariate analysis of variance; QGIS: Quantum geographic information system; RTK: Real time kinematic

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### Authors' contributions

JC carried out the field study, performed the analysis, and wrote the manuscript. JHK participated in the field study and wrote and reviewed the manuscript. E.J.L. conceived the study and reviewed the manuscript. JC and JHK made equal contributions to this study. All authors read and approved the final manuscript.

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### Availability of data and materials

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

### Declarations

#### 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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