이학석사 학위논문

Vegetation change of natural salt marsh for past 16 years at Donggeom, Ganghwa island

2021 년 2 월

서울대학교 대학원

생명과학부 식물생태학 전공

정재상

Vegetation change of natural salt marsh for past 16 years at Donggeom, Ganghwa island

지도교수 이 은 주

이 논문을 이학석사 학위논문으로 제출함

2021 년 02 월

서울대학교 대학원
생명과학부
정재상

정재상의 이학석사 학위논문을 인준함
2020 년 12 월

위 원 장 정충원 (인)
부위원장 이 은 주 (인)
위 원 신 승 관 (인)

Abstract

Salt marshes are wetlands located on the shore that are exposed or submerged in salt water by waves. As an ecosystem that connects marine ecosystems and terrestrial ecosystems, it has high absorption of carbon and heavy metals and is a home for many organisms. Changes in the rate of sea level rise, the amount of sediment inflow or outflow, and nutrients due to human influence can reduce the area of the salt marsh. In Donggeom-do, Ganghwa, there are some natural salt marshes. However, since 1980, many reclamation and construction projects have been carried out in the waters near Ganghwa Island due to the construction of the Gimpo landfill site and the Incheon International Airport, resulting in sedimentation up to 7 cm per year in the eastern tidal flat of Donggeom-do in the 2000s. Although the sedimentation rate in the eastern tidal flat of Donggeom-do stabilized in 2010, it was necessary to observe how the area and vegetation of the salt marsh had changed. I checked the vegetation changes in the salt marsh over 16 years where a preceding researcher surveyed the vegetation of it in 2004.

As a result of vegetation surveys on the salt marshes in the eastern part of Donggeom-do (site 1) and the salt marshes in the western part (site 2), a total of 61 species occurred, including 20 species of halophytes. Site 1 was distributed with *Phragmites communis, Carex*

scabrifolia, Triglochin maritima, and *Zoysia sinica* communities, and site 2 had 12 dominant halophyte communities including *P. communis* and *Suaeda japonica* communities. Depending on the area of each communities, a total of 128 square quadrats with a size of 1 x 1 m^2 were installed to measure coordinates, altitude, coverage of each species occurred in the quadrat, height of the above−ground part of the species and cover of bare ground. Based on the occurrence/absence data with their coverage, I conducted a cluster analysis by Ward. D linkage method with Bray−Curtis dissimilarity matrix. It was divided into cluster A, dominated by *P. communis*, cluster B, dominated by *S. japonica*, and cluster C, communities except *P. communis* and *S. japonica*.

As a result of comparing the area of each communities of the salt marsh based on the existing vegetation and the data in 2004, the *P. communis* community increased from 944.8 m^2 to 5085.1 m^2, while *Limonium tetragonum* and *S. japonica* communities disappeared, resulting in a total area from 1625.0 m^2 to 5661.4 m^2, increased less than the area increase of the *P. communis* community. At the location where the *S. japonica* community disappeared, there was a *T. maritima* community. As a result of comparing the area of *P. communis* community between 2004 and 2020 using orthoimages in polygons, it was confirmed that the area of *P. communis* community increased over the past 16 years.

As a result of checking whether there are differences by environmental factors between the clusters previously divided by PERMANOVA, it was found that there were significant differences in altitude, soil moisture, soil organic matter, salinity, sand, clay and silt ratios. CCA analysis based on the coverage of each species occurred in the quadrat resulted the proportion of sand increased as the altitude increased. It was found that the *S. japonica* appeared in soil with a relatively high silt proportion. In the case of the *P. communis* community, it was confirmed that it distributed at a lower salinity. It seems that the *P. communis* community can expand toward the salty sea, with the drainage which fresh water flows as the source area.

....

Key words: coastal salt marsh, Donggeom-do, vegetation change, halophyte, *Phragmites communis*

Student number: 2019-22418

Table of Contents

List of Tables

List of Figures

Chapter Ⅰ. General introduction

1.1 Definition of salt marsh

Salt marshes are wetlands located on the shore that are exposed or submerged in salt water by waves and can be divided into coastal salt marshes and estuary salt marshes according to their location. Salt marshes are classified into low marsh and high marsh depending on the altitude, that is, the time of submerged in salt water, and also according to the vegetation that emerges (Ranwell 1972; Petersen, Kers, and Stock 2014). There are many concerns that the salt marsh area will decrease due to sea level rise caused by recent climate change. However, since the altitude of the salt marsh increases as the sea level rises, and the salt marsh may expand to land, there are few cases in which the area of the salt marsh actually decreases (Kirwan et al. 2016). But if the salt marsh is artificially built on the boundary of the coastline so that it cannot move forward to the land, or the amount of sediment, the supply of nutrients, and the rate of sea level rise are changed due to construction, the salt marsh area may decrease (Pontee 2013; Kirwan and Megonigal 2013). In Korea, most of the land near the coastline has been used by people for farming, houses, factories, and sightseeing since the past, and artificial levees are built on the boundary of the coastline and are constantly affected by humans. So it is necessary to check changes in vegetation and area of salt marshes (Je et al. 1999).

1.2 Change detection of vegetated area on salt marsh

There are several ways to observe changes in salt marsh area or vegetation. The most direct method is to install permanent quadrats and continue on-site surveys. (Chen et al. 2020; Olff et al. 1997; Roozen and Westhoff 1985). Monitoring vegetation changes at one site has an advantage of being able to check the succession process, but there a disadvantage that it takes too long time to confirm the succession. There is also an indirect method of estimating the change in the area of the salt marsh or the surrounding land use by comparing the old map with the current coastline. Recently, a technique has been developed to gather information of salt marshes using high-resolution satellite images, aerial photographs, and drones, and then to classify the community as well as the total area of the salt marsh with an unsupervised classification procedure or a supervised classification procedure (Burns, Alber, and Alexander 2020; Sunwoo et al. 2016; Sunwoo, Nguyen, and Choi 2018; Belluco et al. 2006). In this method, more accurate results can be obtained by gathering information to places where it is difficult for people to enter, but some halophytes appear to be difficult to distinguish.

1.3 *Phragmites communis* at salt marsh

Phragmites communis Trin. (or *Phragmites australis* (Cav.) Trin. ex Steud.) is a perennial herb belonging to Gramineae and is an arbitrary halophyte, not an absolute halophyte that requires Na^+ for survival, but can inhabit a very wide range of salt concentrations (Burdick and Konisky 2003). In addition, it is also resistant to water level, so it has been shown to survive even at a water level of 75 cm (Vretare et al. 2001). In the United States, *P. australis* appearing in salt marshes is regarded as an invasive species, and studies are conducted on the causes of their expansion or prevention of expansion, mainly in relation to human development activities (Bertness, Ewanchuk, and Silliman 2002; Bart and Hartman 2000). Bart and Hartman (2000) found that fresh water from the mosquito dike reduced the concentration of sulfides in the surrounding soil, providing a suitable environment for *P. australis* to live.

1.4 Salt marshes of Donggeom-do, Ganghwa

Ganghwa Island is located in the estuary of the Han River and has been subjected to a lot of development interference from the past. Many reclamation and construction projects were carried out in the waters near Ganghwa for the construction of the Gimpo landfill site and Incheon International Airport since 1980, particularly in the

1990s such as the connection between Yeongjong−do and Yongyu−do and construction of the airport expressway. As a result, abnormal sedimentation of up to 7 cm per year occurred in the tidal flats in the east of Donggeom−do in the 2000s (Jung et al. 2008). Lee et al. (2011) was able to calculate the decrease in the velocity of ocean currents in the eastern part of Ganghwa, where sedimentation was actively occurring with the hydrodynamic modeling using satellite images. It was confirmed that the sedimentation rate was around 1 cm per year in 2010, and that rate of sedimentation shows that the tidal flat is in equilibrium as the upper tidal flat (Woo, Jang, and Kwon 2012; MOF 2019). A study on salt marshes conducted in Donggeom−do revealed that the zonal distribution of halophytes is related to environmental factors such as salinity and exposure time, and that the halophyte community is related to organic matter content (Lee et al. 2006; 2016). And in the summer of 1999, there is a data that visited 7 salt marshes on Donggeom−do and examined the 20 species of coastal plants that appeared there (Je et al. 1999). Shin, Kim, and Lee (2020) studied the effect on *Spartina anglica* C.E.Hubb. seed settlement at *Suaeda japonica* Makino community in Donggeom. Lee, Lee, and Kim (2018) visited 13 salt marshes on the west coast of Korea, including Dongmak−ri, Ganghwa, and Donggeom−do, to investigate the relationship between the distribution of halophyte and soil environmental factors.

1.5 Objectives of this study

Currently, there are no studies in the Kyonggi-Bay area that have monitored the vegetation of natural coastal salt marshes for more than 10 years. Therefore, I visited the salt marshes of Donggeom-do, Ganghwa, and conducted a vegetation survey where the vegetation map surveyed in 2004 by another preceding research is existing. I wanted to observe how vegetation changes in salt marshes where the sedimentation rate is equilibrated.

To do this, I asked some questions to find the answers.

1) Has there been any change in the area and species composition of the salt marsh?

2) Is there any change in the area of the salt marsh in aerial photography?

3) What environmental factors affect the distribution of salt marsh community?

The results of this study are expected to provide basic data for the evaluation of vegetation changes in salt marshes near Kyonggi-Bay in Korea.

Chapter Ⅱ. Vegetation change at salt marshes of Donggeom−do for last 16 years (2004 – 2020)

2.1 Introduction

Coastal salt marshes are ecosystems that connect terrestrial and marine ecosystems, have high absorption of carbon and heavy metals, and are home to many living things (McLeod et al. 2011; Lutts and Lefèvre 2015). It is said that it is unlikely that the area of the salt marsh will decrease due to sea level rise affected by recent climate change. However, it has been found that there are some cases in which the area of the salt marsh may decrease if changes in the sedimentation speed occur due to human influence, such as building a levee or carrying out a construction near shoreline (Kirwan et al. 2016; Kirwan and Megonigal 2013). In the case of Korean salt marshes, an unsupervised classification procedure was applied to KOMPSAT-2 satellite images in 2009, 2014, and 2015 to confirm changes in the area of salt marshes, tidal flats, and buildings of Daebudo, Julpoman and Gochang, and Jeongdo tidal flats. And it was found that the area of salt marshes in Gyeonggi decreased by 20% (Sunwoo, Nguyen, and Choi 2018). In addition, 11 ha of *S. japonica* community disappeared in 2007 due to the rapid sedimentation rate in east of Donggeom-do, Ganghwa (Lee et al. 2014).

A representative example of systematic observation of vegetation changes in salt marshes is the study of the Wadden Sea. In the Wadden Sea, which spans Germany, Denmark and the Netherlands, researchers observed changes in species abundance and dominance in areas with or without disturbances such as herbivory and aboveground removal for 46 years. As a result, it was confirmed that in the absence of disturbance, the late successional species, *Elymus athericus* (Link) Kerguélen, dominated and the species abundance decreased, but when there was disturbance, the species abundance was maintained and the mid-transient species, *Festuca rubra* L. dominated (Chen et al. 2020). Kim (2018a; 2018b) observed changes in vegetation by installing permanent quadrats, and found that the distribution of stress-tolerant plants decreases at low altitudes and increases in competitive plants growing in upper salt marshes over six years. In addition, while it is generally known that the distribution of halophyte species is highly influenced by altitude, a model was suggested that other factors other than altitude would affect the distribution of species. In the United States, as a result of comparing the vegetation of the restored salt marsh with the natural salt marsh, it was confirmed that if there are invasive plants in the vegetation before restoration, the invasive species dominates even if the inflow of native plants is sufficient (Clifton, Hood, and Hinton 2018).

There are not many cases in Korea that have observed long-term changes in coastal salt marshes. As a representative example, as a result of monitoring Hampyeong Bay for 10 years, it was confirmed that the area of the halophyte community as a whole increased but fragmented, and the community area decreased in 2013 (Yun et al. 2018). Since 2015, the research has been conducted on tidal flats across the country at the national level to determine the vegetation, area, and other environmental factors of salt marshes once every two years, but some tidal flats are excluded from the survey. Ganghwa Island is located in the estuary of the Han River, and has been subjected to high development pressure and interference from development from the past. Many reclamation and construction projects were carried out in the waters near Ganghwa-do, for the construction of the Gimpo landfill site and the Incheon International Airport, which began in 1980, especially in the 1990s including the connection between Yeongjong-do and Yongyu-do and the Airport Expressway. As a result, in the eastern tidal flat of Donggeom-do, sedimentation of up to 7 cm per year occurred in the 2000s (Korea Institute of Ocean Science & Technology 2008). However, in 2010, it stabilized at an average annual deposition rate of 1 cm (Woo, Jang, and Kwon 2012; MOF 2019).

The study site is not included in the salt marshes subject to the National Marine Ecosystem Monitoring Program, and the vegetation map surveyed in 2004 exists, or even if the vegetation map does not exist, the results of the study of the coverage of halophyte appeared by installing a transect based on a point on the shoreline in Donggeom-do, Ganghwa. I visited there to conduct vegetation surveys to observe how vegetation changes took place in the salt marsh where the sedimentation rate was balanced. This study predicted that the area of upper salt marshes such as *P. communis* would increase, but the area of pioneer species such as *S. japonica* would decrease as it continuously undergoes 1 cm of sedimentation per year.

2.2 Methods

2.2.1. Study sites

The study was conducted in Donggeom-do, Ganghwa, with East (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 (Figure 1). Yangdo (500), which is the closest to the research site, has an annual average temperature of 11.5 ℃ for the last 10 years and an average annual rainfall of 1169.9 mm (KMA 2020). The average tidal range measured over the three years from 2016 to 2018 at the tide observation point of Yeongjong Bridge, located near the research site, is 6.4 m (KHOA 2016; 2017; 2018).

For Site 1, a preceding researcher Lee (2011) installed 1 x 1 m^2 quadrats in a homogeneous plantings in 2004, and recorded the cover, abundance and local conditions using the plant sociological method of Braun-Blanquet (1964). Existing vegetation map was created with a scale of 1:5000, and a small artificial bank was installed to induce the growth of *S. japonica*. Visited in 2020, the southern part of Site 1 was created as a tidal flat experience site, and a trail that goes down next to the road was made so that access to the tidal flat and the salt marsh was free. There was a drainage hole near the land where the *P. communis* community was widely distributed, and water used in the surrounding houses and farmland was flowing out. In some of the *P. communis* communities, there was a lot of disturbance caused by the activities of the surrounding residents, such as the removal of the above−ground part to keep the ships bound.

In Site 2, Lee et al. (2006) installed a transect toward the sea in 1997 and collected the types of cover, above−ground and underground parts that appeared in a 50 x 50 cm^2 quadrats, and grasped the relationship between environmental factors such as soil and climate. It is in contact with various crops and mugwort fields to the northwest and a sandy beach to the east. This is the place where *S. anglica* appeared in the past and removal was performed, but in a field survey conducted in 2020, it was confirmed that *S. anglica* was distributed in a patch form, and some invaded the *P. communis* community to grow. In Site 2, there was no physical effect on the plant community such as removing the above−ground part like Site 1, but the village residents dumped household waste on the upper part of the salt marsh, and household waste was accumulated in the salt marsh community. And on top of the artificial retaining wall, a new pension was constructed in 2019, where additional environmental disturbances were concerned.

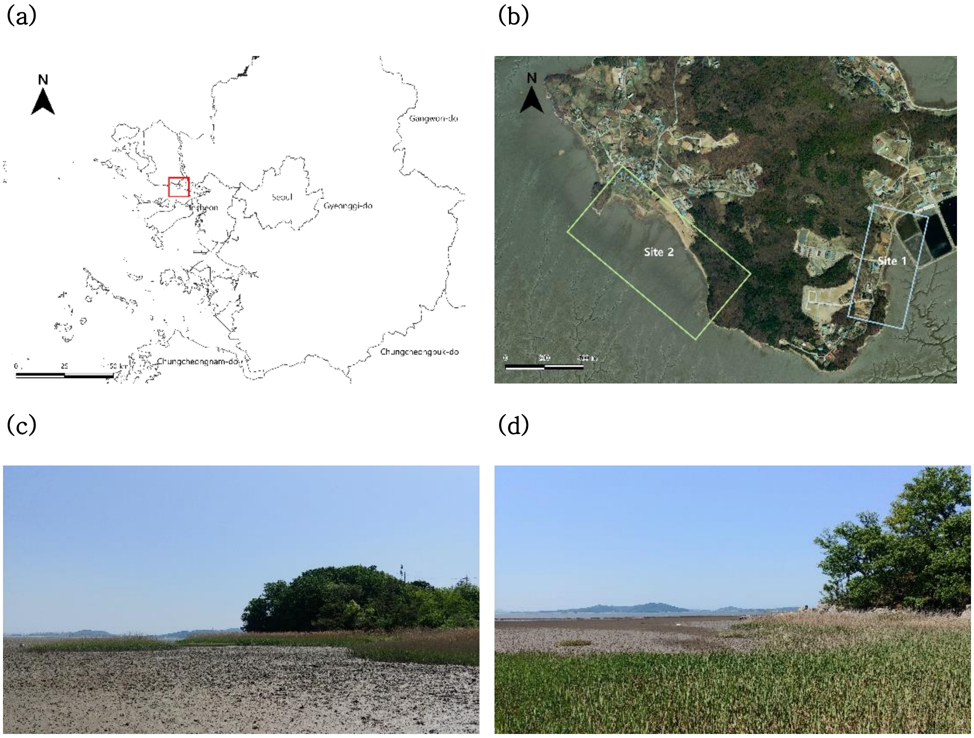


Figure 1. Locations of study sites. (a) Donggeom−do is part of Incheon. Scale of 1:800,000. (b) Site 1 salt marsh is in east of Donggeom−do, and Site 2 salt marsh in west of Donggeom−do. Scale of 1:8,000. (c) View of Site 1. (d) View of Site 2.

2.2.2. Fields surveys

Vegetation surveys were conducted through field surveys from July to October 2020. Species that appeared in the sites were recorded on the basis of artificial retaining walls, natural cliffs, and high ground, so that the erosion of waves did not occur and the dead *P. communis* piled up like a bank. Plant communities were classified on the basis of 30% or more coverage, excluding the *S. japonica* community. Species that could not be identified in the field were collected and identified in the laboratory using Lee (2003), Cho, Kim and Park (2016) and Kim (2008). The scientific name followed the Korea Biodiversity Information System (http://www.nature.go.kr/main/Main.do) excluding *S. anglica*. The scientific name of *S. anglica* was followed from the biodiversity of the Korean Peninsula (https://species.nibr.go.kr/index.do) of the National Institute of Biological Resources (NIBR). For a list of halophyte, I refered to Protocol of National Marine Ecosystem Monitoring Program (MOF/KMEM 2019). By calculating the area for each community obtained using the network-RTK connected to the mobile antenna, 2 to 25 random points were set in QGIS according to the area of the community. Temporary quadrats with a size of 1 x 1 m^2 were installed at the location of the resulting random points, and the coordinates, altitude, emergence species and their coverage, bare ground coverage, and the height of five plants by species were recorded for each quadrat (Figure 2 (a)). Coverage was recorded in increments of 0.05% for less than 1%, 1% for 1% to 50%, and 5% for 50% or more. During the low tide period, three soil samples around the quadrat were scooped out to a depth of 15 cm for each quadrat, placed in a zipper bag, transported to the laboratory, and refrigerated at 4°C.

2.2.3. Vegetation mapping

The GPS received from network−RTK (PX1122R; NavSpark 2020) was connected to a tablet (SM−T830; Samsung 2018) at the site. With QField for GIS version 1.5.8 (OPENGIS.ch 2020) installed in the tablet, polygons representing the boundaries of each community were created at the site and the existing vegetation map was drawn (Figure 2 (b)). In the case of the *S. japonica* community of Site 2, it was spread out to a very distant place, so it was impossible to create polygons by walking the boundaries of the community with an RTK receiver. So, I used a drone (Mavic pro; DJI Co. 2017) to draw a polygon of *S. japonica* community. After shooting the area of *S. japonica* with a drone, the 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 in indoors manually with the TIFF file (Figure 2 (c)). Existing vegetation map was completed by correcting errors in the laboratory.

(a) (b)

(c)

Figure 2. Parts of field survey. (a) Used 1 x 1 m^2 quadrats to survey coverages and heights of species. (b) Making vegetation maps with network-RTK GPS. (c) A map showing distributions of *Suaeda japonica* by merging images taken with drone. The image's north is on left.

2.2.4. Comparison of salt marsh vegetated area

For Site 1, the changes in the area and species of the salt marsh were confirmed by comparing the existing vegetation data and species data surveyed by Lee (2011) in 2004. The similarity between the species appearing in 2004 and 2020 was calculated using the 'vegan' package of R (Oksanen et al. 2020). The existing vegetation map drawn by Lee (2011) was referenced with the georeferencer of QGIS version 3. 10. 11 (QGIS.org 2020), and the halophyte community was drawn as polygon and the area was confirmed.

Since there are many annual herbaceous species in halophytes and the size of the halophyte community can change significantly due to the sedimentation rate caused by ocean currents (Lee et al. 2014), additional data are needed to support the vegetation change over 16 years. For this, orthophotos provided by National Geographic Information Institute (NGII) was used (Table 1). In the case of the *P. communis* community, it can be easily checked manually from the image data, so the geometrically corrected image was compared with the changes in the area of *P. communis* by year by drawing polygons in QGIS.

Table 1. Images used in vegetated area of salt marsh comparison.

Image source	Spatial resolution	Image date
Orthophoto (provided by NGII)	Multispectral: 0.25 m	2010-09-15
		2014-04-06
		2016-05-22
		2018-04-16

2.2.5. Statistical analysis

The difference in area by community was significant, and the difference in the number of quadrats selected by reflecting the area of the community was also large. So, it was difficult to compare the soil environmental factors affecting the community, so cluster analysis was conducted based on the coverage data of species that appeared in each quadrat. Based on the Bray-Curtis dissimilarity matrix, the cluster was divided by Ward. D linkage method of the 'NbClust' package of R (Charrad et al. 2014). For the divided clusters, the similarity between quadrats and emergent species was visualized using Non-metric Multidimensional Scaling (NMDS) based on the Bray-Curtis dissimialrity matrix between quadrats. All statistical analysis was performed with R version 4.0.3 (The R Foundation for Statistical Computing 2020).

2.3 Results

2.3.1. Salt marsh vegetation of east and west Donggeom

As a result of field surveys, 31 species were found in site 1, 51 species were found in site 2, and a total of 61 species appeared (Table 2). Among 135 species defined as halophyte in the Protocol of National Marine Ecosystem Monitoring Program, 11 species appeared in Site 1 and 18 species were found in Site 2. In the case of Site 1, the vegetation of the salt marsh could be divided into *P. communis*, *Triglochin maritima* L., *Zoysia sinica* Hance, *Carex scabrifolia* Steud. communities. Vegetation of the salt marsh at site 2 could be divided into *S. japonica*, *P. communis*, *Z. sinica*, *C. scabrifolia*, *T. maritima*, *Phacelurus latifolius* (Steud.) Ohwi, *Artemisia fukudo* Makino, *Carex pumila* Thunb., *S. anglica*, *Suaeda maritima* (L.) Dumort, *Suaeda glauca* (Bunge) Bunge, *Limonium tetragonum* (Thunb.) Bullock communities. In particular, the *S. japonica* community was sparsely distributed in the tidal flat (Table 3, Figure 3).

Table 2. List of plant species occurred in study sites. * means halophytes, classified by KOEM (2019)

Family	Species	Site 1	Site 2
Amaranthaceae	*Achyranthes japonica* (Miq.) Nakai	0	
	Amaranthus retroflexus L.	0	
	Portulaca oleracea L.	0	
Cannabaceae	*Humulus japonicus* Sieboid & Zucc.		0
Caryophyllaceae	*Cucubalus baccifer* var. *japonicus* Miq.	0	
	Spergularia marina (L.) Besser*		0
Chenopodiaceae	*Chenopodium album* var. *centrorubrum* Makino		0
	Chenopodium ficifolium Smith	0	
	Salsola komarovii Iljin*		0
	Suaeda glauca (Bunge) Bunge*	0	0
	Suaeda japonica Makino*	0	0
	Suaeda maritima (L.) Dumort*	0	0
Commelinaceae	*Commelina communis* L.		0
Compositae	*Ambrosia artemisiifolia* L.	0	0
	Artemisia capillaris Thunb.*		0
	Artemisia fukudo Makino*		0
	Artemisia princeps Pamp.	0	0
	Bidens bipinnata L.		0
	Conyza canadensis (L.) Cronquist	0	0

Family	Species	Site 1	Site 2
Compositae	*Conyza sumatrensis* E.Walker		0
	Eclipta prostrata (L.) L.	0	
	Erechtites hieracifolia Raf.		0
	Sigesbeckia pubescens (Makino) Makino		0
Compositae	*Sonchus brachyotus* DC.*	0	
Convolvulaceae	*Calystegia soldanella* (L.) Roem. & Schultb.*		0
Cruciferae	*Capsella* sp.		0
Cyperaceae	*Bolboschoenus planiculmis* (F.Schmidt) T.V.Egorova*	0	0
	Carex scabrifolia Steud.*	0	0
	Carex pumila Thunb.*		0
	Cyperus amuricus Maxim.	0	0
	Schoenoplectus tabernaemontani (C.C.Gmel.) Palla		0
Fagaceae	*Castanea crenata* Siebold & Zucc.		0
	Quercus acutissima Carruth.		0
Gramineae	*Digitaria ciliaris* (Retz.) Koel.	0	0
	Echinochloa crus-galli (L.) P.Beauv.	0	0
	Miscanthus sinensis var. *purpurascens* (Andersson) Rendle		0
	Panicum bisulcatum Thunb.	0	

Family	Species	Site 1	Site 2
Gramineae	*Phacelurus latifolius* (Steud.) Ohwi*		0
	Phragmites communis Trin.*	0	0
	Setaria faberii Herrm.	0	0
	Setaria viridis (L.) P.Beauv.	0	0
	Setaria x *pycnocoma* (Steud.) Henrard ex Nakai		0
	Spartina anglica C.E.Hubb.*		0
	Themeda triandra var. *japonica* (Willd.) Makino		0
	Zoysia sinica Hance*	0	0
Juncaceae	*Juncus haenkei* E.Mey.*		0
Juncaginaceae	*Triglochin maritima* L.*	0	0
Labiatae	*Leonurus japonicus* Houtt.	0	0
Leguminosae	*Amorpha fruticosa* L.		0
	Pueraria lobata (Willd.) Ohwi		0
	Vigna angularis var. *nipponensis* (Ohwi) Ohwi & H.Ohashi		0
Malvaceae	*Abutilon theophrasti* Medicus		0
Menispermaceae	*Cocculus trilobus* (Thunb.) DC.	0	
Oxalidaceae	*Oxalis stricta* L.		0
Pinaceae	*Pinus densiflora* Siebold & Zucc.	0	0
Plumbaginaceae	*Limonium tetragonum* (Thunb.) Bullock*	0	0

Family	Species	Site 1	Site 2
Polygonaceae	*Persicaria longiseta* (Bruijn) Kitag.	0	
	Polygonum bellardii All.*	0	
	Rumex crispus L.	0	0
Portulacaceae	*Portulaca oleracea* L.		0
Solanaceae	*Datura meteloides* DC. ex Dunal		0
Vitaceae	*Parthenocissus tricuspidata* (Siebold & Zucc.) Planch.		0
Number of species		31	51

Table 3. Area of each salt marsh vegetation (m^2). Values in parentheses mean quadrat numbers surveyed.

Species	Site 1	Site 2
Artemisia fukudo Makino	–	222.6(5)
Carex pumila Thunb.	–	100.3(3)
Carex scabrifolia Steud.	120.9(3)	452.3(6)
Limonium tetragonum (Thunb.) Bullock	–	11.2(2)
Phragmites communis Trin.	5085.1 (20)	17598.2(26)
Phacelurus latifolius (Steud.) Ohwi	–	280.4(3)
Spartina anglica C.E.Hubb.	–	48.1(2)
Suaeda glauca (Bunge) Bunge	–	12.3(2)
Suaeda japonica Makino	–	45236.3(22)
Suaeda maritima (L.) Dumort	–	15.2(2)
Triglochin maritima L.	227.9(6)	300.9(6)
Zoysia sinica Hance	227.6(6)	1117.1(14)
Total vegetated salt marsh area	5661.4	65394.9

(a)

(b)

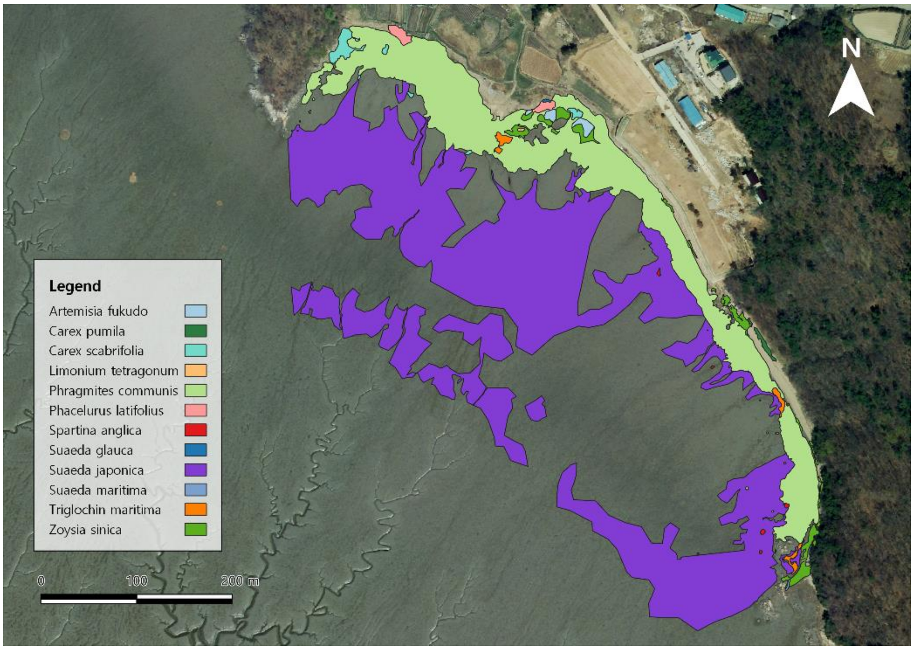


Figure 3. Vegetation map of study sites surveyed in 2020.

(a) site 1. (b) site 2.

As can be seen in Figure 3, the *P. communis* community was greatly developed in both study sites. In particular, in the sandy beach developed to the east of Site 2, sand dune plants such as *C. pumila* also appeared and formed a community, and it was confirmed that the salt marsh was very large and developed as a mixed community of various species. In the *P. communis* community of Site 1, except for the boundaries of the community, only *P. communis* appeared, but in the *P. communis* community of site 2, *T. maritima*, *C. scabrifolia* and , *Schoenoplectus tabernaemontani* (C.C.Gmel.) Palla were found in the lower layer despite the high *P. communis* cover of 80% or more in the upper layer. *A. fukudo* community was occurred together with *P. communis* and *Z. sinica*. *C. scabrifolia* community was frequently appeared with *P. communis* grew up in an upper layer. The *L. tetragonum* community appeared along with *Z. sinica* and *A. fukudo*. The *S. glauca* community appeared with *P. latifolius, P. communis*, and the *Z. sinica* community with *P. communis, L. tetragonum, A. fukudo*, and *S. maritima*.

2.3.2. Result of cluster analysis

As a result of cluster analysis based on the presence/absence and coverage data of species obtained from a total of 128 quadrats, it can be divided into 3 clusters where *P. communis* dominates (A), cluster where only *S. japonica* appears (B), and clusters where the other halophytes dominate (C) (Figure 4). From the results of NMDS, it was confirmed that cluster B had very same species distribution (Figure 5). It was found that the cluster C was more broadly distributed than the cluster A. The occurrence and coverage type of species that can be found in Site 1 can also be confirmed in Site 2. *C. pumila* and *S. japonica* do not appear well together with other plants. *A. fukudo, Z. sinica*, and *L. tetragonum* appear well with *S. maritima*, and *C. scabrifolia* together with *P. communis* and *S. tabernaemontani*. Glycophytes, *Humulus japonicus* Sieboid & Zucc., *Setaria* x *pycnocoma* (Steud.) Henrard ex Nakai and *P. latifolius* seem to appear together.

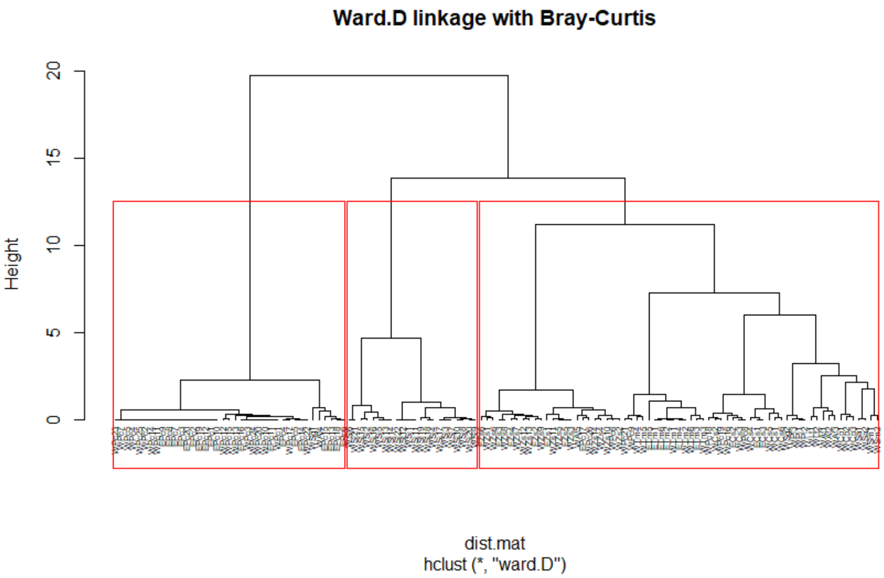


Figure 4. Cluster dendrogram based on occurrence and abundance data of quadrats. Abbreviations are E: site 1, W: site 2, Af: *Artemisia fukudo,* Cp: *Carex pumila*, Cs: *Carex scabrifolia*, Hj: *Humulus japonicus*, Lt: *Limonium tetragonum*, Pc: *Phragmites communis*, Pl: *Phacelurus latifolius*, Sa: *Spartina anglica,* Sg: *Suaeda glauca*, Sj: *Suaeda japonica*, Sm: *Suaeda maritima*, Sp: *Setaria* x *pycnocoma*, St: *Schoenoplectus tabernaemontani,* Tm: *Triglochin maritima*, Zs: *Zoysia sinica.*

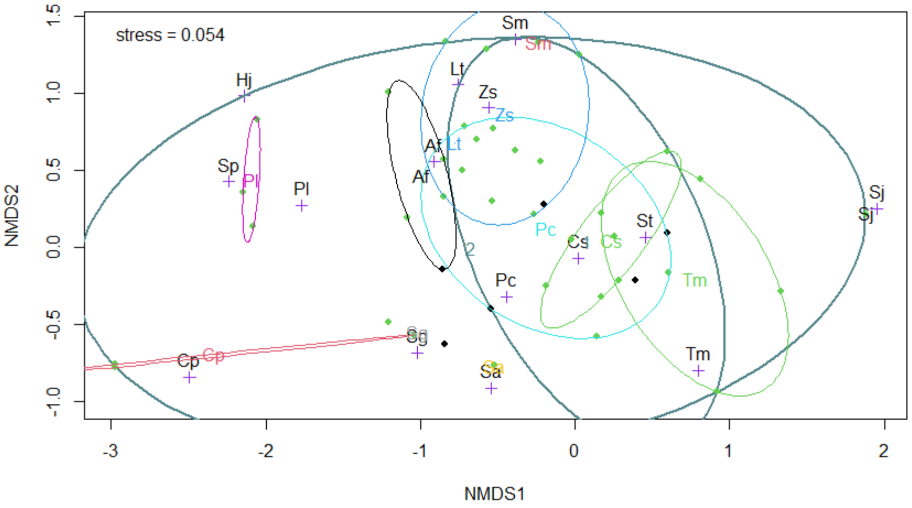


Figure 5. NDMS ordination based on Bray−Curtis dissimilarity distance. Crutches show ordinations of species, points show ordinations of quadrats. Black points are quadrats of group A, and green points are quadrats of group C. Ellipses show species abundance and composition range of study sites and dominant vegetation groups. Abbreviations are same as in figure 4.

2.3.3. Vegetated salt marsh comparison between 2004 and 2020

In site 1, *P. communis, S. japonica, Z. sinica, L. tetragonum*, and *T. maritima* communities were distributed in 2004 (Figure 6). When surveyed the site in 2020, the communities of *P. communis, T. maritima, Z. sinica,* and *C. scabrifolia* were distributed, and few *S. japonica* individuals were found. In the case of *L. tetragonum*, it was sparsely distributed in the *Z. sinica* community. In addition, the total area of the salt marsh increased by about 3.8 times from 1625 m^2 to 5661.4 m^2, and in particular, the area of the *P. communis* community increased more than 5 times from 944.8 m^2 to 5085.1 m^2 (Table 3, 4). The *L. tetragonum* community in 2004 was changed to the *P. communis* or *Z. sinica* community, and the *S. japonica* community was changed to the *T. maritima* community. The *P. communis* community, which was located on the coastline, greatly expanded toward the tidal flat. Some of the *Z. sinica, P. communis* and *T. maritima* communities that were distributed far from the coastline have disappeared, or some of the *Z. sinica* community has been changed to the *P. communis* or *C. scabrifolia* community.

The species appeared increased from 25 species in 2004 to 31 species in 2020. Plants of Amaranthaceae, Gramineae, invasive species *Ambrosia artemisiifolia* L. which is the invasive species and

Compositae, as well as *Cucubalus baccifer* var. *japonicus* Miq., *Chenopodium ficifolium* Smith, *Cyperus amuricus* Maxim., *Leonurus japonicus* Houtt., *Cocculus trilobus* (Thunb.) DC., *Pinus densiflora* Siebold & Zucc., and the halophyte *Bolboschoenus planiculmis* (F.Schmidt) T.V.Egorova newly appeared. Plants of Compositae, Cruciferae, Gramineae, *Chenopodium glaucum* L., *Aeschynomene indica* L., and *Atriplex gmelinii* C. A. Mey. ex Bong. and *C. pumila* belonging to halophyte were not found (Table 5). The Jaccard distance was 0.739 for the species that appeared in site 1 in 2004 and 2020.

Table 4. Area of each salt marsh vegetation (m^2) surveyed on 2004. List was sorted in ascending names of species.

Species	Area (m^2)
Limonium tetragonum	96.8
Phragmites communis	944.8
Suaeda japonica	339.6
Triglochin maritima	63.4
Zoysia sinica	180.5
Total vegetated salt marsh area	1625.0

Figure 6. Vegetation map of site 1 surveyed on 2004. Polygons were re-drawn by scanning the original vegetation map (Lee 2011) and georeferencing the map on basemap.

Table 5. List of plant species occurred in site 1 on 2004. * means halophytes, classified by KOEM (2019)

Family	Species
Chenopodiaceae	*Chenopodium glaucum* L.
	Atriplex gmelinii C. A. Mey. ex Bong.*
	Suaeda glauca (Bunge) Bunge*
	Suaeda japonica Makino*
	Suaeda maritima (L.) Dumort*
Commelinaceae	*Commelina communis* L.

Family	Species
Compositae	*Bidens bipinnata* L.
	Conyza bonariensis (L.) Cronquist
	Ixeris repens (L.) A. Gray*
	Sonchus asper (L.) Hill
	Sonchus brachyotus DC.*
	Sonchus oleraceus L.
Cruciferae	*Lepidium apetalum* Willd.
	Rorippa indica (L.) Hiern
Cyperaceae	*Carex scabrifolia* Steud.*
	Carex pumila Thunb.*
Gramineae	*Agropyron tsukushiense* var. *transiens* (Hack.) Ohwi
	Avena fatua L.
	Phragmites communis Trin.*
	Setaria viridis (L.) P.Beauv.
	Spartina anglica C.E.Hubb.*
	Zoysia sinica Hance*
Juncaginaceae	*Triglochin maritima* L.*
Leguminosae	*Aeschynomene indica* L.
Plumbaginaceae	*Limonium tetragonum* (Thunb.) Bullock*
Polygonaceae	*Persicaria hydropiper* (L.) Delarbre
	Polygonum bellardii All.*

As a result of comparing the area of the *P. communis* community with polygons based on the field survey and orthophotos, it could be confirmed that the area of the *P. communis* community is steadily increasing, although there is a slight variation (Figure 7, Table 6). As shown in Figure 7, the sparsely distributed *P. communis* communities in 2004 merged into one, and although there are slight differences by year, it can be seen that they are gradually expanding toward the sea. And it was confirmed that a new *P. communis* community was formed, which did not exist in the south of site 1.

Table 6. Vegetation area of *Phragmites communis* (m^2) at site 1

Year	Area (m^2)
2004	944.8
2010	4,044.5
2014	3,298.8
2016	4,233.6
2018	4,388.9
2020	5,085.1

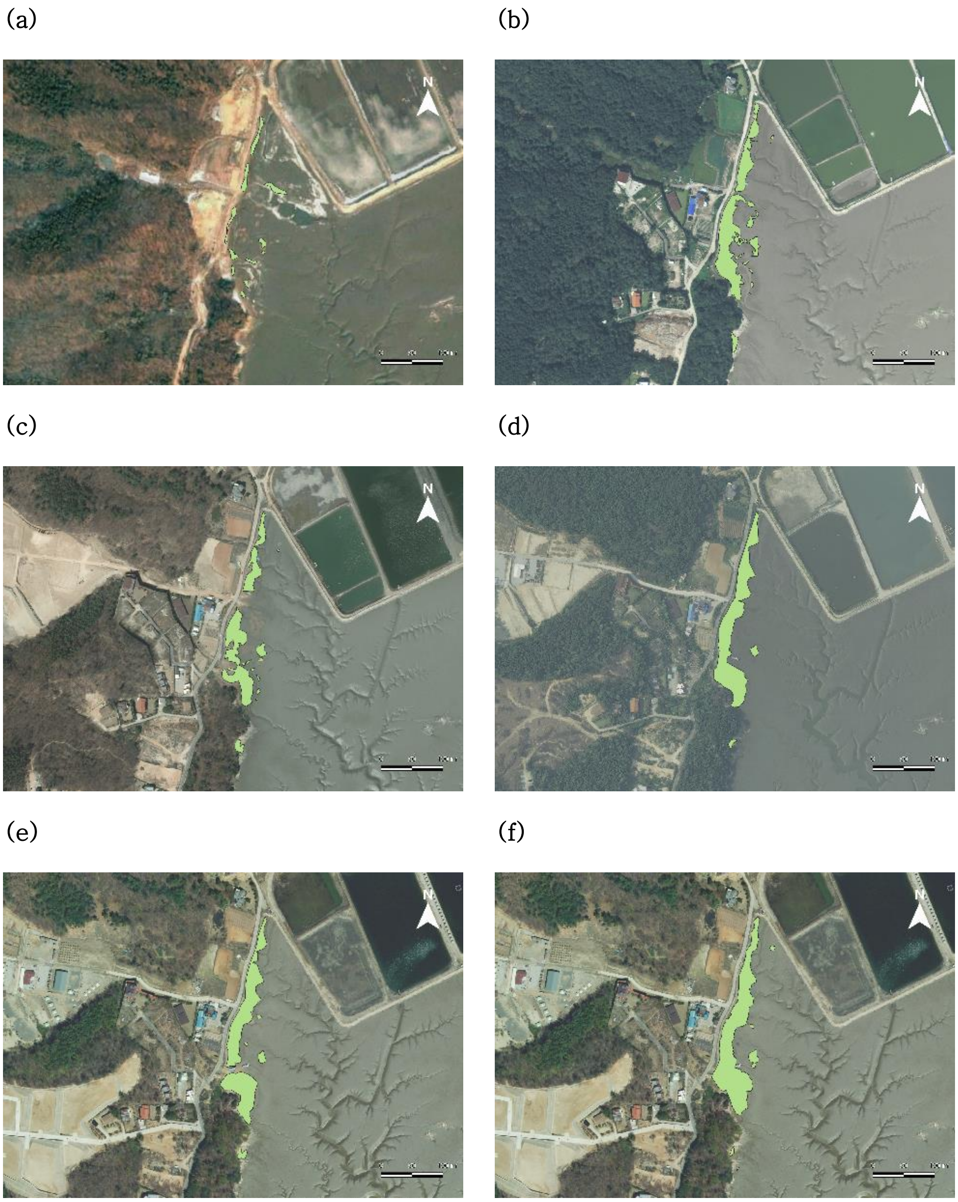


Figure 7. Vegetation map of *Phragmites communis*. (a)2004, (b)2010, (c)2014, (d)2016, (e)2018, (f)2020. Years of background map is (a) 2003, (b) 2010, (c) 2014, (d) 2016, (e) 2018, (f) 2018. Background map of (a) is not an orthophoto, but a Google Earth aerial photograph.

2.4 Discussion

As a result of comparing the area of salt marshes in 2004 and 2020 of Site 1, the area of the *P. communis* community increased by more than 5 times, but the *L. tetragonum* and *S. japonica* communities disappeared, and the total area increased by about 3.5 times. In particular, it was confirmed that the *P. communis* community was formed in the *L. tetragonum* community in the past and the *T. maritima* community was formed in the *S. japonica* community. And as a result of comparing the areas of *P. communis* community based on the orthophoto, it was confirmed that the area of the *P. communis* community steadily increased over the past 16 years. These results are consistent with the prediction that the area of upper salt marshes such as *P. communis* will gradually increase, while the number of pioneer species such as *S. japonica* will decrease.

2.4.1. Salt marsh vegetation of east and west Donggeom

As a result of conducting a field survey on a total of 71056 m^2 of salt marshes, 12 dominant communities were identified and 61 species including 20 halophytes were found (Table 2). Cluster analysis was performed based on the species and coverage data appeared in 128 quadrats, and it could be divided into cluster A dominated by *P.*

communis, cluster B dominated by *S. japonica*, and cluster C dominated by other halophytes (Figure 4, 5).

Salt marshes are also divided into pioneer zone, low marsh, and high marsh based on the vegetation of the salt marsh (Petersen, Kers, and Stock 2014). As a result of comparing the clusters defined in this study, it is correct that cluster B has the characteristics of the pioneer zone, but there is a limitation that low marsh and high marsh are not distinguished except for the *P. communis* community.

The reason for this seems to be that the number of quadrats surveyed in the *P. communis* community was close to 1/3 of the total number of quadrats surveyed. In order to distinguish between low marsh and high marsh halophyte communities, it seems more desirable to install quadrats by dividing areas by altitude rather than installing quadrats compared to the area of halophyte communities (van Regteren et al. 2020).

In general, as a criterion for classifying the community, the dominant species has more than 30% coverage. However, a quadrat with less than 30% coverage was included in the *S. japonica* community. This is because it is very difficult to distinguish regions with more than 30% coverage in the images taken with drones, and pioneer zones such as *S. japonica* also include pioneer species with more than 5% coverages (van Regteren et al. 2020). When the clusters of *S. japonica* are classified using images taken with a drone, it seems that the area of the *S. japonica* community is calculated using vegetation indices such as OSAVI or NDVI, or the wavelength absorbed or reflected by each halophyte rather than visually (Hong, Chun, and Eom 2015; Lee et al. 2007).

In the results of the National Marine Ecosystem Monitoring Program conducted in 2019 at Donggeom−do in a different location from the study site, the *S. japonica* appeared in all of the *T. maritima, Z. sinica, P. communis*, and *S. maritima* communities (MOF 2019). But in this study, *S. japonica* did not appear in the *Z. sinica* or *S. maritima* community. And in the *S. japonica* community of this study, no other halophytes appeared. This seems to be due to the fact that the community surveyed in this study was divided in more detail than the criteria for dividing the community in the National Marine Ecosystem Monitoring Program. Meanwhile, in the two study sites, invasive species such as *S. anglica*, including *A. artemisiifolia*, *H. japonicus*, appeared, and it seems necessary to continuously monitor their distribution patterns in the future.

2.4.2. Vegetated salt marsh comparison between past and present

Compared with the existing vegetation map in 2004 and orthophotos in Site 1, the area of the *P. communis* community has steadily increased over the past 16 years. And the area of *Z. sinica* community also increased slightly from 180.5 m^2 to 227.6 m^2. This result was consistent with the results of 10 years of monitoring the salt marsh of Hampyeong Bay (Yun et al. 2018). It is presumed that eutrophication of fresh water was continuously introduced through water dikes located in various places along the road, providing a favorable environment for the survival of *P. communis* (Bertness, Ewanchuk, and Silliman 2002).

The *S. japonica* community, which was widely distributed on the eastern coast of Donggeom slightly further north than Site 1, disappeared between 2006 and 2007. It was estimated that sediment was continuously supplied from the water channels located in the southern part of Donggeom-do as the cause of this phenomenon (Lee et al. 2014). In the same way, the *S. japonica* community, which existed in 2004, disappeared due to the change of currents which many construction projects around Donggeom in the past made resulting sedimentation up to 7 cm per year in eastern Donggeom-do (Woo, Jang, and Kwon 2012). It appears to have occurred beyond the depth at which *S. japonica* seeds can germinate (Lee et al. 2014). *T. maritima* community was found at the location where *S. japonica* community was distributed. The *T. maritima* community is distributed in the upper middle salt marsh rather than the altitude where pioneer species such as Salicornia europa are distributed (Mossman, Davy, and Grant 2012; Roozen and Westhoff 1985) From this, it appears that the sedimentation caused the altitude to rise, making it suitable for the settlement of the *T. maritima* community.

Site 2, like site 1, does not have a vegetation map for the past, so direct comparison with site 1 is not possible. Instead, when comparing the coverage patterns of the presence/absence of species along the transect based on a point on the shoreline in the field survey, it was confirmed that the present species by quadrat and the coverage of them did not change significantly (Lee et al. 2006). On the other hand, under investigation, the village residents said that in the past, benthic organisms such as shellfish and worms were abundant, but they were not found recently. It is expected to require further study on changes in the benthic fauna.

2.5 Conclusion

A cluster analysis was conducted based on the species and coverage of each quadrat that were investigated by installing 128 quadrats in the salt marshes in the east and west of Donggeom−do. As a result, it could be divided into three clusters composed of *P. communis*, a pioneer species like *S. japonica*, or different halophytes dominated communities. The clusters of the low marsh or pioneer zone were well−divided, but the reason that the halophyte community except *P. communis* was not well classified according to the altitude seems to be that many of the installed quadrats were from the *P. communis* community.

As a result of comparing the results of the 2020 field survey with the vegetation map mapped by the preceding researcher in 2004 at site 1, I could find that the area of the *P. communis* community and the *Z. sinica* community has increased over the past 16 years. As a result of confirming the change in the area of the *P. communis* community through the vegetation map and orthophotos, it was confirmed that the area of the *P. communis* community continued to increase. Meanwhile, the *L. tetragonum* and *S. japonica* communities that found in 2004 disappeared. In the case of *L. tetragonum*, when visiting the study site in 2020, it was confirmed that it was growing in the *Z. sinica* community, but *S. japonica* was hardly found. Meanwhile, the *T. maritima* community was found at the location where the *S. japonica* community was appeared. This is because of a landfill and construction project that took place around the eastern part of Donggeom-do in the past, and it made changes in ocean currents. This change appears to make sedimentation above the depth at which S. japonica seeds can germinate.

Chapter Ⅲ. Factors influencing halophyte distribution of salt marsh at Donggeom−do, Ganghwa

3.1. Introduction

The distribution of halophyte in salt marshes tends to be zonal distribution along altitude (Bang, Bae, and Lee 2018; Santelmann et al. 2019). This is because the time to immerse in seawater varies depending on the altitude (Santelmann et al. 2019), because the time to submerge in seawater itself puts great stress on plants. So the distribution of halophyte is determined by the plant's ability to withstand such an oxygen-free, high-saline environment, or to excrete or avoid salt well (Parida and Das 2005; Colmer and Flowers 2008). Other factors besides altitude include soil texture (Brereton 1971; Ihm et al. 2007), salinity (Silvestri, Defina, and Marani 2005), herbivory (Olff et al. 1997), and interspecific competition (Bertness and Ellison 1987). In general, pioneer species, which are highly resistant to stress, can inhabit in places where the altitude is low and are subject to periodic inundation of seawater. And in areas with high altitude and low seawater flooding, competition between species determines the distribution of halophyte (Bertness, Ewanchuk, and Silliman 2002). And Kim (2018b) modeled using vegetation changes and environmental data for 6 years, and found that the altitude had a large effect. However, if the spatial autocorrelation is excluded, other environmental factors, such as the concentration of cations, which have not received much attention so far, are considered to have an effect.

P. communis is a arbitrary halophyte that lives at high salt concentrations in a way that avoids Na^+, unlike the absolute halophyte, which requires Na^+ to live (Kim 2013). In the United States, *P. communis* is an endemic species that originally appears near freshwater wetlands such as rivers, but when it appears in salt wetlands, it covers salt marshes very quickly enough to be called invasive species. As a result of experimentation on the expansion conditions and invasion cause of this *P. communis*, it was found that artificial disturbance that causes freshwater inflow lowers the concentration of sulfides and causes *P. communis* to invade (Bart and Hartman 2000). In Korea, as a result of analyzing whether there are differences in the growth characteristics and soil conditions of *P. communis* distributed in freshwater, coastal, and intertidal zones, it was found that salinity gave the largest difference between the habitats (Cho, Lee, and Kim 2017).

In this study, I tried to confirm whether environmental factors such as those of the literature influence the distribution of halophyte community in the salt marsh of Donggeom-do in Ganghwa. In addition, as the expansion of the *P. communis* community is remarkable among the vegetation changes in the salt marsh that have occurred at Site 1 over the past 16 years, Canonical correspondence analysis (CCA) was conducted to determine what factors affect the distribution of the *P. communis* community in Donggeom-do.

3.2 Methods

3.2.1. Soil analysis

The soil transported to the laboratory was filtered through a 2 mm sieve to remove gravel and any plant materials. Of these, about 20 g was taken out and used to measure soil moisture (SM) and organic matter content (SOM), and the remaining soil was dried in shadeand used to analyze soil pH, salinity, and soil texture.

I put raw soil (W_w) in a soil evaporation dish, measured the wet weight, dried it at 105°C for 24 hours, and measured the dry weight (W_d, W_{105}). This made calculate the soil moisture, and burned the dried matter at 550°C for 4 hours (W_{550}). The organic matter content was calculated using the burning loss method to measure the organic matter content (Boyle 2004).

$$Soil\ Moisture(\%) = \frac{W_w(g) - W_d(g)}{W_w} \times 100$$

$$Soil\ Organic\ Matter(\%) = \frac{W_{105}(g) - W_{550}(g)}{W_{105}} \times 100$$

After mixing so that the ratio of 5g of soil dried at shade and distilled water is 1:5, I shaked at 180 rpm for 30 minutes and centrifuged at 3000 rpm for 1 minute (ALLEGRA x-15R BECKMAN COULTE). The pH and salinity were measured with PC-2000 (THERMO EUTECH, Singapore). For soil texture, 40g of soil dried at shade, 100 mL of 5% sodium hexametaphosphate solution, and 300 mL of distilled water were mixed and shaken for 12 hours or longer, and then the mixture was poured into a 1 L volumetric cylinder and quantified with distilled water to 1 L. The measuring cylinder was shaken 120 times with the cylinder turned over, and the ratio of sand, silt, and clay was calculated by measuring with a hydrometer after 40 seconds and 7 hours (Carter and Gregorich 2007). The calculated ratio of sand, silt and clay was classified according to Folk (1980).

$$Sand(\%) = \frac{W_{soil} - (R_{40s} - R_{con1})}{W_{soil}} \times 100$$

$$Clay(\%) = \frac{R_{7h} - R_{con2}}{W_{soil}} \times 100$$

$$Clay(\%) = 100 - (Sand(\%) + Clay(\%))$$

3.2.2. Statistical analysis

The correlation between environmental factors were identified by a Pearson correlation index. Environmental factors include altitude, soil moisture, soil organic matter content, soil salinity, pH, and soil texture. In the case of altitude, the coordinates and ellipsoid height obtained by Network-RTK were substituted into the national geoid model, KNGeoid18, and the elevation was calculated. Permutational

Multivariate Analysis of Variance (PERMANOVA) was performed with the 'vegan' package (Oksanen et al. 2020) to confirm whether the cluster classification divided using NbClust is significant for the measured environmental factors. The Dunn test was performed on environmental factors with significant differences (Ogle, Wheeler, and Dinno 2021).

To check the relationship between vegetation and environmental factors, CCA was implemented as a "vegan" package. In addition, spatial interpolation was used to visually show the distribution of each factor in the research paper for each environmental factor. In the case of soil-related factors, ordinary kriging was performed as ordinary kriging due to its high predictive power of spatial distribution (Zare-Mehrjardi, Taghizadeh-Mehrjardi, and Akbarzadeh 2010). For this, Moran's I was calculated with the 'spdep' package (Bivand, Müller, and Reder 2009) to see if the measured factors have spatial autocorrelation, and in the case of spatial autocorrelation, a semi-variogram was drawn and modeled and used for kriging. According to the preceding result that IDW has more predictive power about the distribution of the organisms, the distribution of organisms was interpolated with IDW for the cover and the relative height of the *P. communis* (Zarco-Perello and Simões 2017). Semi-variogram preparation, kriging, and IDW used the'gstat' package (Pebesma 2004). All analyzes were conducted with R 4.0.3 (2020 The R Foundation for Statistical Computing).

3.3 Results

3.3.1. Soil analysis

In addition to 128 quadrats with vegetation selected based on the halophyte communities, 12 control quadrats were installed to analyze the soil moisture, soil organic matter content, pH, salinity, and soil texture. As a result of soil texture analysis, the cluster B, *S. japonica* cluster, had the highest silt content among the 4 units, and was mainly silt(Z) and sandy silt(sZ) (Figure 8). Cluster A was found in a relatively wide range of sand and silt conditions. In the case of the cluster C, the community of species distributed in areas with a high proportion of silt rather than sand such as *T. maritima* and *C. scabrifolia* communities and species distributed in areas with a high proportion of sand such as *Z. sinica* and *C. pumila* are mixed. So the range seems to be wide. In the case of control where halophyte is not distributed, sand(S) is predominant for quadrats installed near *C. pumila* community, and sandy silt(sZ) or silt(Z) is predominant for quadrats installed near *S. japonica* and other halophytes.

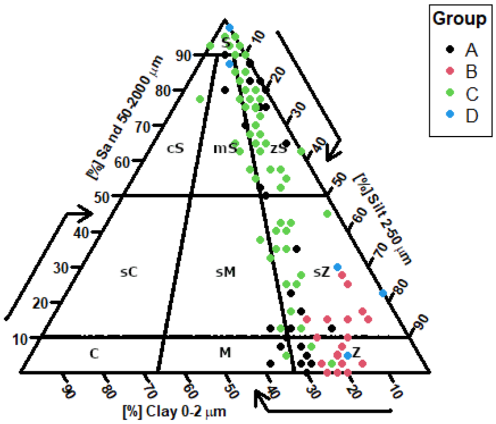


Figure 8. Soil texture graph. Group A–C is same as cluster A–C analyzed by cluster analysis. Group D is control quadrats. Soil classification is based on Folk (1980).

3.3.2. Environmental variables

As a result of evaluating the Pearson correlation index to see if there is a correlation by environmental factors, it was found that altitude had a correlation with a significance of less than 0.05 for all environmental variables examined (Figure 9). Altitude had a positive correlation of 0.53 with sand content, while a negative correlation of 0.56 with silt. Soil moisture had a positive correlation of 0.82 and 0.81 with soil organic matter content and silt, respectively, and soil organic matter content had a correlation of −0.76 with sand content and 0.75 and 0.72 with clay and silt content. There was no significant correlation between pH and other factors except altitude. The sand content had a correlation of −0.86 with clay and −0.98 with silt.

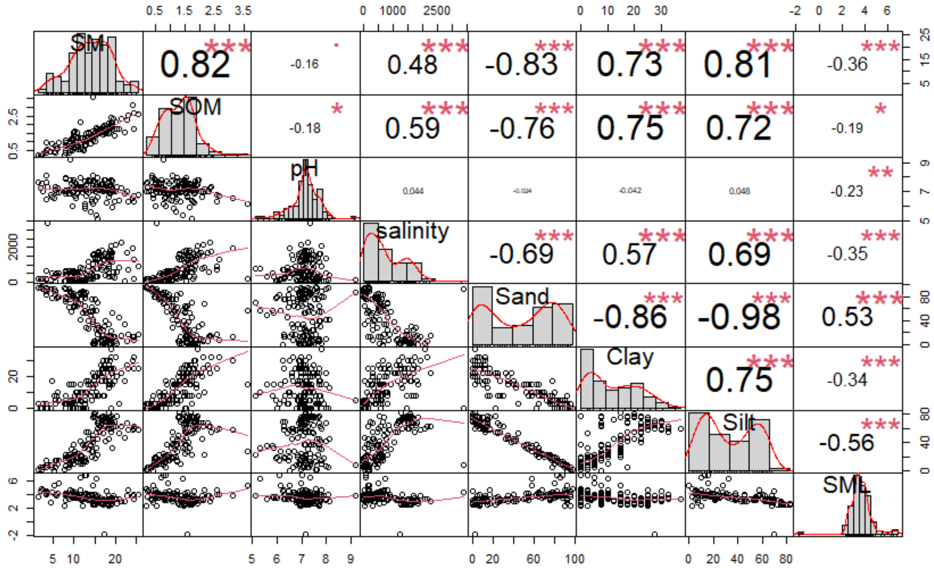


Figure 9. Pearson correlation index between environmental variables. On the top of the diagonal means the value of the correlation with the significant level as stars. ***: p<0.001, **: p<0.01, *: p<0.05, .: p<0.1.

As a result of performing PERMANOVA on the clusters divided using NbClust for environmental variables, p values of less than 0.05 for the altitude, soil moisture, soil organic matter content, salinity, sand, silt, and clay contents excluding pH were significant for each of the three clusters. It was confirmed that there was a difference

(Table 7). As a result of Dunn test for environmental factors other than pH, most of the clusters B showed significant differences from the A and C clusters. The altitude of cluster B dominated by *S. japonica* was lower than that of other clusters, and it was confirmed that the soil organic matter content differed by cluster.

Table 7. Mean values of environmental factors with standard deviations in parentheses across the three clusters and control groups. Alphabets indicate significant differences between clusters based on Dunn test (P<0.05).

	A	B	C	D
Altitude (m)	3.71 (1.26) [a]	2.82 (0.23) [b]	3.89 (0.73) [a]	3.31 (0.69)
Soil moisture (%)	14.70 (5.03) [a]	17.51 (1.70) [b]	11.96 (5.29) [c]	13.54 (5.83)
Soil organic matter (%)	1.28 (0.62) [a]	1.70 (0.25) [b]	1.24 (0.67) [a]	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) [a]	1508.54 (367.09) [b]	564.33 (548.07) [a]	1036.58 (537.65)
Sand (%)	45.97 (35.33) [a]	8.71 (8.11) [b]	60.39 (26.31) [a]	35.64 (36.16)
Clay (%)	15.29 (12.33) [a]	17.73 (6.02) [b]	10.59 (8.40) [a]	12.91 (9.17)
Silt (%)	38.74 (23.74) [a]	73.55 (4.85) [b]	29.23 (19.00) [a]	51.45 (30.10)

CCA analysis was conducted to determine how each cluster has a relationship with environmental factors (Figure 10). CCA1 explained 8.8% of the total variance (eigenvalue 0.6850), and CCA2 explained 6.2% of the total variance (eigenvalue 0.4845) (Figure 10 (a)). In the positive direction of CCA1, silt and clay content, soil moisture, soil organic matter content, and salinity tended to increase, and 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). The present species best explained by CCA1 were the glycophytes, *Setaria* x *pycnocoma*(Sp), and *S. japonica* (Sj), the pioneer species of halophytes. Toward the positive direction of CCA2 tended to increase the soil moisture and clay content, and decrease the pH and salinity (soil moisture: 0.40, clay: 0.31, pH: −0.31, salinity: −0.36). The species best explained by CCA2 were *S. glauca* (Sg), *Setaria* x *pycnocoma* (Sp), *S. maritima* (Sm) and *H. japonicus* (Hj). In the case of cluster A, it appeared in a wide altitude range and was found in a place with lower salinity than the average. And it could be confirmed that in addition to *P. communis*, several species tend to appear together. It was found that the cluster B was mainly high in salinity and *S. japonica* was found. The silt content and soil organic matter content, soil moisture and clay content had similar trends.

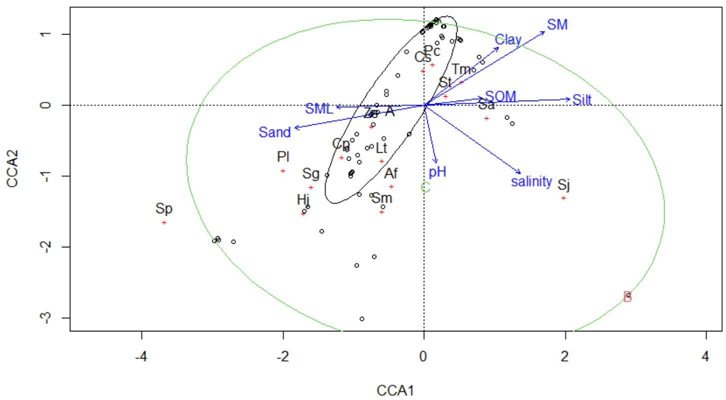


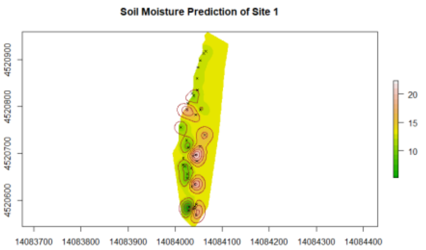
Figure 10. Ordination of CCA. Crutches are ordination of species, and ellipses are clusters determined by CA. Abbreviations are same as figure 5. V. means relative height of species. Ordination of CCA with species abundance and environmental factors.

3.3.3. Visualization of environmental variables and vegetation of *Phragmites communis*

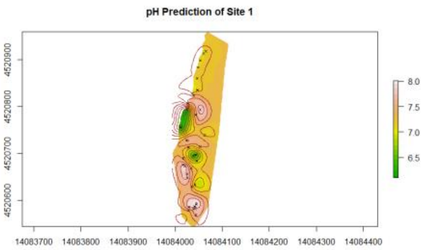
In order to visually see the distribution of environmental factors in the study site, Kriging, one of the spatial interpolation methods, was used. As a result of calculating Moran's I to check whether environmental factors have spatial autocorrelation, site 1 had positive spatial autocorrelation for soil moisture, pH, sand, clay, and silt. Site 2 had positive spatial autocorrelation for altitude, soil moisture, organic matter content, sand, clay, silt, and salinity. Figure 11 shows the result of kriging after setting a suitable model by drawing a semi-variogram for environmental factors that show spatial autocorrelation. Some interpolation results show a pattern that the predictive power deteriorates even if the distance from the quadrats is a little further away.

Figure 12 shows the predicted IDW distribution of *P. communis* communities in Sites 1 and 2. In the case of IDW, as the distance from the quadrat increased where *P. communis* appeared, the predicted *P. communis* coverage and the relative above-ground height decreased significantly. Site 1 showed very high coverage of *P. communis* except for the part where the above-ground part of *P. communis* was removed to anchor the ship in the center of the study site, and near the tidal flat experience site located in the south. The height of the relative above-ground part also showed a similar tendency to the distribution of cover (Figure 12 (a), (b)). In the case of Site 2, the quadrat in the southeastern part of the study was sparse than that of Site 1, and it was confirmed that the predictive power was slightly lower when compared with the site results.

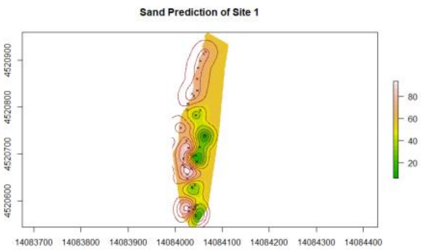
(a)


Soil Moisture Prediction of Site 1
20
15
10

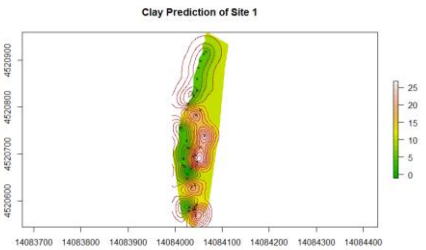
(b)


pH Prediction of Site 1
8.0
7.5
7.0
6.5

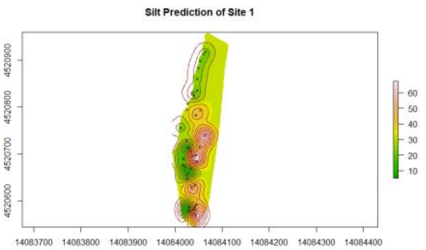
(c)


Sand Prediction of Site 1
80
60
40
20

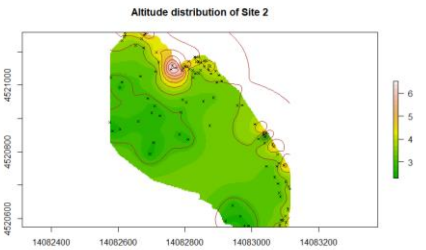
(d)


Clay Prediction of Site 1
25
20
15
10
5
0

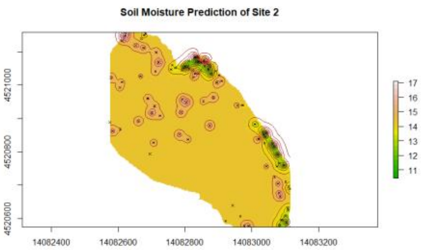
(e)


Silt Prediction of Site 1
60
50
40
30
20
10

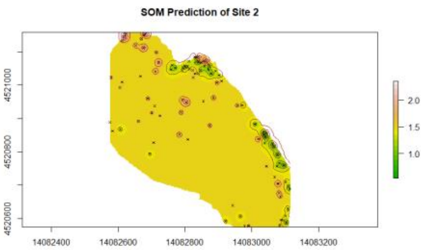
(f)


Altitude distribution of Site 2
6
5
4
3

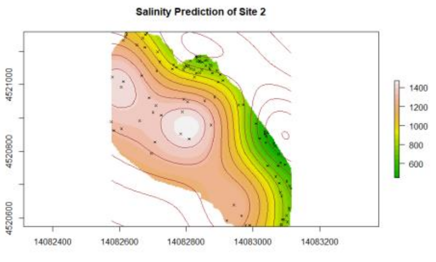
(g)


Soil Moisture Prediction of Site 2
17
16
15
14
13
12
11

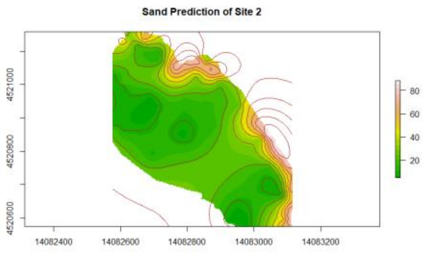
(h)


SOM Prediction of Site 2
2.0
1.5
1.0

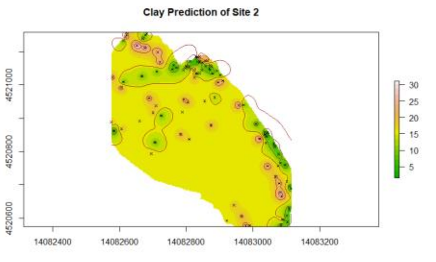
(i)



(j)



(k)



(l)

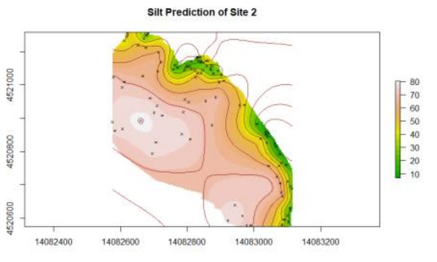


Figure 11. Spatial distributions of environmental variables in study sites. (a)–(e) for site 1, (f)–(l) for site 2. Marks show quadrats of group A–C, and control quadrats.

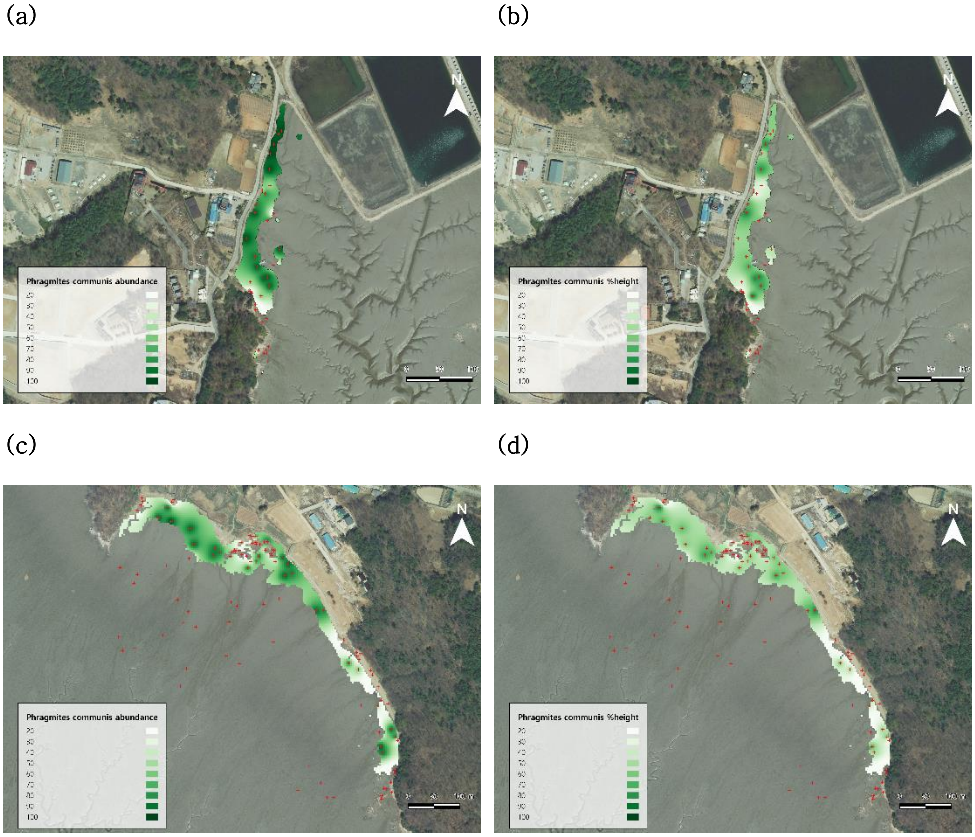


Figure 12. Prediction of *P. communis* abundance and relative height distribution across study sites. (a) *P. communis* abundance of site 1. (b) *P. communis* relative height of site 1. (c) *P. communis* abundance of site 2. (d) *P. communis* relative height of site 2.

3.4 Discussion

Soil textures of 128 quadrats with halophyte vegetation and 12 control quadrats with no vegetation were analyzed. As a result, mainly sand(S), silty sand(zS), sandy silt(sZ), and silt(Z) sedimentary phases were shown. This result was similar to the sedimentary facies in the tidal flat of the west coast in the National Marine Ecosystem Monitoring Program conducted from 2015 to 2019 (MOF 2019). The contents of sand and silt of cluster A, which was a *P. communis* community, had a very wide range and the average contents of sand and clay was 45.97% and 15.29%. On the other hand, the contents of sand and clay in the coastal salt marsh where *P. communis* appeared, which was investigated by Cho, Lee, and Kim (2017), was 82.81% and 4.85%, respectively. As the average ratio of sand and clay in the *P. communis* community located in Suncheon Bay was 2.0% and 44.8% (Jang et al. 2013), the difference in soil texture by habitat seems to be large. There were differences in soil moisture, soil organic matter content, salinity, and soil texture, including altitude between cluster B and other clusters. Pioneer species such as *S. japonica* have strong salt tolerance and can survive at lower altitudes, and are likely to emerge in soils with a relatively high silt content as they are advantageous for seeding settlement in soils with smaller grain sizes such as silt or clay than sand (van Regteren et al. 2020; Kim 2018a).

As a result of checking the correlation for each measured environmental factor including altitude and soil texture, altitude was correlated with all measured environmental factors with a significance of less than 0.05. The difference in the physical environment of altitude has an effect on seawater movement, such as the time submerged in seawater and differences in size of sediment particles being swept away by waves. Chemical changes appear to have occurred due to differences in the clusters of living organisms (Santelmann et al. 2019; Bart and Hartman 2000; van Regteren et al. 2020).

A total of 128 quadrats were installed in the halophyte community, and the major environmental factors affecting the distribution of halophyte were confirmed by CCA. CCA1 accounted for 8.8% of the total variance and CCA2 accounted for 6.2% of the total variance, accounting for only 15% of the total variance. However, the eigenvalue of each CCA was more than 0.3, showing a good distribution trend (Braak, JF, and Verdonschot 1995). The higher the altitude, the higher the content of sand, while the soil moisture, the contents of silt and clay, the soil organic matter content, and the salinity tended to decrease. In the late 1990s, the main soil texture of the eastern tidal flat of Donggeom-do was the silt-rich muddy tidal flat. However, due to the large-scale development near Ganghwa-do in the 1990s, the currents changed and the east coast of Donggeom-do was continuously sedimented. At this time, there is a result that the soil texture is gradually changing to the sandy mud tidal flat because sand is mixed in the sediment deposited (Woo 2013). This result is consistent with the higher the altitude in the CCA, the higher the sand content. In this study, the salinity of cluster A, where the *P. communis* community appeared, was lower than the average, which was similar to the results of the Siheung salt marsh (Bang, Bae, and Lee 2018).

Freshwater influx is the cause of P. communis appearing in salt marshes and rapidly expanding its area (Bart and Hartman 2000). Site 1 also maintains relatively low salinity due to the presence of drainage holes for freshwater inflow. It appears to have become a source area allowing expansion towards higher salinity oceans (Hong 2015).

The kriging result showed that even if the distance from the quadrat is slightly distant, the predictive power decreases. This seems to be caused by the large deviation of the model created for kriging.

3.5 Conclusion

Based on the Bray–Curtis dissimilarity index for the coverage of each type of halophyte in each quadrat, there are differences in altitude, soil moisture, soil organic matter content, salinity, sand, silt, and clay contents for 3 clusters. In the case of the *P. communis* community, it was difficult to confirm whether the soil texture was living in an environment similar to that of the literature, as the difference in soil texture was large. However, it was confirmed that pioneer species such as *S. japonica* appeared in soil with a relatively high silt content. For *P. communis* community that stood out of halophyte distribution changes in Site 1, it was found to be distributed at lower salinity. It seems that the *P. communis* community can expand toward the salty sea, starting with the drainage hole through which fresh water flows.

Chapter Ⅳ. General discussion

Rather than reducing the area of the salt marsh due to sea level rise caused by climate change, the speed of accumulation of sediments changes due to projects such as reclamation and development in the vicinity of the salt marsh, and the installation of dike changing the contents of nutrients flowing into the salt marsh can reduce the area of the salt marsh (Kirwan and Megonigal 2013; Kirwan et al. 2016). The sea area near Ganghwa-do is located at the mouth of the Han River, and since the 1980s, many reclamation and construction projects have been carried out, including the construction of the Gimpo Landfill and Incheon International Airport. As a result, the currents changed and the speed of the currents decreased in the eastern part of Ganghwa, and the tidal flats in the eastern part of Donggeom-do near Ganghwa had sedimentation of up to 7 cm per year in the 2000s (Lee et al. 2014; Jung et al. 2008). In 2010, the sedimentation rate of the Ganghwa/Gyeonggi area tidal flats stabilized at an annual average of 1 cm (Woo, Jang, and Kwon 2012; MOF 2019). I thought it was necessary to check how the area and vegetation of the Donggeom salt marsh change, as the results of vegetation monitoring that has been conducted for more than 10 years in the natural salt marsh in the Gyeonggi region cannot be found. I visited the salt marsh where a preceding researcher conducted a vegetation survey in 2004 to check the vegetation changes in the salt marsh over past 16 years.

In Site 1, the area of *P. communis* community increased from 944.8 m^2 to 5085.1 m^2, while *L. tetragonum* and *S. japonica* communities disappeared. As a result of confirming the change in the area of the *P. communis* community by orthophotos, it was found that the area of *P. communis* has increased over the past 16 years. *L. tetragonum* often appeared in the *Z. sinica* community when viewed in the field, but *S. japonica* was rarely found. This result was similar to the result of the disappearance of 11 ha of *S. japonica* community within one year due to the rapid sedimentation rate in the eastern salt marsh of Donggeom−do near site 1 (Lee et al. 2014). Meanwhile, the *T. maritima* community appeared at the site where the *S. japonica* community was found in 2004. Since *T. maritima* is distributed at an altitude higher than that of pioneer species such as *S. europa*, sedimentation supported the disappearance of the S. japonica community (Mossman, Davy, and Grant 2012; Roozen and Westhoff 1985).

As a result of comparing species that appeared in research sites other than the quadrat survey, the Jaccard distance was 0.739 from 25 species in 2004 to 31 species in 2020. Although there may be differences in the timing of the investigation or the identification ability of each researchers, it is believed that human−induced disturbances were large as *A. artemisiifolia*, an invasive species, appeared newly (DiTommaso 2004). In Site 2, invasive species such as *A. artemisiifolia, H. japonicus*, and *S. anglica* appeared, and it seems necessary to continuously check their distribution patterns.

The cluster analysis was performed because the area of each halophyte community and the number of quadrats accordingly differed up to 13 times. As a result, it could be divided into cluster A dominated by *P. communis*, cluster B dominated by *S. japonica*, and cluster C dominated with halophytes excluding *S. japonica* and *P. communis*. As a result of checking whether there are differences by environmental factors between these three clusters using PERMANOVA, there were differences in soil moisture, soil organic matter content, salinity, and soil texture, as well as altitude from other clusters in particularly, cluster B was significantly different from other clusters. 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 because they are advantageous for seeding settlement in soils with small grain sizes (van Regteren et al. 2020; Kim 2018a).

As a result of analyzing the major environmental factors influencing the distribution of halophytes by CCA, the proportion of sand increased as the altitude increased, and the proportion of soil moisture, silt and clay, soil organic matter content, and salinity tended to decrease. In this study, the salinity of cluster A, where the P. communis community appeared, was lower than the average, which was similar to the results in the Siheung salt marsh (Bang, Bae, and Lee 2018).

The expansion of P. communis begins in the source area with low salinity or low sulfide concentration due to the inflow of fresh water, and occurs toward the ocean with relatively high environmental stress through nutrient translocation (Bart and Hartman 2000; M. G. Hong 2015). In the case of Site 1, it seems that the P. communis community has expanded as the drainage hole located on the coast serves to continuously supply fresh water.

Recently, the Donggeom Bridge connecting Donggeom-do and Ganghwa-do has been improved to allow seawater to flow, but I think there may be a change in the current near Donggeom-do, which has been stabilized on sedimentation. It will be necessary to continuously monitor how the vegetation of the salt marsh will change due to changes in ocean currents. When classifying *S. japonica* clusters with images taken with a drone, it is expected that the area of the *S. japonica* community is calculated using vegetation indices such as OSAVI and NDVI. Alternatively, the use of different wavelength bands for absorbing or reflecting for each halophytes can increase the reliability of community classification (Hong, Chun, and Eom 2015; Lee et al. 2007). On the other hand, the distribution of halophyte at site 2 did not change significantly, but according to the village residents, it is estimated that the benthic biota was changed due to the change of the sedimentary environment, and a study on the change of the benthic biota is expected.

Bibliography

Bang, Jeong Hwan, Mi Jung Bae, and Eun Ju Lee. 2018. "Plant Distribution along an Elevational Gradient in a Macrotidal Salt Marsh on the West Coast of Korea." *Aquatic Botany* 147 (August 2017): 52–60. https://doi.org/10.1016/j.aquabot.2018.03.005.

Bart, David, and Jean Marie Hartman. 2000. "Environmental Determinants of Phragmites Australis Expansion in a New Jersey Salt Marsh : An Experimental Approach." *OIKOS* 89: 59–69.

Belluco, Enrica, Monica Camuffo, Sergio Ferrari, Lorenza Modenese, Sonia Silvestri, Alessandro Marani, and Marco Marani. 2006. "Mapping Salt-Marsh Vegetation by Multispectral and Hyperspectral Remote Sensing." *Remote Sensing of Environment* 105 (1): 54–67. https://doi.org/10.1016/j.rse.2006.06.006.

Bertness, Mark D., Patrick J. Ewanchuk, and Brian Reed Silliman. 2002. "Anthropogenic Modification of New England Salt Marsh Landscapes." *Proceedings of the National Academy of Sciences of the United States of America* 99 (3): 1395–98. https://doi.org/10.1073/pnas.022447299.

Bertness, Mark D ., and Aaron M . Ellison. 1987. "Determinants of Pattern in a New England Salt Marsh Plant Community." *Ecological Monographs* 57 (2): 129–47.

Bivand, Roger, Werner G. Müller, and Markus Reder. 2009. "Power Calculations for Global and Local Moran's I." *Computational Statistics and Data Analysis* 53 (8): 2859–72. https://doi.org/10.1016/j.csda.2008.07.021.

Boyle, John. 2004. "A Comparison of Two Methods for Estimating the Organic Matter Content of Sediments." *Journal of Paleolimnology* 31 (1): 125–27. https://doi.org/10.1023/B:JOPL.0000013354.67645.df.

Braak, Ter, Cajo JF, and Piet FM Verdonschot. 1995. "Canonical Correspondence Analysis and Related Multivariate Methods in Aquatic Ecology." *Aquatic Sciences* 57 (3): 255–89.

Braun-Blanquet, Josias. 1964. *Pflanzensoziologie, Grundzüge Der*

Vegetationskunde. Pflanzensoziologie. 3rd editio. Springer-Verlag. https://doi.org/10.1007/978-3-7091-8110-2.

Brereton, A . J . 1971. "The Structure of the Species Populations in the Initial Stages of Salt-Marsh Succession." *Journal of Ecology* 59 (2): 321–38.

Burdick, David M., and Raymond A. Konisky. 2003. "Determinants of Expansion for Phragmites Australis, Common Reed, in Natural and Impacted Coastal Marshes." *Estuaries* 26 (2): 407–16. https://doi.org/10.1007/BF02823717.

Burns, Christine J., Merryl Alber, and Clark R. Alexander. 2020. "Historical Changes in the Vegetated Area of Salt Marshes." *Estuaries and Coasts*. https://doi.org/10.1007/s12237-020-00781-6.

Carter, M.R, and E.G Gregorich. 2007. *Soil Sampling and Methods of Analysis. CRC Press*. https://doi.org/10.1201/9781420005271.ch57.

Charrad, Malika, Nadia Ghazzali, VéRonique Boiteau, and Azam Niknafs. 2014. "Nbclust: An R Package for Determining the Relevant Number of Clusters in a Data Set." *Journal of Statistical Software* 61 (6): 1–36. https://doi.org/10.18637/jss.v061.i06.

Chen, Qingqing, Jan P. Bakker, Juan Alberti, and Christian Smit. 2020. "Long-Term Management Is Needed for Conserving Plant Diversity in a Wadden Sea Salt Marsh." *Biodiversity and Conservation* 29 (7): 2329–41. https://doi.org/10.1007/s10531-020-01976-w.

Cho, Jang Sam, Jeom Sook Lee, and Jong Wook Kim. 2017. "Distribution of Phragmites Australis Communities with Different Habitat Salinity." *Journal of Coastal Research* 33 (5): 1210–16. https://doi.org/10.2112/JCOASTRES-D-16-00065.1.

Cho, Y. H., J. H. Kim, and S. H. Park. 2016. *Grasses and Sedges in South Korea*. Geobook.

Clifton, Brenda C., W. Gregory Hood, and Steve R. Hinton. 2018. "Floristic Development in Three Oligohaline Tidal Wetlands after Dike Removal." *Ecological Restoration* 36 (3): 238–51. https://doi.org/10.3368/er.36.3.238.

Colmer, Timothy D., and Timothy J. Flowers. 2008. "Flooding Tolerance in Halophytes." *New Phytologist* 179 (4): 964–74. https://doi.org/10.1111/j.1469-8137.2008.02483.x.

DiTommaso, Antonio. 2004. " Germination Behavior of Common Ragweed (Ambrosia Artemisiifolia) Populations across a Range of Salinities ." *Weed Science* 52 (6): 1002–9. https://doi.org/10.1614/ws-04-030r1.

Folk, Robert L. 1980. *Petrologie of Sedimentary Rocks. Hemphll Publishing Company, Austin*.

Hong, Mun Gi. 2015. "Effects of Freshwater Inflow, Salinity, and Water Level on the Growth of Common Reed in Salt Marsh." Seoul National University.

Hong, Seok Hwi, Seung Soo Chun, and Jin Ah Eom. 2015. "The 2009-Based Detailed Distribution Pattern and Area of Phragmites Communis-Dominant and Suaeda Japonica-Dominant Communities on the Suncheon-Bay and Beolgyo Estuarine Wetlands." *Journal of Wetlands Research* 17 (1): 26–37. https://doi.org/10.17663/jwr.2015.17.1.026.

Ihm, Byung Sun, Jeom Sook Lee, Jong Wook Kim, and Joon Ho Kim. 2007. "Coastal Plant and Soil Relationships along the Southwestern Coast of South Korea." *Journal of Plant Biology* 50 (3): 331–35. https://doi.org/10.1007/BF03030663.

Jang, Hyung-guk, Jung-tae Gong, Byung-wook Kong, Sang-ho Han, Deog-gwan Ra, and Cheong-jo Cheong. 2013. "Distribution Pattern of Halophytes and Its Soil Environment of the Saltmarsh in the Sunheon Bay." *Journal of Korean Society of Environmental Technology* 14 (6): 399–410.

Je, Jong Geel, Han Jun Woo, Kap Sik Jeong, Hee Jun Lee, Su-Jae Kwon, Yong-sik Choo, Hyo-Young Kim, et al. 1999. *Tidal Flat Studies for Conservation and Sustainable Use*. Korea Ocean Research & Development Institute.

Jung, Kyung Tae, Hee Jun Lee, Sang Hoon Lee, Yeong Gil Park, Han Joon Kim, Hyeong Tae Jou, Chan Su Yang, et al. 2008. *Development of Management and Restoration Technologies for Estuaries with Focus on Han River Estuary Region*. Korea Institute of Ocean Science & Technology. https://sciwatch.kiost.ac.kr/handle/2020.kiost/36550.

Kim, Daehyun. 2018a. “Characterizing the Pathway and Rate of Salt Marsh Vegetation Dynamics: A Multivariate Approach.” *Estuaries and Coasts* 41 (5): 1370–80. https://doi.org/10.1007/s12237-018-0377-8.

———. 2018b. “Modeling Spatial and Temporal Dynamics of Plant Species Richness across Tidal Creeks in a Temperate Salt Marsh.” *Ecological Indicators* 93 (March): 188–95. https://doi.org/10.1016/j.ecolind.2018.04.080.

Kim, Eun-Kyu. 2013. *Halophytes of Korea*. Econature.

Kim, Eun-Kyu, Soul Chun, Young-K Joo, Yeong-Sang Jung, and Hyeung-Gun Jung. 2008. “Soil Salinity and Continuum Distribution of Vegetation on the Three Reclaimed Tidal Flats of Kyonggi-Bay in the Mid-West Coast of Korea.” *Korean Journal of Soil Science and Fertilizer* 41 (2): 83–93.

Kirwan, Matthew L., and J. Patrick Megonigal. 2013. “Tidal Wetland Stability in the Face of Human Impacts and Sea-Level Rise.” *Nature* 504 (7478): 53–60. https://doi.org/10.1038/nature12856.

Kirwan, Matthew L., Stijn Temmerman, Emily E. Skeehan, Glenn R. Guntenspergen, and Sergio Fagherazzi. 2016. “Overestimation of Marsh Vulnerability to Sea Level Rise.” *Nature Climate Change* 6 (3): 253–60. https://doi.org/10.1038/nclimate2909.

Korea Hydrographic and Oceanographic Agency. 2017. “Annual Report of Korea Oceanographic Observation Network (2016).”

———. 2018. “Annual Report of Korea Oceanographic Observation Network (2017).”

———. 2019. “Annual Report of Korea Oceanographic Observation Network (2018).” http://library1.nida.ac.th/termpaper6/sd/2554/19755.pdf.

Korea Meteorological Administration. 2020. “Weather Data Opening Portal.” 2020. https://data.kma.go.kr/cmmn/main.do.

Lee, Hyung Gon, Heung Sik Park, Jae Sang Hong, Jong Geel Je, and Jae Hac Lee. 2006. “Spatio-Temporal Variation in the Benthic Environmental Conditions and Salt Marsh Vegetation in Donggeomdo, Incheon, Korea.” *Korean Journal of Fisheries and Aquatic Sciences* 39: 180–88.

Lee, Hyung Gon, Kon Tak Yoon, Heung Sik Park, Jae Sang Hong, and Jae Hac Lee. 2016. "The Influence of Environmental Variables on Distribution of Macrobenthic Community in Salt Marsh Vegetation in Donggeomdo, Ganghwa on the West Coast of Korea." *Ocean and Polar Research* 38 (2): 115–28. https://doi.org/10.4217/OPR.2016.38.2.115.

Lee, Seung Ho. 2011. "Distribution of Halophyte Communities along Altitudinal Gradient and Growth Induction of the Vegetation in Salt Marshes." Mokpo National University.

Lee, Seung Ho, Jeom Sook Lee, and Jong Wook Kim. 2018. "Relationship between Halophyte Distribution and Soil Environmental Factors in the West Coast of South Korea." *Journal of Ecology and Environment* 42 (1): 1–8. https://doi.org/10.1186/s41610-017-0062-z.

Lee, T. B. 2003. *Coloured Flora of Korea*. Hayangmunsa.

Lee, Yoon-Kyung, Jin-Ah Eom, Joo-Hyung Ryu, and Joong-Sun Won. 2007. "Analyzing Spectral Characteristics of Salt Marsh Vegetation around Donggumdo Tidal Flat in Ganghwado, Korea." *Korean Journal of Remote Sensing* 23 (6): 575–81.

Lee, Yoon-Kyung, Wook Park, Jong Kuk Choi, Joo Hyung Ryu, and Joong Sun Won. 2014. "Halophyte Die-off in Response to Anthropogenic Impacts on Tidal Flats." *Estuarine, Coastal and Shelf Science* 151: 347–54. https://doi.org/10.1016/j.ecss.2014.09.009.

Lee, Yoon-Kyung, Joo-Hyung Ryu, Jong-Kuk Choi, Jae-Gwi Soh, Jin-Ah Eom, and Joong-Sun Won. 2011. "A Study of Decadal Sedimentation Trend Changes by Waterline Comparisons within the Ganghwa Tidal Flats Initiated by Human Activities." *Journal of Coastal Research* 276 (5): 857–69. https://doi.org/10.2112/jcoastres-d-10-00150.1.

Lutts, Stanley, and Isabelle Lefèvre. 2015. "How Can We Take Advantage of Halophyte Properties to Cope with Heavy Metal Toxicity in Salt-Affected Areas?" *Annals of Botany* 115 (3): 509–28. https://doi.org/10.1093/aob/mcu264.

McLeod, Elizabeth, Gail L. Chmura, Steven Bouillon, Rodney Salm, Mats Björk, Carlos M. Duarte, Catherine E. Lovelock, William H. Schlesinger, and Brian R. Silliman. 2011. "A Blueprint for Blue Carbon: Toward an Improved Understanding of the Role of

Vegetated Coastal Habitats in Sequestering CO2." *Frontiers in Ecology and the Environment* 9 (10): 552–60. https://doi.org/10.1890/110004.

Ministry of Oceans and Fisheries. 2019. "Annual Report of National Marine Ecosystem Monitoring Program (2019)."

Ministry of Oceans and Fisheries / Korea Marine Environment Management Corporation. 2019. "Protocol of National Marine Ecosystem Monitoring Program." 3rd ed.

Mossman, Hannah L., Anthony J. Davy, and Alastair Grant. 2012. "Does Managed Coastal Realignment Create Saltmarshes with 'equivalent Biological Characteristics' to Natural Reference Sites?" *Journal of Applied Ecology* 49 (6): 1446–56. https://doi.org/10.1111/j.1365-2664.2012.02198.x.

Ogle, D.H., P. Wheeler, and A. Dinno. 2021. "FSA: Fisheries Stock Analysis." https://github.com/droglenc/FSA.

Oksanen, Jari, Blanchet Guillaume. F, Friendly Michael, Kindt Roeland, Legendre Pierre, Mcglinn Dan, Peter R Minchin, et al. 2020. "Package ' Vegan .'"

Olff, H., J. De Leeuw, J. P. Bakker, R. J. Platerink, and H. J. van Wijnen. 1997. "Vegetation Succession and Herbivory in a Salt Marsh: Changes Induced by Sea Level Rise and Silt Deposition Along an Elevational Gradient." *The Journal of Ecology*. Vol. 85. https://doi.org/10.2307/2960603.

Parida, Asish Kumar, and Anath Bandhu Das. 2005. "Salt Tolerance and Salinity Effects on Plants: A Review." *Ecotoxicology and Environmental Safety* 60 (3): 324–49. https://doi.org/10.1016/j.ecoenv.2004.06.010.

Pebesma, Edzer J. 2004. "Multivariable Geostatistics in S: The Gstat Package." *Computers & Geosciences* 30: 683–91.

Petersen, Jörg, Bars Kers, and Martin Stock. 2014. *TMAP-Typology of Coastal Vegetation in the Wadden Sea Area*. Version 1. Common Wadden Sea Secretariat (CWSS), Wilhelmshaven, Germany.

Pontee, Nigel. 2013. "Defining Coastal Squeeze: A Discussion." *Ocean and Coastal Management* 84: 204–7. https://doi.org/10.1016/j.ocecoaman.2013.07.010.

Ranwell, D. S. 1972. *Ecology of Salt Marshes and Sand Dunes*. Chapman and Hall London.

Regteren, M. van, D. Amptmeijer, A. V. de Groot, M. J. Baptist, and K. Elschot. 2020. “Where Does the Salt Marsh Start? Field−Based Evidence for the Lack of a Transitional Area between a Gradually Sloping Intertidal Flat and Salt Marsh.” *Estuarine, Coastal and Shelf Science* 243. https://doi.org/10.1016/j.ecss.2020.106909.

Roozen, A. J.M., and V. Westhoff. 1985. “A Study on Long−Term Salt−Marsh Succession Using Permanent Plots.” *Vegetatio* 61 (1–3): 23–32. https://doi.org/10.1007/BF00039807.

Santelmann, Mary V., Brett A. Boisjolie, Rebecca Flitcroft, and Megan Gomez. 2019. “Relationships between Salt Marsh Vegetation and Surface Elevation in Coos Bay Estuary, Oregon.” *Northwest Science* 93 (2): 137–54. https://doi.org/10.3955/046.093.0205.

Shin, Wonhyeop, Jae Hyun Kim, and Eun Ju Lee. 2020. “Effect of Native Suaeda Japonica Structure on the Initial Seed Settlement of an Invasive Plant Spartina Anglica.” *Aquatic Botany* 161 (December 2018): 103175. https://doi.org/10.1016/j.aquabot.2019.103175.

Silvestri, Sonia, Andrea Defina, and Marco Marani. 2005. “Tidal Regime, Salinity and Salt Marsh Plant Zonation.” *Estuarine, Coastal and Shelf Science* 62 (1–2): 119–30. https://doi.org/10.1016/j.ecss.2004.08.010.

Sunwoo, Wooyeon, Daeun Kim, Seokkoo Kang, and Minha Choi. 2016. “Application of KOMSAT−2 Imageries for Change Detection of Land Use and Land Cover in the West Coasts of the Korean Peninsula.” *Korean Journal of Remote Sensing* 32 (2): 141–53. https://doi.org/10.7780/kjrs.2016.32.2.7.

Sunwoo, Wooyeon, Hoang Hai Nguyen, and Minha Choi. 2018. “Coastal Wetland Change Detection Using High Spatial Resolution KOMPSAT−2 Imagery.” *Terrestrial, Atmospheric and Oceanic Sciences* 29 (5): 509–21. https://doi.org/10.3319/TAO.2018.05.18.01.

Vretare, V., S. E.B. Weisner, J. A. Strand, and W. Granéli. 2001. “Phenotypic Plasticity in Phragmites Australis as a Functional Response to Water Depth.” *Aquatic Botany* 69 (2–4): 127–45.

https://doi.org/10.1016/S0304-3770(01)00134-6.

Woo, Han Jun. 2013. “Long-Term Changes of Sediment and Topography at the Southern Kanghwa Tidal Flat, West Coast of Korea.” *Journal of Wetlands Research* 15 (4): 493–500. https://doi.org/10.17663/jwr.2013.15.4.493.

Woo, Han Jun, Seok Jang, and Su Jae Kwon. 2012. “Changes in Sediment Characteristics in the Eastern Tidal Flat of Donggum Island in Ganghwa, West Coast of Korea.” *Journal of Wetlands Research* 14 (3): 375–84. https://doi.org/10.17663/JWR.2012.14.3.375.

Yun, Chung Weon, Sei Woong Choi, Young Han You, Sang-im Lee, Bom Chul Kim, Gea-Jae Joo, and Jeom Sook Lee. 2018. *The Influence of Climate Change*. National Institute of Ecology. https://library.nie.re.kr/material/view?format=&pageSize=10&method=KEYWORD&fields=ALL&keywords=장기모니터링&x=0&y=0&uid=CAT-53086.

Zarco-Perello, Salvador, and Nuno Simões. 2017. “Ordinary Kriging vs Inverse Distance Weighting: Spatial Interpolation of the Sessile Community of Madagascar Reef, Gulf of Mexico.” *PeerJ* 2017 (11). https://doi.org/10.7717/peerj.4078.

Zare-Mehrjardi, Mohammad, Ruhollah Taghizadeh-Mehrjardi, and Ali Akbarzadeh. 2010. “Evaluation of Geostatistical Techniques for Mapping Spatial Distribution of Soil PH, Salinity and Plant Cover Affected by Environmental Factors in Southern Iran.” *Notulae Scientia Biologicae* 2 (4): 92–103. https://doi.org/10.15835/nsb244997.

Appendix

Appendix Ⅰ. List of plants with Korean names. * means halophytes, classified by KOEM (2019)

Family	Species	Korean name
Amaranthaceae	*Achyranthes japonica* (Miq.) Nakai	쇠무릎
	Amaranthus retroflexus L.	털비름
	Portulaca oleracea L.	쇠비름
Cannabaceae	*Humulus japonicus* Sieboid & Zucc.	환삼덩굴
Caryophyllaceae	*Cucubalus baccifer* var. *japonicus* Miq.	덩굴별꽃
	Spergularia marina (L.) Besser*	갯개미자리
Chenopodiaceae	*Atriplex gmelinii* C. A. Mey. ex Bong.*	가는갯는쟁이
	Chenopodium glaucum L.	취명아주
	Chenopodium album var. *centrorubrum* Makino	명아주
	Chenopodium ficifolium Smith	좀명아주
	Salsola komarovii Iljin*	수송나물
	Suaeda glauca (Bunge) Bunge*	나문재
	Suaeda japonica Makino*	칠면초
	Suaeda maritima (L.) Dumort*	해홍나물
Commelinaceae	*Commelina communis* L.	닭의장풀
Compositae	*Ambrosia artemisiifolia* L.	돼지풀
	Artemisia capillaris Thunb.*	사철쑥
	Artemisia fukudo Makino*	큰비쑥

Family	Species	Korean name
Compositae	*Artemisia princeps* Pamp.	쑥
	Bidens bipinnata L.	도깨비바늘
	Conyza bonariensis (L.) Cronquist	실망초
	Conyza canadensis (L.) Cronquist	망초
	Conyza sumatrensis E.Walker	큰망초
	Eclipta prostrata (L.) L.	한련초
	Erechtites hieracifolia Raf.	붉은서나물
	Ixeris repens (L.) A. Gray*	갯씀바귀
	Sigesbeckia pubescens (Makino) Makino	털진득찰
	Sonchus asper (L.) Hill	큰방가지똥
	Sonchus oleraceus L.	방가지똥
	Sonchus brachyotus DC.*	사데풀
Convolvulaceae	*Calystegia soldanella* (L.) Roem. & Schultb.*	갯메꽃
Cruciferae	*Capsella* sp.	냉이속
	Lepidium apetalum Willd.	다닥냉이
	Rorippa indica (L.) Hiern	개갓냉이
Cyperaceae	*Bolboschoenus planiculmis* (F.Schmidt) T.V.Egorova*	좀매자기
	Carex scabrifolia Steud.*	천일사초
	Carex pumila Thunb.*	좀보리사초
	Cyperus amuricus Maxim.	방동사니

Family	Species	Korean name
Cyperaceae	*Schoenoplectus tabernaemontani* (C.C.Gmel.) Palla	큰고랭이
Fagaceae	*Castanea crenata* Siebold & Zucc.	밤나무
	Quercus acutissima Carruth.	상수리나무
Gramineae	*Agropyron tsukushiense* var. *transiens* (Hack.) Ohwi	개밀
	Avena fatua L.	메귀리
	Digitaria ciliaris (Retz.) Koel.	바랭이
	Echinochloa crus-galli (L.) P.Beauv.	돌피
	Miscanthus sinensis var. *purpurascens* (Andersson) Rendle	억새
	Panicum bisulcatum Thunb.	개기장
	Phacelurus latifolius (Steud.) Ohwi*	모새달
	Phragmites communis Trin.*	갈대
	Setaria faberii Herrm.	가을강아지풀
	Setaria viridis (L.) P.Beauv.	강아지풀
	Setaria x *pycnocoma* (Steud.) Henrard ex Nakai	수강아지풀
	Spartina anglica C.E.Hubb.*	영국갯끈풀
	Themeda triandra var. *japonica* (Willd.) Makino	솔새
	Zoysia sinica Hance*	갯잔디
Juncaceae	*Juncus haenkei* E.Mey.*	갯골풀

Family	Species	Korean name
Juncaginaceae	*Triglochin maritima* L.*	지채
Labiatae	*Leonurus japonicus* Houtt.	익모초
Leguminosae	*Aeschynomene indica* L.	자귀풀
Leguminosae	*Amorpha fruticosa* L.	족제비싸리
	Pueraria lobata (Willd.) Ohwi	칡
	Vigna angularis var. *nipponensis* (Ohwi) Ohwi & H.Ohashi	새팥
Malvaceae	*Abutilon theophrasti* Medicus	어저귀
Menispermaceae	*Cocculus trilobus* (Thunb.) DC.	댕댕이덩굴
Oxalidaceae	*Oxalis stricta* L.	선괭이밥
Pinaceae	*Pinus densiflora* Siebold & Zucc.	소나무
Plumbaginaceae	*Limonium tetragonum* (Thunb.) Bullock*	갯질경
Polygonaceae	*Persicaria hydropiper* (L.) Delarbre	여뀌
	Persicaria longiseta (Bruijn) Kitag.	개여뀌
	Polygonum bellardii All.*	큰옥매듭풀
	Rumex crispus L.	소리쟁이
Solanaceae	*Datura meteloides* DC. ex Dunal	털독말풀
Vitaceae	*Parthenocissus tricuspidata* (Siebold & Zucc.) Planch.	담쟁이덩굴

국문 초록

염습지는 파도에 의해 염수에 잠기거나 드러나는 해안에 위치한 습지이다. 그리고 해양 생태계와 육상 생태계를 연결하며 탄소 및 중금속 흡수력이 높으며 많은 생물들의 터전이 된다. 인간의 영향으로 해수면의 상승 속도, 유입 또는 유출되는 퇴적물의 양, 영양분에 변화가 생길 경우 염습지의 면적이 감소할 수 있다. 강화 동검도에는 일부 자연성을 유지한 염습지가 분포하고 있다. 그러나 1980 년부터 김포 매립지, 인천국제공항 건설 등으로 강화도 인근 해역에 많은 매립 및 건설 사업이 진행되어 동검도 동부 갯벌에서 2000 년대 최대 연 7 cm 까지 퇴적이 일어나기도 했다. 2010 년에 들어서 동검도 동부 갯벌에서 퇴적 속도가 안정이 되기는 했지만 염습지의 면적 및 식생은 어떻게 변화했을 지 관찰할 필요가 있다고 판단, 2004 년에 선행 연구자가 식생조사를 진행한 곳을 방문하여 16 년간 염습지의 식생 변화를 확인하였다.

동검도 동부(site 1)의 염습지와 서부(site 2)의 염습지를 대상으로 식생조사를 진행한 결과 염생식물 20 종을 포함하여 총 61 종이 출현하였다. Site 1 은 갈대 군락을 비롯하여 천일사초, 지채, 갯잔디 군락이 분포하고 있었고 site 2 는 갈대 군락와 칠면초 군락을 포함하여 12 종의 우점 군락이 분포하고 있었다. 군락별 면적에 따라 1 x 1 m^2 크기의 방형구를 총 128 개 설치하여 좌표, 고도, 출현종별 피도, 지상부의 높이, 나지의 피도를 측정하였다. 출현종별 피도를 기준으로 Bray-Curtis dissimilarity matrix 를 바탕으로 Ward. D linkage

방법으로 군집 분석을 한 결과 갈대가 우점하는 A 군집, 칠면초가 우점하는 B 군집, 갈대와 칠면초 군락을 제외한 C 군집으로 나뉘었다.

2004 년에 선행 연구자가 작성한 현존 식생도와 이번에 조사한 자료를 바탕으로 염습지의 군락별 면적을 비교하였다. 갈대 군락이 944.8 m^2 에서 5085.1 m^2 로 증가하는 한편, 갯질경과 칠면초 군락이 사라져 총 면적은 1625.0 m^2 에서 5661.4 m^2 로 갈대 군락의 면적 증가폭보다는 작게 증가하였다. 칠면초 군락이 출현했던 위치에는 지채 군락이 분포하고 있었다. 정사영상을 이용하여 2004 년과 2020 년 사이의 기간에 갈대 군락의 면적을 폴리곤으로 작성하여 비교한 결과 갈대 군락의 면적은 지난 16 년간 증가한 것을 확인할 수 있었다.

PERMANOVA 로 앞서 나눈 군집간 환경 요인별 차이가 있는지 확인한 결과 고도, 토양 수분, 토양 유기물 함량, 염도, 모래, 미사, 점토의 비율이 유의하게 차이가 있는 것으로 나타났다. 방형구 내 출현종별 피도를 바탕으로 CCA 분석을 한 결과 고도가 증가할수록 모래의 비율이 증가하는 것으로 나타났다. 칠면초는 비교적 미사 비율이 높은 토양에서 출현하는 것으로 나타났다. 갈대 군락의 경우 보다 낮은 염도에서 분포하는 것을 확인할 수 있었다. Site 1 에 존재하는 담수가 흘러들 수 있는 배수구를 source area 로 시작하여 염도가 높은 바다 쪽으로 갈대 군락이 확장할 수 있는 것으로 보인다.

....

주요어 : 해안 염습지, 동검도, 식생 변화, 염생식물, 갈대

학 번 : 2019-22418