이학석사학위논문

# *Spartina anglica* settlement and effect on macrofauna in the west coast of Korea

한국 서해안에서 영국갯끈풀의 정착요인과

대형저서동물에 미치는 영향

2018년 2월

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# *Spartina anglica* settlement and effect on macrofauna in the west coast of Korea

A Thesis Presented

By

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# *Spartina anglica* settlement and effect on macrofauna in the west coast of Korea

## 한국 서해안에서 영국갯끈풀의 정착요인과 대형저서동물에 미치는 영향

지도교수 이 은 주

이 논문을 이학석사 학위논문으로 제출함

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# Abstract

*Spartina anglica,* an invasive perennial marsh grass, brings changes in ecosystem of tidal flat causing sediment stabilization. It has been identified as invasive species in foreign countries such as USA, Canada, and China. *S. anglica* was first discovered in Ganghwa Island in Incheon, Korea in 2012 and designated as 'Invasive alien Species' by the Ministry of Environment in 2016. However, there are a few studies on the *S. anglica* settlement and its effect on the tidal flats in Ganghwa Island. I conducted outdoor experiment to identify the factors for the *S. anglica* seed settlement and *S. anglica* patch effects on macrofauna. Additionally, an indoor experiments was performed to determine the factors influencing germination rate of *S. anglica*. Average of the seed number of *S. anglica* in *S. japonica* vegetation was 7.1 ± 1.31 $m^{-2}$ and in mudflat was 0.6 ± 0.26 $m^{-2}$. The seed number of *S. anglica* per unit area ($m^2$) was higher in *S. japonica* vegetation than mudflat. However, Spearman correlation analysis among density, coverage, height, underground biomass of *S. japonica*, and number of seeds of *S. anglica* showed no correlation. To identify a certain inundation time germinating *S. anglica* seeds, germination experiment was conducted. The Cox Proportional-Hazard Model suggested that inundation treatment had no significant effect on germination probability. It indicated inundation time might not have effect on seed settlement. First result suggests that *S. japonica* vegetation play a role as a trap for *S. anglica* seed. The second study was carried out to examine the difference of *S. anglica* patch structure along invasion history within 5 years and the effect of *S. anglica* on benthic macrofauna. The survey area was divided into 2 sections by habitats, *S. japonica* vegetation from 0 to 60 m away and mudflat 60 to 90 m away from the embankment. The patch size of *S.*

*anglica* was categorized into small (1 – 4 $m^2$), medium (5 – 11 $m^2$), and large (13 – 40 $m^2$) in area with four replicates for each habitat. The mean of live leaf and rhizome biomass in small size patch of *S. anglica* was significantly higher than in medium and large size patch of *S. anglica*, indicating more resource allocation to be underground in small size patch. After *S. anglica* invasion in Dongmak-ri, macrofauna richness (70%), diversity (80%), and abundance (67%) were decreased. However, infaunal spartina feeder *Perinereis linea* and epifauna *Batillaria cumingi* and *Lactiforis takii* may be increased by *S. anglica*. In CCA analysis for macrofauna assemblages, Mudflat where *S. anglica* invaded was not mixed with *S. japonica* vegetation where *S. anglica* invaded. However, Mudflat and *S. japonica* vegetation with no invasion were mixed. It suggested that habitat with *S. anglica* invasion may change the macrofauna assemblages with negative effect and the result differs depending on the habitat.

Keyword: Cordgrass, estuary, invasion history, invasive species, macrofauna, patch structure, seed settlement, *Spartina anglica*

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# Contents

# List of Tables

# List of Figures

# Chapter Ⅰ. General introduction

## 1.1. History of *Spartina anglica*

Mudflat and saltmarsh are valuable habitats that have diverse ecosystem services, providing food to valuable animal fauna such as benthic macrofauna, birds, and fish (Adam et al. 1985, Costanza et al. 1997, Barbier et al. 2011). However, due to global changes and disturbances caused by humans, ecosystem destruction and alien species invasion are spreading (Ayres and Strong 2002, Worm et al. 2006, Lotze et al. 2006). Wetlands are especially vulnerable to invasive species, having profound impact and long-lasting trait (Lodge 1993, Boorman 1999, Zedler and Kercher 2004). Schirmel et al. (2016) showed that coastal and marine habitat are vulnerable to establishment by invasive species, because of distinct habitat having dynamics and frequent disturbances. Biological invasion introduced by human brings serious environmental problems that may be relate to economic and social development (Sala et al. 2000, Grosholz 2002, Vilà et al. 2010). The west coast of Korea has large area (2,487 $km^2$) and high biodiversity per the area (Ministry of Oceans and Fisheries 2013). Therefore, it is ranked as one of the top five tidal flats in the world along with North Sea, East coast of Canada, East coast of Georgia, and Amazon coast of South America. Kim et al. (2015) found *Spartina anglica*, an invasive weed, in the Dongmak beach of Ganghwa Island in the west coast of Korea in 2012.

*Spartina anglica* CE Hubbard belongs to Poaceae, grass family, and the genus *Spartina* (Raybould et al. 1991, Hedge et al. 2003). It has been reported that *S. anglica* arose after *Spartina alterniflora* Louiseleur in the northeastern United States was hybridized with *Spartina maritima* Fernald, a native species of the southern coast of England (Raybould et al. 1991, Baumel et al. 2002). *Spartina* was introduced into several estuaries and coasts in North America (Ayres and Strong 2002), China (Chung

1993), New Zealand (Hubbard and Partridge 1981) and Australia (Kriwoken and Hedge 2000) for the purpose of stabilizing tidal flats, embankment stabilization and coastline stabilization because roots and rhizomes grew or tightly tangled. Invasive species have a phenotypic plasticity, enabling them to propagate in different conditions from where they are native (Pennings and Bertness 2001, Maron et al. 2004, Hejda et al. 2009). The adaptation, growth, and propagation of seeds of *Spartina* are very active, and the problem of destroying the existing vegetation and ecological environment arose around the world (Daehler and Strong 1996, Xiao et al. 2010, Cutajar, Shimeta, and Nugegoda 2012). *Spartina* transformed marine habitat into monoculture (Millard and Evans 1984), smothering other benthic communities by accreting sediment to its dense roots and rhizomes (Thompson 1991), and changing sediment characteristics such as grain size, pH, salinity, organic matter (Hubbard and Stebbings 1968, Sheehan and Ellison 2014), and retarding the flow of water by their above organ (Morris et al. 2002, Bouma, De Vries, and Herman 2010). *S. anglica* was designated as Invasive Species Special Group (ISSG) by IUCN (Strong and Ayres 2013). Therefore, research for the seed settlement and *Spartina* influence on macrofauna has been actively conducted (Marks and Truscott 1985, Baldwin, McKee, and Mendelssohn 1996, Xiao et al. 2016).

## 1.2. *Spartina anglica* seed settlement

*Spartina* propagates by seeds floating on the water and making the area monotypic plantation by active asexual reproduction with tillering and rhizome (Gray et al. 1991, Strong and Ayres 2009). In Europe, the seeds of *S. anglica*, which inhabited the southern coast of England, spread to the La Baie des Veys in France through the English

Channel in 1906 (Strong and Ayres 2013). However, since *Spartina* propagation is more active in the newly settled area than in their native habitat, the seed production and the settlement rate are considered important (Schneider and Sharitz 1988, Cappers 1993). Seed production depends on seed location and type of seed. According to the Washington State report, the seed production of *S. anglica* (0.25 $m^{-2}$) in the UK amounts 175 individuals in cobble beach, 200 individuals in high-salinity marshes, 320 individuals in low-salinity marshes and 350 individuals were produced the highest yields in the tidal flats. Seeds are suitable for settlement from early March to April, and habitats suitable for germination are wetlands and tidal flats with low salinity (Dethier and Hacker 2004). For seed settlement, a simple physical structure such as vegetation attached to land or floating has an important function as the trap for the seed (Huiskes et al. 1995, Neff and Baldwin 2005).

## 1.3. *Spartina anglica* effects on marofauna

Environmental changes have an influence on the native animal communities by modifying their habitats (Grosholz et al. 2009). Quantifying impacts of plant invasion on benthic communities is important for better understanding causes of underlying invasion (Prieur-Richard et al. 2000, Wu et al. 2009). After the settlement, *S. anglica* changes ecological conditions both habitats and environments (Ehrenfeld 2003). *S. anglica* blocks the energy supply to macroalgae since their shoots form a shade on the tidal flats reducing the light transmittance and the food web considerably changes because the roots and the rhizomes grow high in density and cause monotypic meadow and change of soil environment (Thompson 1991, Cutajar et al. 2012). As *S. anglica* patches expand, algae change into detritus, subsurface deposit feeders increase, and suspension feeders and detritivores decrease (Thompson 1991, Neira et al. 2006, Cutajar et al. 2012). In northern Europe and Australia, both species diversity and abundance of infauna, inhabiting seafloor, decreased (Neira et al. 2007, Tang and Kristensen 2010, Cutajar et al. 2012). *S. anglica* in Tasmania, southeastern Australia, however, has no impact on benthic invertebrates and fish (Hedge and Kriwoken 2000, Wu et al. 2009). *Spartina* invasions was accompanied with a substantial reduction in macrofauna species richness and diversity (Neira et al. 2007, Chen et al. 2007, Tang and Kristensen 2010). It has been shown *S. anglica* tends to have a negative impact on benthos diversity and invertebrate diversity, but their effects may vary depending on the habitat environment. Patch structures of *Spartina* vary depending on spatial and temporal condition and provide indication for long term development and global climate changes (Neira et al. 2007, Balke et al. 2012, Castillo et al. 2016).

## 1.4. Previous studies on *Spartina anglica* in Korea

For the first time in Korea, the botanical characteristics and distribution of *S. anglica* is confirmed at the Dongmak beach in Ganghwa Island in Incheon in 2012, and *S. anglica* was designated as 'unintroduced species' by Ministry of Environment (Kim et al. 2015). Kim et al. (2015) suggested classification criteria for identification of *S. densiflora*, *S. pectinata*, *S. gracilis*, and *S. anglica* in the genus *Spartina*, and identify that *Spartina* invading Dongmak beach is *S. anglica*. Furthermore, Kim et al. (2015) mentioned the ecological damage and the control method of *S. anglica*. Kim (2016) introduced the spreading characteristics and control methods of *S. anglica* and *S.*

*alterniflora* which invaded Jindo-gun, Jeollanam-do, and suggested that the combined treatment (mowing and herbicide treatment) is an effective control method before flowering. At the present time, in Korea there have been only two research, one is on the identification of *S. anglica* characteristics and the other is about the control methods of foreign studies.

## 1.5. Objectives of the study

Despite the harm of *S. anglica*, the research on its seed settlement and ecosystem impact on tidal flat in Korea has been limited. The general objective of the study was to investigate the factors on seed settlement and the effects of *S. anglica* on macrofauna. More specifically, the objectives were: (ⅰ) to examine the effects of *Suaeda japonica* population on the seed settlement of *S. anglica*; (ⅱ) to identify patch structures of *S. anglica* within 5years invasion history; (ⅲ) to examine the effects of *S. anglica* on macrofauna. All field studies were conducted in Ganghwa Island; the study area (ⅰ) is Donggeom-ri and the study area (ⅱ and ⅲ) is Dongmak-ri.

# Chapter Ⅱ. The effect of *Suaeda japonica* population on seed settlement of *Spartina anglica*

## 2.1. Introduction

### 2.1.1. The effect *Suaeda japonica* population on seed settlement of *Spartina anglica*

Wetland species spread with seeds through one or two more complex dispersal modes. Among them, the main medium is water in many wetland systems (Schneider and Sharitz 1988, Smits et al. 1989, Cappers 1993). Neff and Baldwin (2005) reported that total seedling density of wetland species such as *Bidens Frondosa* was significantly higher in the stationary water traps than equal-sized stationary wind trap. *S. anglica* can form vast monotypic colonies, but the spread to various areas is caused by the seed floating on the water (Strong and Ayres 2009). Huiskes et al. (1995) reported that large proportion of *S. anglica* seed was caught in the standing net and *S. anglica* seedling was caught in the floating net indicating that many propagules would be trapped in the vegetation.

*S. anglica* was found in Donggoem-ri, Buno-ri, and Dongmak-ri, on southern coast of Ganghwa Island in 2016. As a result of the preliminary research in autumn of 2016, it was confirmed that *S. anglica* formed the patches close to the coastline in southern coast of Buno-ri and Dongmak-ri. In the western part of Donggeom-ri, the patches of *S. anglica*, however, were formed in the population of *S. japonica*, at least 30 m away from the coastline. I hypothesized that the simple physical structure like *S. japonica* would be catchment structures for the seed of *S. anglica*. This study was designed to investigate height, density, coverage, and biomass to survey physical trait of *S. japonica*. I collected the seed of *S. anglica* and soil in bare mudflat and *S. japonica* population. This study will help to clarify the role of *S. japonica* on seed settlement of *S. anglica*.

## 2.1.2. Light and inundation for *Spartina anglica* germination

Seed germination has an ecological important meaning that it is settled in habitat, develops and disperses. Appropriate germination of halophyte in saline environment determines their distribution (Tobe et al. 2000). *S. anglica* rapidly increased in the west coast of Korea and was designated as invasive alien species in 2016 (Kim et al. 2015). However, germination condition of this species have been rarely studied. Marks and Truscott (1985) examined germination factors of this species such as storage conditions and temperature. They concluded that germination was accelerated at 5℃ and 60 days storage and was more rapid at 20℃ than at 10℃. Although light and flooding condition have negative effect on seed germination in a variety of wetland species (Galinato and Van der Valk 1986; Tobe, Li, and Omasa 2000), there have been few studies on *S. anglica*. Germination condition referred to survey conducted in March 2017. Soil environments such as the water content (WC), soil organic matter (SOM), electrical conductivity (EC), and pH were changed constantly along gradients in the western coast of Donggeom-ri, Ganghwa Island, but the change was not large, except for $NH_4^+$. Inundation may be important factor to decide *S. anglica* zonation and light condition indicates seed situations on mudflat.

## 2.2. Method

### 2.2.1. Study area

The study was carried out in the tidal marsh in the western part of Donggeom-ri (37°35´16.72´´N; 126°30´44.46´´E), Ganghwa Island in Korea. *Suaeda japonica* Makino and *Phragmites communis* Trinius were most common marsh plant species. *S. japonica* occurs 50 – 100 m far away from coastline (Fig. 2.1 and 2.2). *S. anglica* formed several patches in the *S. japonica* vegetation. *S. japonica* was being replaced by *S. anglica*. Mean annual temperature is 11.74℃, maximum and minimum mean annual temperature is 6.88 and 16.84℃, total annual precipitation is 787 mm, mean wind velocity is 2.02 m $s^{-1}$, and total annual duration of sunshine is 2274.2 hours (Climatic data from Korea Meteorological Administration, based on in 2017 at Ganghwa weather station).

**Figure 2.1 *Suaeda japonica* vegetation 50 m away from coastline.**

### 2.2.2. Vegetation survey on *Suaeda japonica*

In the western part of Donggeom-ri, Ganghwa Island, *S. japonica* formed communities at intervals of about 50 m to 100 m from the coastline. 7 patches of *S. anglica* were found in the *S. japonica* vegetation on March 2017. March was appropriate period to survey the number of *S. anglica* seed since the degree of seed spreading was considered to be the maximum (Huiskes et al. 1995). The study to investigate the effect of *S. japonica* structures on seed settlement of *S. anglica* was performed using quadrat method (0.5 m x 0.5 m). 20 replicates were sampled along four elevation gradients. Each elevation gradient was separated from others by ≥30 m and each replicate at the same elevation was separated by 5 m. The closest and farthest location from coastline are bare mudflat and the other two middle elevation gradients are *S. japonica* vegetation (Fig 2.2). I recorded the heights of the vegetation, density, and coverage of *S. japonica* in quadrats. The aboveground biomass of *S. japonica* from each replicate plot was harvested and measured after being dried at 80℃ for 48 hours.

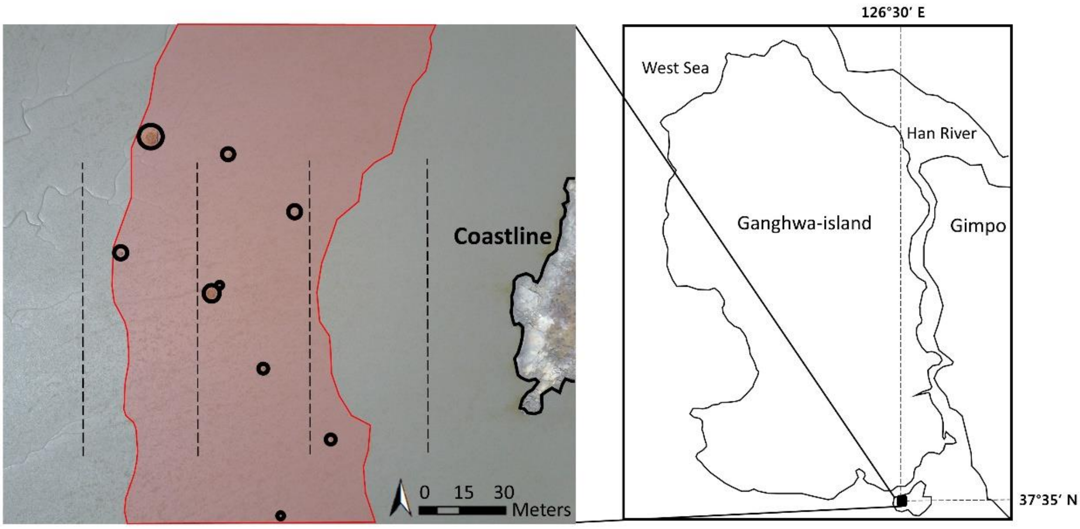


**Figure 2.2 *S. japonica* vegetation infested with *S. anglica* in Donggeom-ri, Ganghwa Island, Korea. Area colored in red represents *S. japonica vegetation*. Circles represent *S. anglica* patches. Dotted lines represent sampling transects.**

## 2.2.3. Collecting *Spartina anglica* seeds

Soil samples from 3–5cm in depth below surface were collected in each replicate plot (0.5 m x 0.5 m) on March 2017 and stored in a refrigerator at 4℃. Soil samples were rinsed with sieves of 1 mm to separate the seeds of *S. anglica* for recording the seed number.

## 2.2.4. Analysis of soil

To analyze the abiotic environment, 300 g soil was isolated from the each soil sample from 5cm in depth and mixed by hand. 5 g was dried at 105℃ for 24 hours to determine the water contents of soil and ashed at 550℃ for 4 hours to determine the organic content of soil. 7 g of air-dried soil was mixed with 35 ml distilled water for suspension for salinity and pH. Salinity and pH were measured after shaking at 180 rpm for 30 minutes and centrifugation at 3000 rpm for a minute. Salinity was measured with PC-2700 (THERMO EUTECH, Singapore) fitted with a CONSEN9201J probe; pH with PC-2700 fitted with ECFG7370101B probe.

$$\text{Water Content (\%)} = (W_F - W_D) / W_F \times 100$$

($W_F$ is weight of Fresh soil and $W_D$ is weight of dry soil)

$$\text{Organic Matter (\%)} = (W_{105} - W_{550}) / W_{105} \times 100$$

($W_{105}$ is weight of soil at 105℃ and $W_{505}$ is weight of soil at 550℃)

$NH_4$-N in soil were extracted with a 2M KCl solution, and $PO_4$-P was extracted with Bray NO. 1 solution (Bray and Kurtz, 1945). $NH_4$-N and $PO_4$-P in water and in the extracted soil solution were analyzed by the indo-phenol method (Murphy and Riley, 1962) and ascorbic acid reduction method (Solorzano 1969), respectively.

### 2.2.5. Effect of light

30 seeds were placed on the moistened filter paper with distilled water in 9 cm diameter petri dish and total 30 petri dishes were used to examine the light effect on germination (Fig. 2.3). Half of them were covered with aluminum foil and sealed in box to block out light. The petri dishes were placed on the growth chamber (HB-301L HANBAEK SCIENTIFIC CO., Korea). The growth chamber was set at 25/15℃with

12-h photoperiod and light intensity of 100 to 110 μmol/$m^2$. Germinated seeds were counted every single day for 50 days. Germination was determined when the radicle appeared (Fig. 2.4).

## 2.2.6. Effect of inundation

All petri dishes with 30 seeds were set in the same procedure as described above. The inundation time was 1, 2, 3 hours and permanent immersion (Fig. 2.3). The seeds in the 0 hour condition were kept only the moistened state and the water depth for inundation conditions was about 2 cm. The seeds were subjected to immersion condition after the point of recording all the seeds. The contaminated petri dishes with mold were replaced to new one for germination. Three replicates were done for each condition.

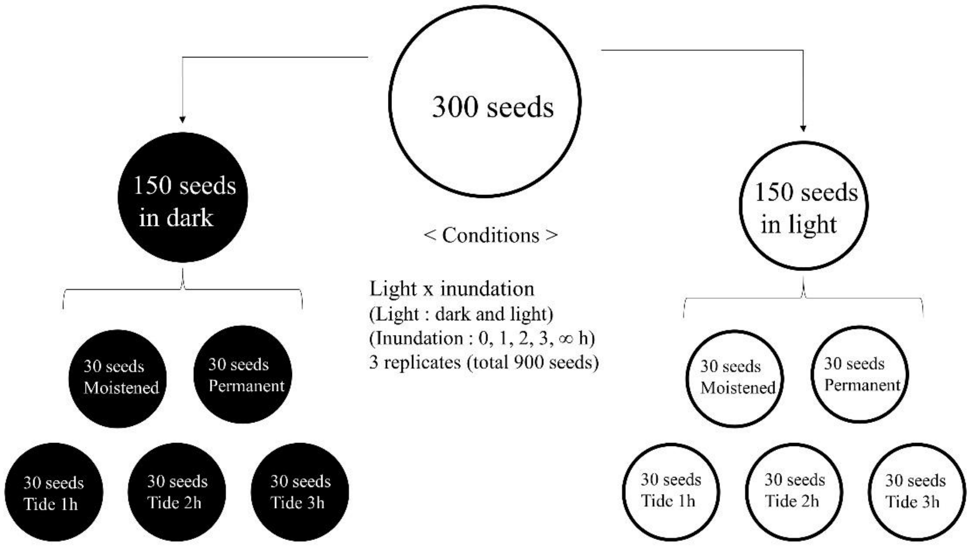


**Figure 2.3 Outline of germination experimental procedures.**

**Figure 2.4 Germination experiment. Left light and inundation condition; Right seedling of *S. anglica*.**

## 2.2.7. Statistical analysis

*S. anglica* seed number, *S. japonica* vegetation, and environmental variables were analyzed with one way ANOVA and Tukey's HSD test or Kruskal-Wallis test and Pairwise t-test. Due to censured data (no germination), semiparametric time-to-event analysis were conducted (McNair, Sunkara, and Frobish 2012). Germinated seeds were assigned as event code of '1' and non-germinated seeds were assigned '0'. Data were log-ranked to compare survival data. The semi-parametric Cox proportional-hazard model was used to determine how it is likely ungerminated within the experimental period (50 days). To reduce the error in Cox model, first two days that any seed didn't showed germination were excluded (Scott et al. 1984).

## 2.3. Results

### 2.3.1. Vegetation survey on *S. japonica* and *S. anglica* seed number .

There were no significant difference in the density, coverage, and aboveground-biomass except height of *S. japonica* in the *S. japonica* vegetation. Average of density, coverage, and aboveground biomass at the site were 43.2 ± 8.17 indi. $m^{-2}$, 42 ± 3.21% $m^{-2}$, 20.11 ± 0.36 cm $m^{-2}$, and 38.95 ± 3.54 g $m^{-2}$ (Table 2.1).

**Table 2.1. Vegetation survey on *Suaeda japonica* 60 m away and 90 m away from coastline in Donggeom-ri.**

| **Habitat (*S. japonica*)** | **Individuals ($m^{-2}$)** | **Coverage (% $m^{-2}$)** | **Height (cm $m^{-2}$)** | **Biomass (g $m^{-2}$)** |
|---|---|---|---|---|
| **N (n = 20)** | | | | |
| mean | $44.6^a$ | $42.5^a$ | $20.98^a$ | $37.4^a$ |
| SE | (14.09) | (4.52) | (0.47) | (3.24) |
| **F (n = 20)** | | | | |
| mean | $41.8^a$ | $41.5^a$ | $19.24^b$ | $40.5^a$ |
| SE | (8.67) | (4.68) | (0.48) | (6.38) |
| Total | | | | |
| mean | 43.2 | 42 | 20.11 | 38.95 |
| SE | (8.17) | (3.21) | (0.36) | (3.54) |

Means with different letters within a column are significantly different at $P < 0.05$ using Turkey's honestly significant difference (HSD) test.

## 2.3.2. Seed of *S. anglica.*

The number of *S. anglica* seed per unit area ($m^2$) was higher in *S. japonica* vegetation than in mudflat. There was no significant difference in the number of seed in each habitat, mudflat and *S. japonica* vegetation (Fig. 2.5). Average of the number of seed of *S. anglica* in *S. japonica* vegetation is 7.1 ± 1.31 $m^{-2}$ and in mudflat is 0.6 ± 0.26 $m^{-2}$.

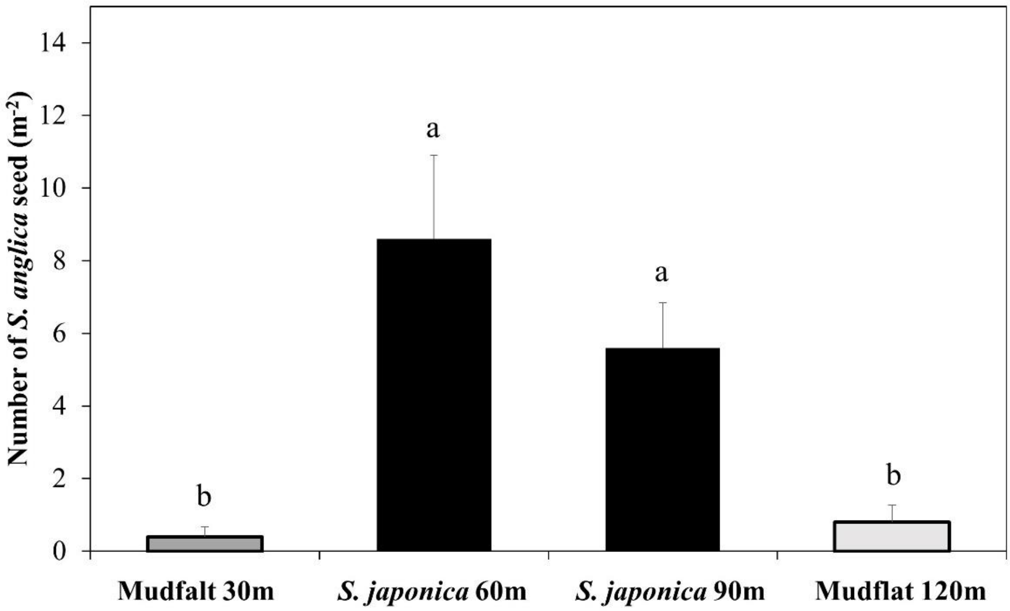


**Figure 2.5 Number of *S. anglica* seed ($m^{-2}$) in Mud flat and *S. japonica* vegetation. Mud flat 30 m away, *S. japonica* 60 m away, *S. japonica* 90 m away , Mud flat 120 m away from coastline in Donggeom-ri. Different letters indicate significant differences between in the Mudflat and in the *Suaeda japonica* vegetation (Kruskal-Wallis test and Pairwise t-test, *P* < 0.05, n = 40).**

Spearman correlation analysis among density, coverage, height, aboveground biomass of *S. japonica*, and number of *S. anglica* seed showed no correlation (Table 2.2). Biomass of *S. japonica* showed positive correlation with coverage, height, and density of *S. japonica* (Strong correlation: coverage and density; intermediate correlation: height). Coverage of *S. japonica* showed positive and strong correlation with density of *S. japonica*.

**Table 2.2 Correlation matrix of number of *S. anglica* seed and the vegetation survey data on *S. japonica* in Donggeom-ri. Spearman correlation analysis was used.**

| | | ***S. anglica*** | ***S. japonica*** | | | |
|---|---|---|---|---|---|---|
| | | **Seed number ($m^{-2}$)** | **Biomass ($g\ m^{-2}$)** | **Coverage (% $m^{-2}$)** | **Height ($cm\ m^{-2}$)** | **Density (indi. $m^{-2}$)** |
| ***S. anglica*** | **Seed number** | 1 | | | | |
| ***S. japonica*** | **Biomass** | 0.285 | 1 | | | |
| | **Coverage** | 0.091 | 0.740** | 1 | | |
| | **Height** | 0.043 | 0.430** | 0.218 | 1 | |
| | **Density** | 0.084 | 0.628** | 0.669** | 0.039 | 1 |

*$P$ < 0.05, **$P$ < 0.01, ***$P$ < 0.001

### 2.3.3. Analysis of soil.

Electrical conductivity, water content, and organic matter tended to decrease depending on the distance from coastline except for pH and $NH_4^+$ (Fig. 2.6). This results represented that the environment was similar to ordinary coast traits. The soil environment of this study site was pH 7.76 ± 0.11; EC 6.89 ± 1.12 mS $cm^{-1}$; WC 37.96 ± 0.34% ; OM 3.90 ± 0.05%; $PO_4^-$ 27.9 ± 0.92 mg $kg^{-1}$; $NH_4^+$; 51 ± 4.39 mg $kg^{-1}$ in Table 2.3. It may be vulnerable conditions to invasion of *S. anglica* with a wide range of environmental tolerance.

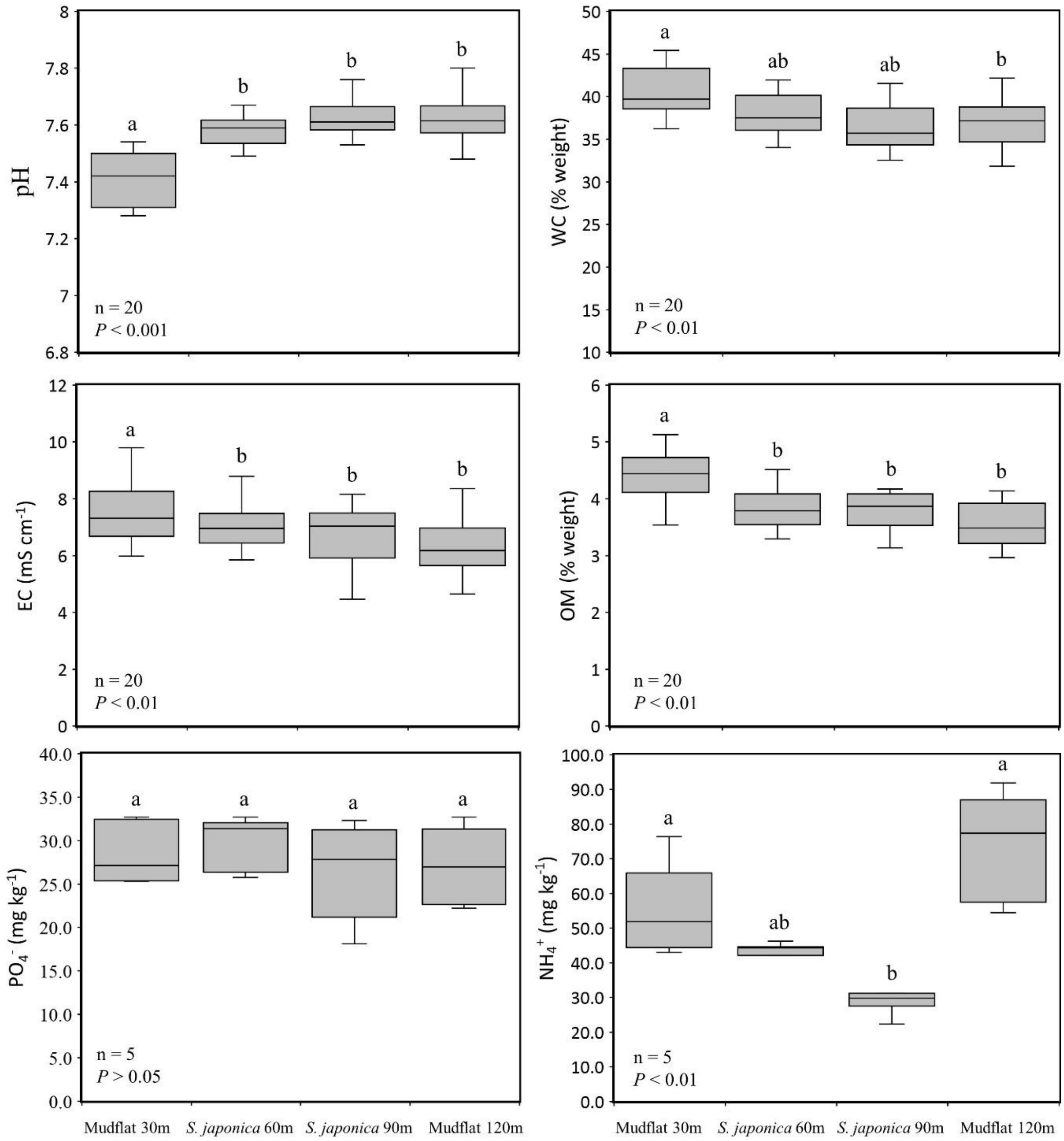


**Figure 2.6 Soil environmental survey on pH, Electrical Conductivity (EC), Water Content (WC), Organic Matter (OM), $PO_4^-$ and $NH_4^+$ along four distance (30 m, 60m, 90m, and 120 m) from coastline in the west of Donggeom-ri. Different letters indicate significant differences between the habitats (ANOVA and Tukey-HSD test, *P* < 0.05)**

**Table 2.3 Environment variables recorded in the western coast of Donggeom-ri, Ganghwa Island, Korea. Mudflat 30 m: Mud flat 30 m away; *S. japonica* 60 m: *S. japonica* 60 m away; *S. japonica* 90 m: *S. japonica* 90 m away, Mudflat 120m; Mudflat 120 m away from coastline; EC: electrical conductivity; WC: water content; OM: organic matter.**

| | pH | EC (mS $cm^{-1}$) | WC (% weight) | OM (% weight) | $PO_4^-$ (mg $kg^{-1}$) | $NH_4^+$ (mg $kg^{-1}$) |
|---|---|---|---|---|---|---|
| **Mudflat 30m (n=20)** | | | | | | |
| **mean** | $7.41^a$ | $7.55^a$ | $40.65^a$ | $4.43^a$ | $28.55^a$ | $56.32^a$ |
| **SE** | -0.01 | -0.24 | -0.63 | -0.09 | -1.54 | (1.79) |
| ***S. japonica* 60m (n=20)** | | | | | | |
| **mean** | $7.58^b$ | $6.97^{ab}$ | $30^b$ | $3.84^b$ | $29.64^a$ | $42.84^{ab}$ |
| **SE** | -0.03 | -0.25 | -0.53 | -0.08 | (2.79) | (4.18) |
| ***S. japonica* 90m (n=20)** | | | | | | |
| **Mean** | $7.6^b$ | $6.74^{ab}$ | $36.38^b$ | $3.8^b$ | $26.52^a$ | $31.12^b$ |
| **SE** | -0.01 | -0.22 | -0.55 | -0.07 | (2.23) | (8.49) |
| **Mudflat 120m (n=20)** | | | | | | |
| **mean** | $7.6^b$ | $6.3^b$ | $36.89^b$ | $3.54^b$ | $26.98^a$ | $73.66^a$ |
| **SE** | -0.02 | -0.21 | -0.58 | -0.09 | (1.81) | (7.22) |

Means with different letters within a column are significantly different at $P < 0.05$ using Turkey's honestly significant difference (HSD) test.

### 2.3.4 Germination model and hazard rates.

Germination began from 2 days after designed light and inundation treatments. The final germination percentages on 50 days were 66.89 ± 2.43% under the light and inundation condition. In light condition, a final germination was low (48%) under inundation conditions and lowest under tide 1hour condition. In addition, inundation treatment (tide 1, 2, and 3 hours) had lower number of days to reach 50% final germination and final germination percentages than other inundation condition (moistened and permanent). In dark condition, final germination was high under tide condition and highest under inundation 2 hours condition. In addition, inundation treatment (tide 1, 2, and 3 hours) had lower number of days to reach 50% final germination and final germination percentages than other inundation conditions (moistened and permanent), which were similar with light condition.

**Table 2.4 Final germination, mean number of days to reach 50% and final germination after designed two Light and five inundation treatments (moistened, tide 1, 2, 3 hours, and permanent) for 50 days.**

| Treatment | | Final germination (%) | Mean number of days | |
|---|---|---|---|---|
| | | | 50% germination | Final germination |
| **Light** | **Moistened** | | | |
| | **Mean** | 68.89 | 21.5 | 39.33 |
| | **SE** | (13.65) | (8.5) | (4.37) |
| | **Tide 1hour** | | | |
| | **Mean** | 47.78 | 10 | 24 |
| | **SE** | (23.28) | NA | (7.81) |
| | **Tide 2hours** | | | |
| | **Mean** | 63.33 | 11 | 32.33 |
| | **SE** | (20) | NA | (5.04) |
| | **Tide 3hours** | | | |
| | **Mean** | 63.33 | 10.5 | 31 |
| | **SE** | (15.28) | (1.5) | (7.09) |
| | **Permanent** | | | |
| | **Mean** | 67.78 | 21 | 37.33 |
| | **SE** | (12.37) | (6) | (1.2) |
| **Dark** | **Moistened** | | | |
| | **Mean** | 68.89 | 20.67 | 43.33 |
| | **SE** | (5.56) | (3.33) | (3.28) |
| | **Tide 1hour** | | | |
| | **Mean** | 74.44 | 15 | 32.33 |
| | **SE** | (6.19) | (1.53) | (0.33) |
| | **Tide 2hours** | | | |
| | **Mean** | 77.78 | 14.33 | 26.33 |
| | **SE** | (4.84) | (1.45) | (1.2) |
| | **Tide 3hours** | | | |
| | **Mean** | 71.11 | 13 | 29.33 |
| | **SE** | (10.6) | (2) | (6.49) |
| | **Permanent** | | | |
| | **Mean** | 65.56 | 20.67 | 30.67 |
| | **SE** | (1.11) | (1.2) | (1.33) |

Final germination percentage ± standard error is the average of 90 seeds divided equally among three petri dishes.

The overall Cox Proportional-Hazard Model suggested that light treatment had a significant effect on germination probability. Seeds under dark condition were more likely to germinate earlier than those under light condition. However inundation condition had no a significant effect on germination probability. Under inundation condition, there were no significant differences between inundation times.

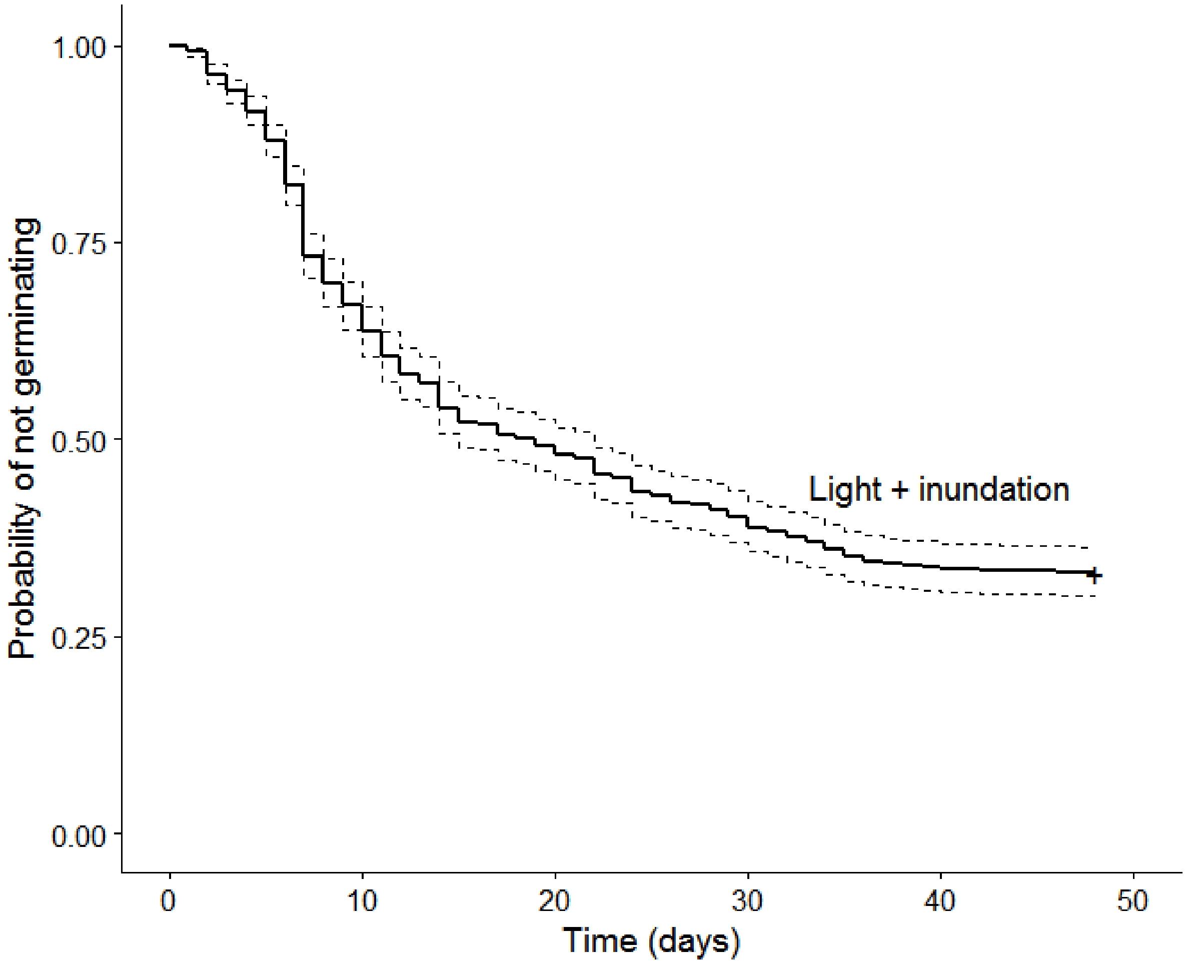


**Figure 2.7 Kaplan-Meier survivor main effects curves of *S. anglica* seed under light and Inundation condition.**

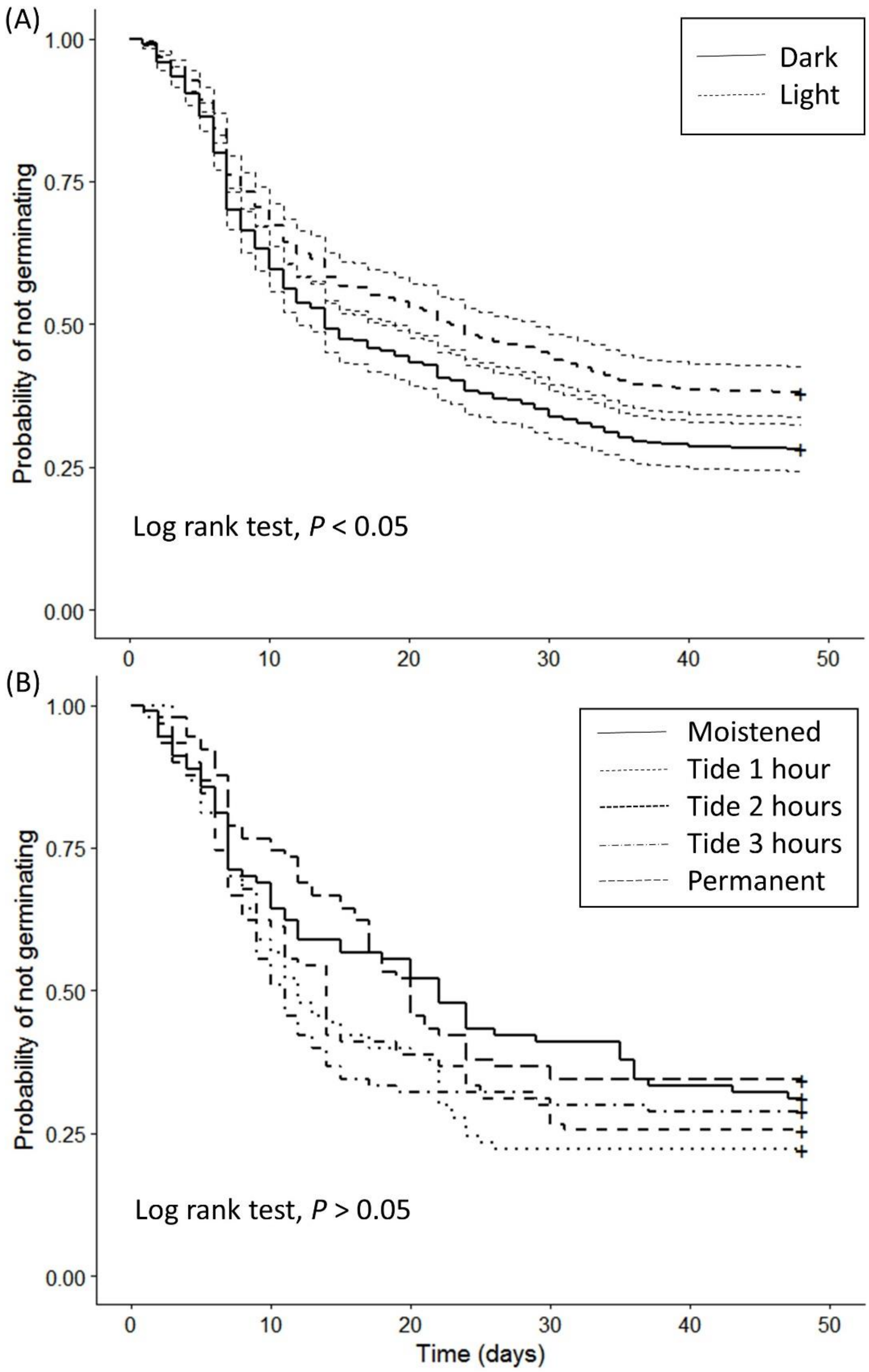


**Figure 2.8 Kaplan-Meier survivor main effects curves of *S. anglica*. (A) Light treatment: light and dark condition, (B) five inundation treatment: Moistened, Tide 1 hour, Tide 2 hours, Tide 3 hour ( Tide 1 h, 2 h and 3 h every single day), and permanent condition.**

**Table 2.5 Summary of the Cox model for *S. anglica* germination data, as produced by function coxph( ), SE denotes the standard error. Multiple comparisons of main effects were compared. Significant is in bold.**

| Covariate | Coefficient, βi | exp(βi) | SE of βi | Z | p |
|---|---|---|---|---|---|
| **Inundation** | -0.078 | 0.92 | 0.086 | -0.903 | 0.366 |
| **Light** | -0.449 | 0.64 | 0.187 | -2.397 | **0.017** |
| **Inundation x light** | 0.06 | 1.06 | 0.056 | 1.064 | 0.287 |

Likelihood ratio test = 12.16 on 3df, P = 0.0068; Wald test = 12.01 on 3df, *P* = 0.0073.

coxph(formula = Surv(day, status) ~ light + inundation + light:inundation, data).

Harzard ratio exp (βi) less than 1 mean seeds germinate later, whereas hazard ratio greater than 1 mean seeds germinate earlier

## 2.4. Discussion

Floating times are critical components of hydrochloric behavior resulting in decision of habitat (Strong and Ayres 2009, Carthey et al. 2016). When seeds and fruits have no buoyancy of their own, they may be dispersed little by water (Huiskes et al. 1995). Propagules with no buoyancy not only travel shorter distances than floating propagules, but move backwards and forwards with the tides for some time, much more than floating propagules (Huiskes et al. 1995). It indicates that the inundation condition in my study indirectly could show a gradient of habitat. Since there was no significant difference among inundation conditions, *S. anglica* seed should have been settled along the gradient of mudflat if there was no *S. japonica* vegetation. However, a positive association between extant vegetation and seed bank composition has also been observed and many propagules may be trapped in the vegetation (Parker and Leck 1985, Huiskes et al. 1995, Neff and Baldwin 2005). These explain that *S. anglica* patches were formed only in *S. japonica* vegetation and higher number of *S. anglica* seed was found in *S. japonica* vegetation. The presence or absence of vegetation affected the abundance of some species in the seed bank but had little effect on species composition (Smith and Kadlec 1985, Baldwin et al. 1996). Since buoyancy period of *S. anglica* seed is 4 – 60 days (Huiskes et al. 1995), the germination period for 50 day was enough to see the total germination and mudflat in Donggeom-ri are flattened, resulting in a short inundation time (0 – 3hours) of the marshes. Poole Harbour in the southern England has a small tidal range and a sheltered position which encourage the establishment of *Spartina* at levels constantly flooded by the high water neap tides (Hubbard 1969). Relatively floating propagules are caught in the vegetation when ebb stream has a low flow (Huiskes 1995). Light condition in germination showed that the germination of seed of *S. anglica* was inhibited by light and this results is the same with previous study (Hubbard 1970). This study will help to clarify the role of *S. japonica* on seed settlement of *S. anglica*.

# Chatper Ⅲ. Patch effects *of Spartina anglica* on benthic macrofauna

## 3.1. Introduction

Benthic macrofauna plays an ecologically important role in regulating soil stability and energy flow with organisms that affect high tropic levels. For this reason, it provides an important indicator for evaluating the degree of disturbance, such as biological disturbance (Snelgrove 1998). *Spartina* that has habitat-engineering effects can lead to change macrofauna assemblages associated with species richness and diversity (Neira et al. 2006). Tang and Kristensen (2010) reported that infauna abundance was lower in *S. anglica* meadow than mudflat while epifauna is opposite and the biomass of dead belowground plant was negatively related with infauna abundance. Hedge and Kriwoken (2000) examined the macroinvertebrate communities between exotic, *S. anglica*, and native vegetated sites. They conclude that species richness and total abundance of invertebrate did not differ but communities can be separated between the two sites. *S. anglica* invasions was accompanied with a substantial reduction in macrofauna species richness and a strong shift in food web leading to an increase in *Spartina* feeder (Neira et al. 2007, Tang and Kristensen 2010). It has been shown that *S. anglica* tends to have a negative impact on benthic diversity and abundance in invertebrates, but their effects may vary depending on the habitat environment.

However, there have been a few studies done on patch effect of *S. anglica* on benthic macrofauna and patch structures difference among patch sizes. Castillo et al. (2016) reported that *Spartina densiflora* can adapt to condition though phenotypical plastic key such as shoot density, height, above and belowground allocation patterns. This study was carried out to examine the effect of *S. anglica* on benthic macfauna.

## 3.2. Method

### 3.2.1. Study area

The study was carried out in the tidal marsh in the southern part of Dongmak-ri (37°35´36.97´´N; 126°26´32.36´´E), Ganghwa Island in Korea (Fig 3.1). *S. japonica* widely occurs and are infested with *S. anglica* forming patches or meadow. It was reported that *S. anglica* invasion has been 5years at least. Weather condition was described in Chapter Ⅱ.

**Figure 3.1 The study area in Dongmak-ri, Ganghwa Island on December in 2016. Left is meadow; right is patches of *S. anglica*.**

### 3.2.2. Vegetation survey

To investigate variation in patch structure of *S. anglica*, 24 patches were selected from *S. anglica* infestation near the embankment (Fig. 3.2). Region was selected in the basis that mudflat, *S. japonica* vegetation, and especially separated patches of *S. anglica* were present together. Neira et al. (2007) pointed out that *Spartina* growth stages and macrofauna communities changed in connection with sediment and environmental properties. Therefore the survey area was divided into 2 sections by habitats, *S. japonica* vegetation from 0 to 60 m and mudflat 60 to 90 m way from the embankment. Photographs from drone (Mavic pro, DJI CO., China) were converted into shape files through eCognition developer 64 and the size of each patch was obtained using ArcGIS 10.1. I named each patch to find patches to investigate in the field. The size of the patch of *S. anglica* was selected to be small (1 to 4 $m^2$), medium (5 to 11 $m^2$), and large (13 to 40 $m^2$) in the area with four replicates for each distance. In the field survey, the shortest, longest diameter, and circumference were measure for each to compare the estimated patch sizes with the actual measurements. The aboveground and the belowground *S. anglica* were also surveyed.

The aboveground *S. anglica* was harvested by clipping vegetation at the sediment surface in (1 m x 1m) quadrats after measuring density and height of dead and live shoots. 5 dead and live shoot for height were selected from 4 edge and center in each quadrat. Dead shoots and leaves were identified by their yellow and brown color and separated from living material (Darby and Turner 2008). The aboveground materials was put in plastic bag and placed in refrigerator 4℃. Each individual was divided into stems and leaves and then washed about 10 times with water to remove the sediment.

The live or dead plant material was put into paper bags, dried at 80℃ for approximately 72 hours, and weighted to the nearest 0.01 g. The aboveground *S. japonica* was harvested and weighted in the same procedure with *S. anglica*.

The belowground *S. anglica* was collected using a 10 cm long PVC core with 15 cm diameter. Two replicates were designed to edge of patch in the same quadrats. Each segment was put in plastic bags and placed in refrigerator at 4℃. The segments were washed in 500 µm sieve to prevent the loss of fine root material and belowground materials were separated into root and rhizome (Fig. 3.3). The root or rhizome was put into paper bags, dried at 80℃ for approximately 72 hours, and weighted to the nearest 0.01 g.

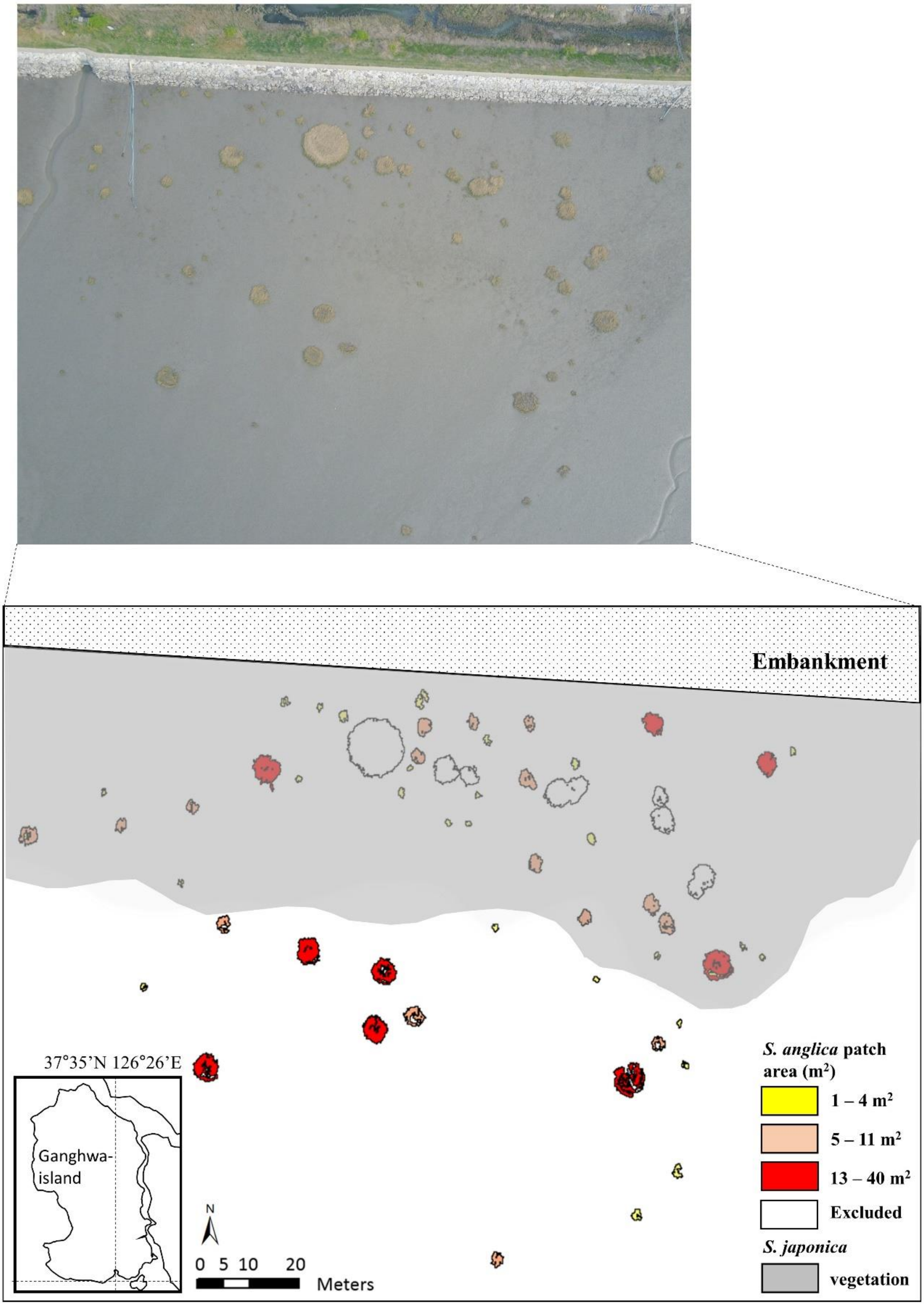


**Figure 3.2 Various patch sizes of *S. anglica* in study location in Dongmak-ri, Ganghwa Island, Korea. The different colors represent different size of patch in the area and *S. japonica* vegetation.**


**Figure 3.3 Procedure of dividing belowground organ into root and rhizome.**

## 3.2.3. Benthic macrofauna survey

To examine the independent effect of each patch, patches within 2 m from other were excluded from the survey. As a control group for *S. anglica* in macrofauna experiment, mudflat and *S. japonica* vegetation were selected and surveyed in the same procedure with *S. anglica*. Each replicate was randomly selected at the same habitat. Benthic macrofauna was sampled in the same procedure with the belowground *S. anglica* sampling method. The segment was sieved to separate macrofauna from root, rhizome, and sediment. Sieved macrofauna was weight to the nearest 0.001 g and preserved in 70% ethanol. It was classified to species level using a dissecting microscope.

### 3.2.4. Analysis of soil

Soil sampling was located in center and approximately 10 cm from each macrofauna core in each quadrat. To reduce processing effort and environment variation, three replicates were mixed in the same quardrat (Hedge and Kriwoken 2000). Soil environment such as the water content (WC), soil organic matter (SOM), electrical conduction (EC), pH, $NH_4^+$, and $PO_4^-$ was examined according to the methods described in Chapter Ⅱ.

### 3.2.5. Statistical analysis

Several assemblage indices were calculated to compare macrofauna assemblages. These included species richness, abundance , Shannon-Wiener species diversity (Pielou 1966), and biomass. Difference in assemblage indices, environmental variables, and *S. anglica* patch structures among habitats were test with one-way ANOVA and Tukey-HSD test in R 3.3.2 version. Principal component Analysis was performed to reduce the number of patch structure trait variables and extract independent PC factor with eigenvalues >1. Canonical Correspondence Analysis (CCA) was performed to summarize the macrofauna assemblage and environmental variables.

# 3.3. Results

## 3.3.1. Density, height, and coverage of *Spartina anglica*

Live shoot density ranged from 173.5 to 227 $m^{-2}$. Dead shoot density ranged from 163.25 to 225.75 $m^{-2}$. Live shoot height ranged from 33.55 to 40.10 cm $m^{-2}$. Dead shoot height ranged from 83.45 to 128.7cm $m^{-2}$. Live organ coverage ranged from 36.25 to 65% $m^{-2}$ (Table 3.1). No discernable patterns were observed among different patch size and habitats in the average of live and dead shoot density ($P > 0.05$). Live shoot height were significant difference in habitats. The mean of live shoot height were significantly higher in *S. japonica* vegetation. Dead shoot height were significant difference in different patch size of *S. anglica*. The mean of dead shoot height were significantly higher in large size patch of *S. anglica*. Live organ coverage were significant difference in different patch size of *S. anglica* and habitats. The mean of live organ coverage were significantly low in large size patch of *S. anglica* in mudflat (Fig. 3.4).

**Table 3.1 Live and dead shoot density and total shoot density (shoot m$^{-2}$), live and dead shoot height (cm), and live coverage (%) for three different patch sizes of *S. anglica* from two habitat, mudflat and *S. japonica* vegetation in Donggeom-ri, Ganghwa Island, Korea. Different letters indicate significant differences between in the habitats or in the patch size of *S. anglica* (Two-way ANOVA and Tukey-HSD test, *P* < 0.05, n = 4)**

| | | Mudflat | | | *S. japonica* vegetation | | |
|---|---|---|---|---|---|---|---|
| | | Patch size of *S. anglica* | | | Patch size of *S. anglica* | | |
| | | Small | Medium | Large | Small | Medium | Large |
| **Live** | **Shoot density (m$^{-2}$)** | | | | | | |
| | **mean** | 227 | 173.5 | 215.5 | 210.25 | 213.25 | 198.5 |
| | **SE** | (33.12) | (19.23) | (16.46) | (28.17) | (56.1) | (44.84) |
| | **Shoot height (cm)** | | | | | | |
| | **mean** | 35.05$^{b}$ | 33.55$^{b}$ | 34.35$^{b}$ | 36.8$^{a}$ | 37.4$^{a}$ | 40.15$^{a}$ |
| | **SE** | (1.33) | (1.67) | (1.12) | (1.76) | (3.22) | (2.77) |
| | **Coverage (%)** | | | | | | |
| | **mean** | 65$^{a}$ | 61.25$^{a}$ | 36.25$^{b}$ | 52.5$^{ab}$ | 63.75$^{a}$ | 56.25$^{ab}$ |
| | **SE** | (4.56) | (8.26) | (2.39) | (4.33) | (4.73) | (2.39) |
| **Dead** | **Shoot density (m$^{-2}$)** | | | | | | |
| | **mean** | 225.75 | 182.5 | 163.25 | 222 | 180.75 | 176.5 |
| | **SE** | (24.36) | (47.09) | (17.34) | (20.47) | (29.89) | (13.94) |
| | **Shoot height (cm)** | | | | | | |
| | **mean** | 83.45$^{b}$ | 105.1$^{ab}$ | 109.6$^{a}$ | 99.85$^{b}$ | 102.4$^{ab}$ | 128.7$^{a}$ |
| | **SE** | (8.37) | (8.14) | (4.09) | (6.51) | (15.8) | (3.75) |
| **Live +dead** | **Shoot density (m$^{-2}$)** | | | | | | |
| | **mean** | 452.75 | 356 | 378.75 | 432.25 | 394 | 375 |
| | **SE** | (53.59) | (60.8) | (31.07) | (41.43) | (84.68) | (38.67) |

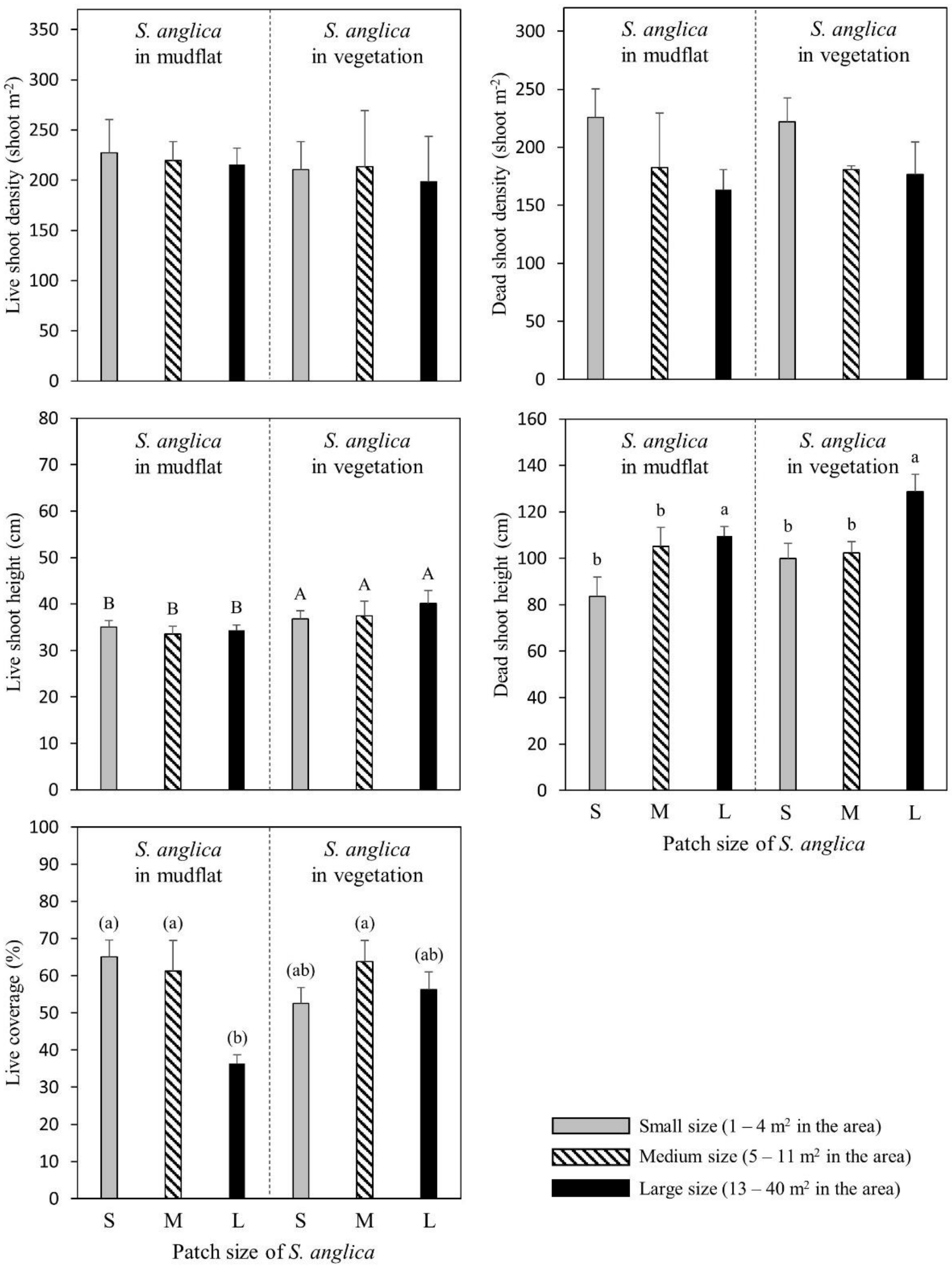


**Figure 3.4 Live and dead shoot density (shoot m$^{-2}$), live and dead shoot height (cm), and live coverage (%) for three different patch sizes of *S. anglica* from two habitat, mudflat and *S. japonica* vegetation in Donggeom-ri, Ganghwa Island, Korea. Error bars indicate standard error of the mean. Different letters indicate significant differences between in the habitats or in the patch size of *S. anglica* (Two-way ANOVA and Tukey-HSD test, $P < 0.05$, n = 4). Small letter for patch size, capital letter for habitat, and small letter with ( ) for interaction between patch size and habitat.**

### 3.3.2. Biomass of *Spartina anglica*

The live aboveground biomass range from 42.91 to 57.21 g $m^{-2}$. The belowground biomass ranged from 176.89 to 302.22 g $m^{-2}$ and account for 16 – 23% of the aboveground biomass (Table 3.2). Among live and dead biomass, only live leaf biomass, dead leave biomass, rhizome biomass were significant different in different patch size of *S. anglica* or two habitats, which were mudflat and *S. japonica* vegetation. Live leaf biomass and rhizome biomass were significant different in different patch size of *S. anglica*, not habitats. The mean of live and rhizome biomass in small size patch of *S. anglica* was significantly higher than in medium and large size patch of *S. anglica* ($P < 0.05$). Dead leave biomass were significant difference in habitats. The mean of dead leave were significantly higher in *S. japonica* vegetation (Fig. 3.5). BGB (Belowground biomass): AGB (Aboveground biomass) was significantly higher in small patch size, indicating that more allocation of resource to underground organ to adapt to the habitat Fig. 3.6).

**Table 3.2. Biomass of leaf and shoot of live and dead state and root and rhizome biomass (g m$^{-2}$) for three different patch sizes of *S. anglica* from two habitat, mudflat and *S. japonica* vegetation in Dongmak-ri, Ganghwa Island, Korea. Different letters indicate significant differences between in the habitats or in the patch size of *S. anglica* (Two-way ANOVA and Tukey-HSD test or Kruskal-Wallis H-test, *P* < 0.05, n = 4).**

| | | Mudflat | | | *Suaeda japonica* vegetation | | |
|---|---|---|---|---|---|---|---|
| | | Patch size of *Spartina anglica* | | | Patch size of *Spartina anglica* | | |
| | | **Small** | **Medium** | **Large** | **Small** | **Medium** | **Large** |
| **Live** | **leaf biomass** | | | | | | |
| | **mean** | 40.31$^{b}$ | 25.34$^{ab}$ | 26.81$^{a}$ | 43.81$^{b}$ | 36.3$^{ab}$ | 25.88$^{a}$ |
| | **SE** | (7.06) | (3.9) | (5.32) | (7.45) | (5.73) | (2.63) |
| | **shoot biomass** | | | | | | |
| | **mean** | 16.9 | 12.96 | 16.53 | 21.89 | 18.73 | 17.03 |
| | **SE** | (2.79) | (3.43) | (2.45) | (2.57) | (4.78) | (4.59) |
| | **aboveground biomass** | | | | | | |
| | **mean** | 57.21 | 38.3 | 43.34 | 65.7 | 55.02 | 42.91 |
| | **SE** | (9.77) | (7.21) | (7.73) | (9.97) | (10.19) | (5.98) |
| **Dead** | **leaf biomass** | | | | | | |
| | **mean** | 34.3$^{b}$ | 29.46$^{b}$ | 44.52$^{b}$ | 68.29$^{a}$ | 46.22$^{a}$ | 54.42$^{a}$ |
| | **SE** | (4.22) | (9.06) | (10.4) | (18.88) | (5.8) | (3.29) |
| | **shoot biomass** | | | | | | |
| | **mean** | 267.11 | 233.43 | 272.8 | 332 | 317.33 | 353.08 |
| | **SE** | (33.01) | (33.02) | (23.01) | (89.99) | (69.3) | (35.85) |
| | **aboveground biomass** | | | | | | |
| | **mean** | 301.41 | 262.89 | 317.31 | 400.29 | 363.55 | 407.51 |
| | **SE** | (36.25) | (41.75) | (33.13) | (108.11) | (74.63) | (38.28) |
| **Live+dead** | **aboveground biomass** | | | | | | |
| | **mean** | 358.62$^{b}$ | 301.19$^{b}$ | 360.65$^{b}$ | 465.99$^{a}$ | 418.57$^{a}$ | 450.42$^{a}$ |
| | **SE** | (35.78) | (43.92) | (38.9) | (101.74) | (74.27) | (38.07) |
| **Root biomass** | | | | | | | |
| | **mean** | 145.42 | 110.37 | 104.73 | 115.24 | 77.45 | 88.12 |
| | **SE** | (23.28) | (8.07) | (10.54) | (25.68) | (15.12) | (2.95) |
| **Rhizome biomass** | | | | | | | |
| | **mean** | 156.8$^{a}$ | 104.67$^{b}$ | 133.51$^{b}$ | 177.9$^{a}$ | 106.75$^{b}$ | 88.77$^{b}$ |
| | **SE** | (26.74) | (2.82) | (9.09) | (12.95) | (28.49) | (15.27) |
| **Root + Rhizome biomass** | | | | | | | |
| | **mean** | 302.22$^{a}$ | 215.04$^{b}$ | 238.25$^{b}$ | 293.14$^{a}$ | 184.2$^{b}$ | 176.89$^{b}$ |
| | **SE** | (47.92) | (6.74) | (5.38) | (31.42) | (41.61) | (16.77) |

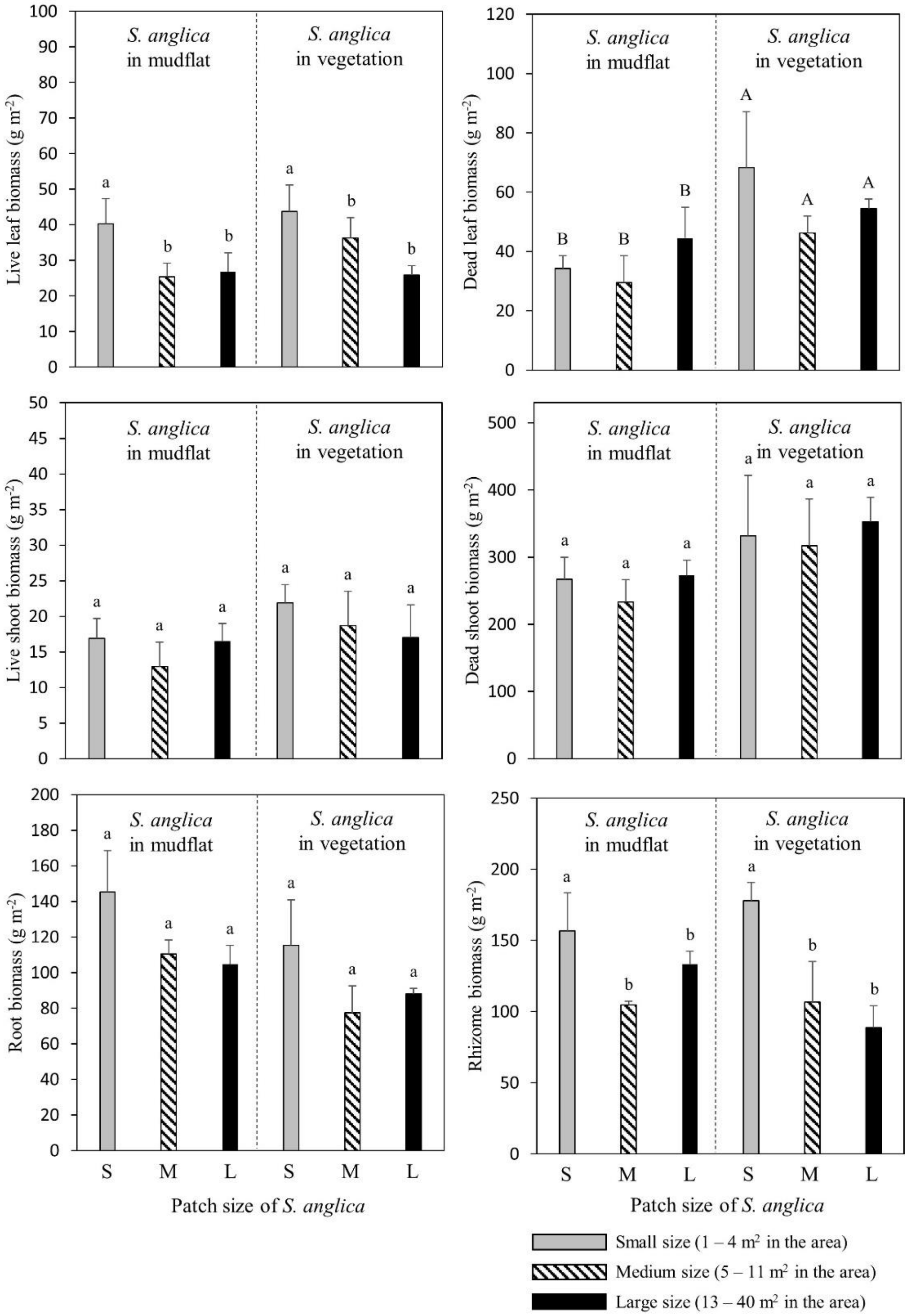


**Figure 3.5 Biomass of leaf and shoot of live and dead state (g m$^{-2}$) for three different patch sizes of *S. anglica* from two habitats, mudflat and *S. japonica* vegetation in Donggeom-ri, Ganghwa Island, Korea. Error bars indicate standard error of the mean. Different letters indicate significant differences between in the habitats or in the patch size of *S. anglica* (Two-way ANOVA and Tukey-HSD test or Kruskal-Wallis H-test, $P < 0.05$, n = 4). Small letter for patch size and capital letter for habitat**

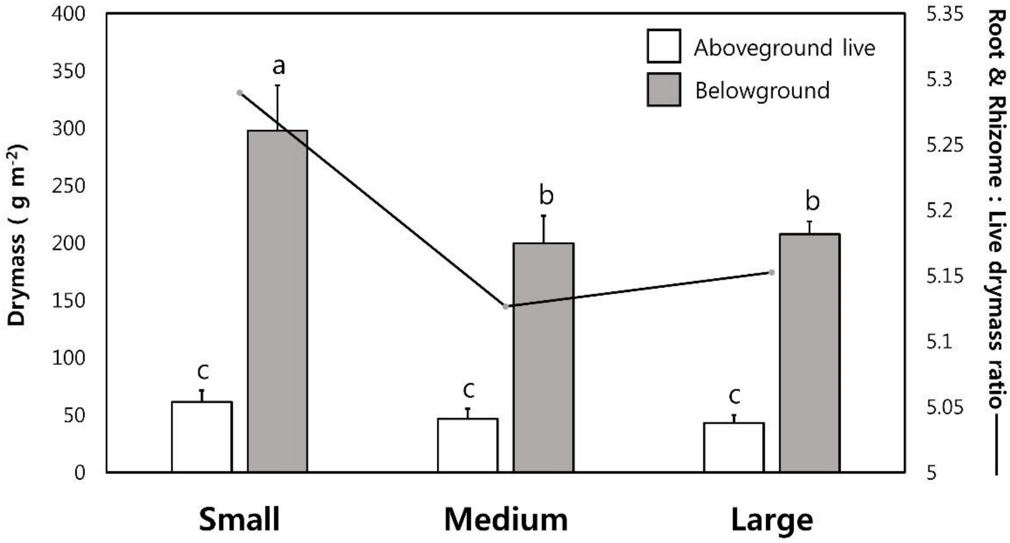


**Figure 3.6 Variation in above and belowground biomass in differenct *S. anglica* patch size. Error bars indicate standard error of the mean. Different letters indicate significant differences in the patch size of *S. anglica* (One-way ANOVA and Tukey-HSD, P < 0.05, n = 8).**

### 3.3.3. Correlation and regression between patch structure traits

There were several correlations between patch trait variables of *S. anglica*. Live shoot biomass increased with live leaf biomass (r = 0.739, $P < 0.05$). Dead shoot density increased with Live density (r = 0.452, $P < 0.05$). Dead shoot height decreased with live leaf biomass (r = -0.497, $P < 0.00$). Dead shoot density mostly had correlation with dead organ. Dead shoot biomass increased with dead shoot density (r = 0.424, $P < 0.05$), dead shoot height (r = 0.449, $P < 0.05$), and dead leaf biomass (r = 0.822, $P < 0.01$). Rhizome biomass increased with root biomass (r = 0.566, $P < 0.01$) in Table 3.3.

**Table 3.3 Correlation matrix of several patch trait variables of *S. anglica* within 5years invasion history in Donggeom-ri, Ganghwa Island, Korea. Pearson correlation was used.**

| | | Live | | | | | Dead | | | | Underground | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Density ($m^{-2}$) | Height (cm $m^{-2}$) | Coverage (% $m^{-2}$) | Leaf (g $m^{-2}$) | Shoot (g $m^{-2}$) | Density ($m^{-2}$) | Height (cm $m^{-2}$) | Leaf (g $m^{-2}$) | Shoot (g $m^{-2}$) | Root (g $m^{-2}$) | Rhizome (g $m^{-2}$) |
| **Live** | **Density ($m^{-2}$)** | 1 | | | | | | | | | | |
| | **Height (cm $m^{-2}$)** | -0.285 | 1 | | | | | | | | | |
| | **Coverage (% $m^{-2}$)** | 0.053 | 0.07 | 1 | | | | | | | | |
| | **Leaf (g $m^{-2}$)** | 0.343 | -0.027 | 0.288 | 1 | | | | | | | |
| | **Shoot (g $m^{-2}$)** | 0.163 | 0.096 | -0.044 | 0.739* | 1 | | | | | | |
| **Dead** | **Density ($m^{-2}$)** | 0.452* | -0.011 | 0.357 | 0.343 | 0.084 | 1 | | | | | |
| | **Height (cm $m^{-2}$)** | -0.067 | 0.367 | -0.368 | -0.497* | -0.292 | -0.222 | 1 | | | | |
| | **Leaf (g $m^{-2}$)** | 0.114 | 0.292 | -0.335 | -0.01 | 0.158 | 0.36 | 0.288 | 1 | | | |
| | **Shoot (g $m^{-2}$)** | 0.177 | 0.334 | -0.17 | -0.121 | 0.049 | 0.424* | 0.449* | 0.822** | 1 | | |
| **Underground** | **Root (g m-2)** | 0.026 | -0.158 | 0.223 | 0.267 | -0.069 | 0.242 | -0.201 | -0.251 | 0.001 | 1 | |
| | **Rhizome (g m-2)** | 0.326 | -0.28 | -0.201 | 0.338 | 0 | 0.376 | -0.065 | 0.243 | 0.243 | 0.566** | 1 |

*$P < 0.05$, **$P < 0.01$, ***$P < 0.001$

PC1 was mostly correlated with live leaf biomass (factor loading = -0.5), Live shoot biomass (factor loading = -0.59), and BGB:AGB ratio (factor loading = 0.603) (Fig. 3.7 and Table 3.4). Those three loading value contained aboveground biomass. In PC1, there was a little difference in aboveground biomass among patch sizes. PC2 was positively correlated with root biomass (factor loading = 0.63) and Rhizome biomass (factor loading = 0.64). Those two loading value contained belowground biomass (Fig. 3.7 and Table 3.4). In PC2, small patch sizes of *S. anglica* had more belowground biomass than other sizes. It indicated that *S. anglica* with short invasion history (1 – 2 years) allocated more resource to belowground organ to adapt to the harsh habitat.

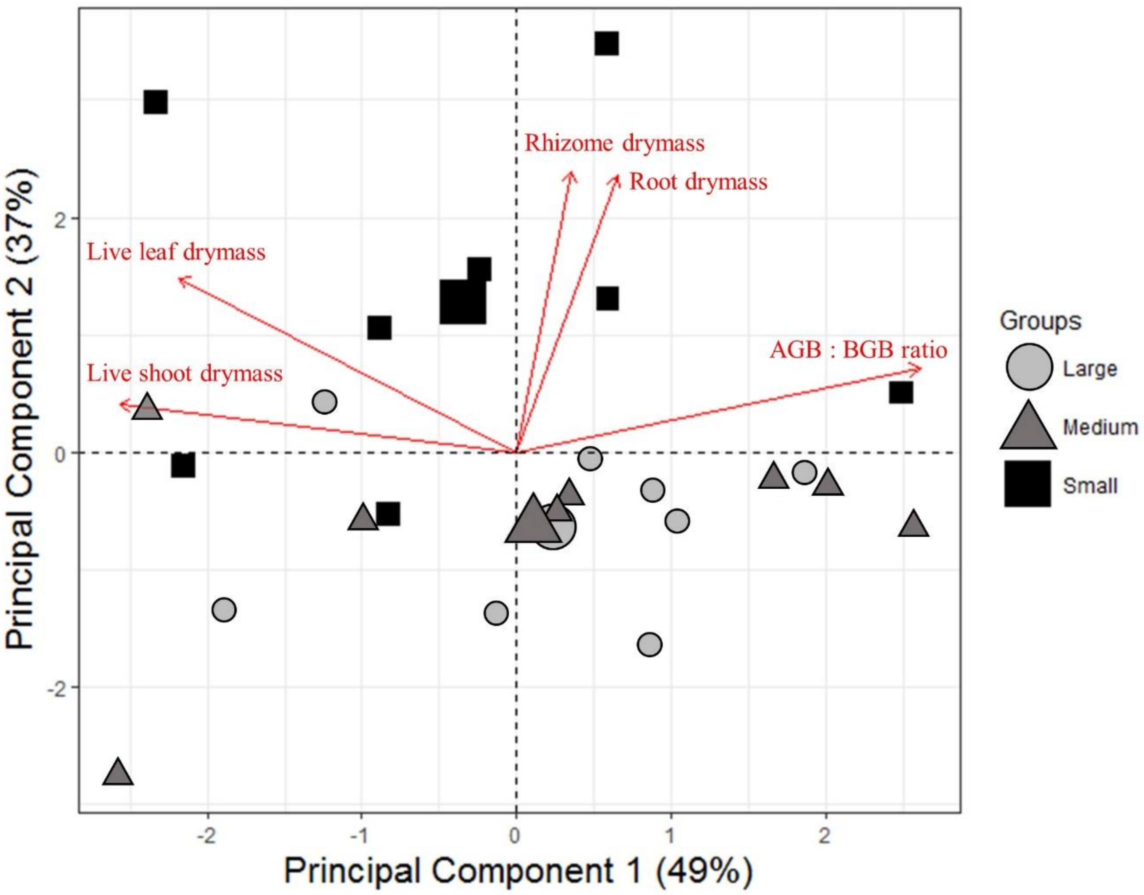


**Figure 3.7 Principal Component Analysis (PCA) plot of patch traits of *S. anglica* from different patch sizes, small (1 – 4 $m^2$ in the area), medium (5 – 11 $m^2$ in the area), and large (13 – 40 $m^2$ in the area) in Dongmak-ri, Ganghwa Island, Korea.**

**Table 3.4 Factor loadings of individual variables obtained by a principal component analysis (PCA) in *S. anglica* different patch size traits from habitat, mudflat and *Suaeda japonica* vegetation in Dongmak-ri, Ganghwa Island, Korea.**

| | **PC1** | **PC2** |
|---|---|---|
| Live leaf biomass | -0.504 | 0.395 |
| Live shoot biomass | -0.594 | 0.107 |
| Root biomass | 0.151 | **0.626** |
| Rhizome biomass | 0.082 | **0.636** |
| AGB:BGB ratio | **0.603** | 0.192 |
| Proportion of Variance | 0.494 | 0.374 |
| Cumulative Proportion | 0.494 | 0.868 |
| Eigen values | 2.47 | 1.869 |

Factor loading > ± 0.600 are marked in bold

### 3.3.4. Benthic macrofauna survey

A total of 16 benthic macrofauna were identified from 4 habitats (Table 3.5). *S. japonica* vegetation yielded the most species (10 species). Mudflat yielded the most individuals (119 individuals $m^{-2}$), consisting predominantly of the deposit feeder *Mediomastus californiensis*. Mudflat and *S. japonica* vegetation with *S. anglica* invasion yielded fewer species (4 and 5 species), dominated by the deposit feeder *Perinereis linea*. Both annelida and mollusca were depleted with *S. anglica* invasion. In annelida population, *Mediomastus californiensis* were most depleted while *Perinereis linea* increased. In mollusca population, *Laternula marilina* were most depleted. 9 species that were found in habitats with no invastion disappeared in the habitat with *S. anglica* invasion. Epifaunal macrofauna, *Batillaria cumingi* and *Lactiforis takii*, was found in *S. anglica* patches.

**Table 3.5 Total number of macrofauna (individuals) and species richness according to habitat in all samples combined. (E): epifauna, (I): infauna.**

| | **Mudfalt** | | ***S. japonica* vegetation** | |
|---|---|---|---|---|
| | **No invasion** | ***S.anglica* invasion** | **No invasion** | ***S.anglica* invasion** |
| **Annelida** | | | | |
| *Eteone* sp. (I) | 1 | 0 | 0 | 0 |
| *Glycera macintoshi* (I) | 0 | 0 | 1 | 0 |
| *Glycinde gurjanovae* (I) | 0 | 0 | 2 | 0 |
| *Mediomastus californiensis* (I) | 54 | 0 | 38 | 3 |
| *Nephtys chemulpoensis* (I) | 3 | 1 | 7 | 0 |
| *oligochaeta* sp. (I) | 4 | 0 | 1 | 0 |
| *Paraleonnates uschakovi* (I) | 0 | 0 | 1 | 0 |
| *Perinereis linea* (I) | 30 | 11 | 15 | 48 |
| Total | 92 | 12 | 65 | 51 |
| **Mollusca** | | | | |
| *Batillaria cumingi* (E) | 0 | 0 | 0 | 1 |
| *Estellacar galactodes* (I) | 1 | 0 | 1 | 0 |
| *Glauconome chinensis* (I) | 1 | 0 | 0 | 1 |
| *Lactiforis takii* (E) | 0 | 3 | 1 | 0 |
| *Laternula marilina* (I) | 24 | 0 | 16 | 2 |
| *Moerella rutile* (I) | 1 | 0 | 0 | 0 |
| *Potamocorbula* sp. (I) | 0 | 2 | 0 | 0 |
| Total | 27 | 5 | 18 | 4 |
| **Species richness** | 9 | 4 | 10 | 5 |

Mean species richness of total macrofauna differed significantly among habitats (Table 3.6). Richness was 70% lower in the mudflat with the *S. anglica* invasion compared to the mudflat with no invasion and *S. anglica* patches reduced richness of annelida than mollusca. On the other hand, there was no significant difference between *S. japonica* vegetation and *S. japonica* vegetation with *S. anglica* invasion (Fig 3.8).

Mean species diversity was over 80% lower in the *S. anglica* patches compared to mudflat and *S. japonica* vegetation with no invasion (80% for mudflat and 94%for *S. japonica* vegetation) and *S. anglica* patches reduced diversity of annelida than mollusca (Fig. 3.8 and Table 3.6).

Mean species abundance and species richness was low in the *S. anglica* patches while mudflat and *S. japonica* vegetation with no invasion did not differ from each other (Fig. 3.8). There were no significant differences in macrofaunal biomass among the habitats (Fig. 3.8)

**Table 3.6 Species richness, diversity, abundance, and biomass for taxonomic groups of macrofauna averaged among sampling cores for each habitat type in Dongmak-ri, Ganghwa Island. Different letters indicate significant differences in the same row (Kruskal-Wallis test and Pairwise t-test, $P < 0.05$, n = 4).**

| | **Mudfalt** | | ***S. japonica* vegetation** | |
|---|---|---|---|---|
| | **No invasion** | ***S. anglica* invasion** | **No invasion** | ***S. anglica* invasion** |
| **Species richness (species m$^{-2}$)** | | | | |
| Annelida | | | | |
| mean | 2.33$^{a}$ | 0.64$^{b}$ | 2.67$^{a}$ | 1.09$^{ab}$ |
| SE | (0.37) | (0.15) | (0.33) | (0.09) |
| Mollusca | | | | |
| mean | 1.22$^{a}$ | 0.45$^{b}$ | 0.56$^{a}$ | 0.36$^{ab}$ |
| SE | (0.22) | (0.21) | (0.24) | (0.15) |
| **Species diversity (*H*')** | | | | |
| Annelida | | | | |
| mean | 0.71$^{a}$ | 0$^{b}$ | 0.83$^{a}$ | 0.1$^{b}$ |
| SE | (0.11) | (0) | (0.11) | (0.05) |
| Mollusca | | | | |
| mean | 0.36$^{a}$ | 0.06$^{b}$ | 0.15$^{a}$ | 0.1$^{b}$ |
| SE | (0.06) | (0.06) | (0.07) | (0.04) |
| **Species abundance (ind. m$^{-2}$)** | | | | |
| Annelida | | | | |
| mean | 289.23$^{a}$ | 30.87$^{b}$ | 204.35$^{b}$ | 131.18$^{ab}$ |
| SE | (47.34) | (8.91) | (34.26) | (21.67) |
| Mollusca | | | | |
| mean | 84.88$^{a}$ | 12.86$^{b}$ | 56.59$^{b}$ | 10.29$^{ab}$ |
| SE | (13.34) | (5.87) | (40.01) | (4.3) |
| **Biomass (g m$^{-2}$)** | | | | |
| Annelida | | | | |
| mean | 0.06$^{a}$ | 0.15$^{a}$ | 0.04$^{a}$ | 0.27$^{a}$ |
| SE | (0.07) | (0.04) | (0.02) | (0.09) |
| Mollusca | | | | |
| mean | 0.07$^{a}$ | 0.12$^{a}$ | 0.09$^{a}$ | 0.39$^{a}$ |
| SE | (0.1) | (0.01) | (0.09) | (0.08) |

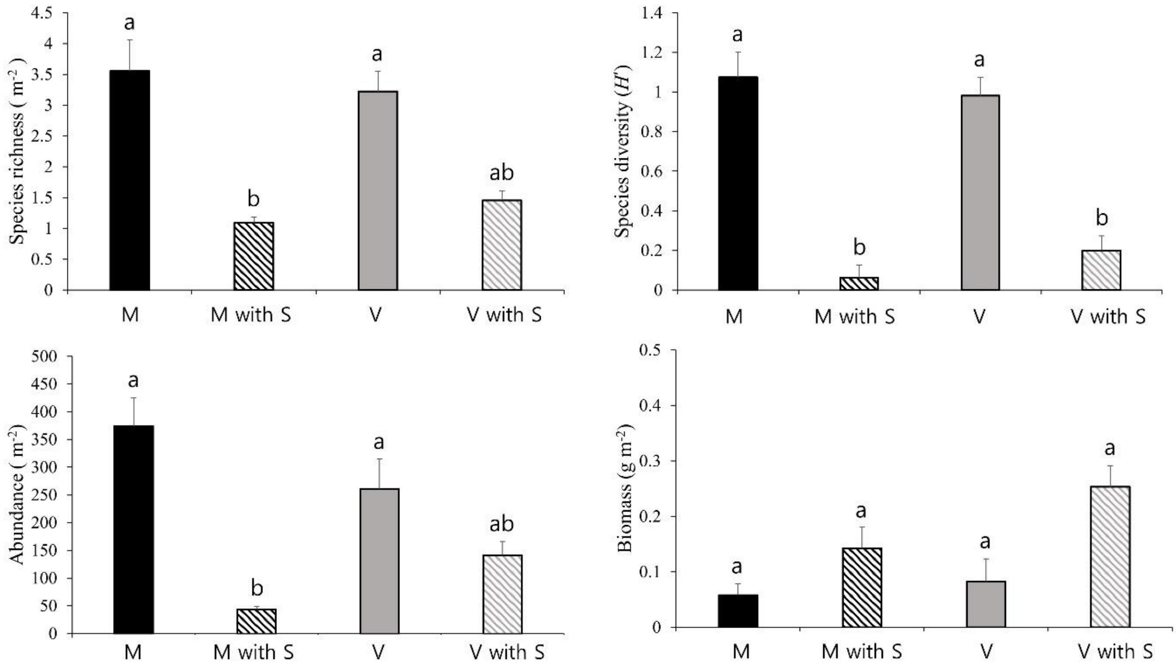


**Figure 3.8 Mean species richness, diversity, abundance, and biomass of total macrofauna averaged among sampling for each habitat type. Error bars indicate standard error of the mean (M, V n = 9; M with S, V with S n = 11). Different letters indicate significant differences in the patch size of *S. anglica* (One-way ANOVA and Tukey-HSD test, $P < 0.05$).**

### 3.3.5. Analysis of soil

The sediment in *S. anglica* patches had significant higher water content than mudflat with no invasion, but similar to *S. japonica* vegetation with no invasion (Table 3.7). Organic matter in *S. japonica* vegetation with *S. anglica* invasion was highest among habitats. $NH_4^+$ in *S. japonica* vegetation with no invasion was highest among habitats. pH in *S. anglica* patches was lower than mudflat and *S. japonica* vegetation with no invasion. There was no significant difference in $PO_4^-$ and salinity.

**Table 3.7 Environment variables averaged among each habitat type. Different letters indicate significant differences (Two-way ANOVA and Tukey-HSD test or a paired *t*-test, *P* < 0.05, n = 4)**

| | **Mudfalt** | | ***S. japonica* vegetation** | |
|---|---|---|---|---|
| | **No invasion** | ***S. anglica* invasion** | **No invasion** | ***S. anglica* invasion** |
| Water content (%) | | | | |
| mean | 31.17$^{b}$ | 35.64$^{a}$ | 33.63$^{ab}$ | 36.88$^{a}$ |
| SE | (1.23) | (0.92) | (1.2) | (0.89) |
| Organic matter (%) | | | | |
| mean | 3.55$^{b}$ | 4.16$^{b}$ | 3.94$^{b}$ | 4.49$^{a}$ |
| SE | (0.3) | (0.27) | (0.27) | (0.11) |
| $NH_4^+$(mg/kg) | | | | |
| mean | 32.59$^{b}$ | 28.46$^{b}$ | 36.61$^{a}$ | 25.09$^{b}$ |
| SE | (2.74) | (2.96) | (3.6) | (1.82) |
| $PO_4^-$(mg/kg) | | | | |
| mean | 17.21$^{a}$ | 20.63$^{a}$ | 21.91$^{a}$ | 21.56$^{a}$ |
| SE | (2.51) | (2.22) | (3.47) | (4.02) |
| pH | | | | |
| mean | 6.82$^{a}$ | 6.64$^{c}$ | 6.76$^{b}$ | 6.58$^{c}$ |
| SE | (0.02) | (0.02) | (0.02) | (0.02) |
| Salinity(ppt) | | | | |
| mean | 3.5$^{a}$ | 3.76$^{a}$ | 3.49$^{a}$ | 4.07$^{a}$ |
| SE | (0.2) | (0.07) | (0.2) | (0.12) |

### 3.3.6. Relationships between macrofauna assemblage and environmental variables

The result of the CCA ordination based on microbenthic density data and five environment variables (Water content, $NH_4^+$, pH, root biomass, and rhizome biomass) in Figure. 3.9. The eigenvalues of the first two CCA axes were 0.38 and 0.19, which accounted for 81% of the total variance. The variation in macrofauna assemblages described by the first two CCA axes revealed pH, root and rhizome biomass. From left to right of the first CCA axes, the macrofauna assemblages showed zonation from mudflat and *S. japonica* vegetation to mudflat and *S. japonica* vegetation with *S. anglica* invasion. The first axis was significantly related to pH (r = -0.65), root biomass (r = 0.94), and rhizome biomass (r = 0.93). In contrast, the second axis was significantly related to $NH_4^+$) in Table 3.8. Mudflat with *S. anglica* invasion was not mixed with *S. japonica* vegetation with *S. anglica* invasion while Mudflat and *S. japonica* vegetation with no invasion were mixed. It suggested that habitat with *S. anglica* invasion may change the macrofauna assemblages depending on the habitat.

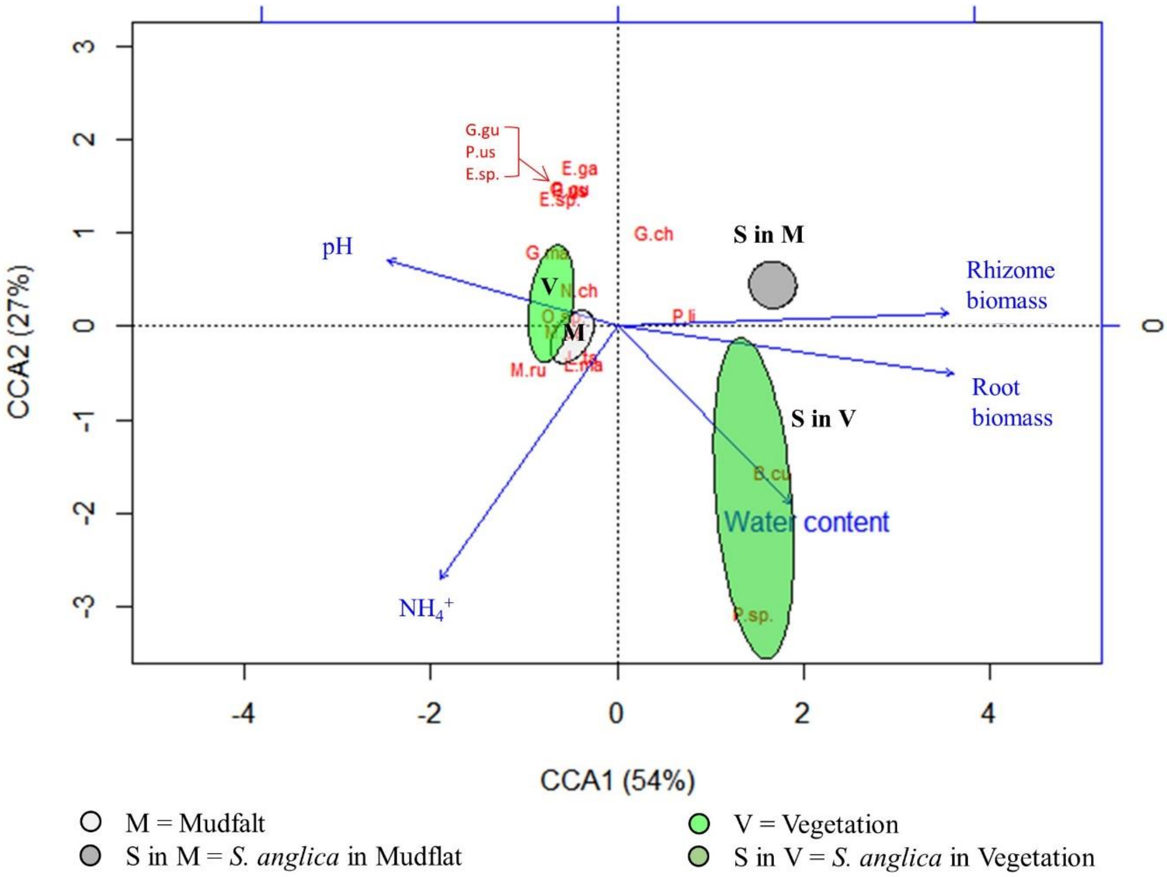


**Figure 3.9 Canocical correspondence analysis (CCA) ordination for macrofauna assemblage and environmental variable from the sampling site at the Dongmak-ri, Ganghwa Island. E.sp, *Eteone* sp.; G.ma, *Glycera macintoshi* G.gu, *Glycinde gurjanovae*; M.ca, *Mediomastus californiensis*; N.ch, *Nephtys chemulpoensis*; O.sp., *oligochaeta* sp.; P.us, *Paraleonnates uschakovi*; P.li, *Perinereis linea*; B.cu, *Batillaria cumingi*; E.ga, *Estellacar galactodes*; G.ch, *Glauconome chinensis*; L.ta, *Lactiforis takii*; L.ma, *Laternula marilina*; M.ru, *Moerella rutile*; P.sp., *Potamocorbula* sp.**

**Table 3.8 Factor loadings of individual variables obtained by a Canonical Corresponse Analysis (CCA) from the sampling site at Dongmak-ri, Ganghwa Island, Korea.**

| | **CCA1** | **CCA2** |
|---|---|---|
| Water content | 0.486 | -0.495 |
| $NH_4^+$ | -0.496 | **-0.707** |
| pH | **-0.645** | 0.186 |
| Root biomass | **0.944** | -0.131 |
| Rhizome biomass | **0.929** | 0.038 |
| Proportion of Variance | 0.540 | 0.268 |
| Cumulative Proportion | 0.540 | 0.808 |
| Eigen values | 0.376 | 0.186 |

Factor loading >±0.600 are marked in bold

# 4.4. Discussion

## 4.4.1. Density, height, coverage of *Spartina anglica*

Biomass production of grasses depends mainly in three structural characters: blade size, shoot density and number of green leaves per tiller (Lemaire et al. 1996). my result showed that patch with different patch size had different structures. Large size patch has significantly higher dead shoot height. Fallen debris from the emergent senescent plants can be an important organic source (Jackson et al. 1986). Plants within the central meadow attain more belowground biomass with greater stem height and densities, which decrease flow energy by increasing frictional effect (Neira et al. 2007). Live organ coverage was higher in *S. japonica* vegetation than in mudflat.

## 4.4.2. Biomass of *Spartina anglica*

Generally, root has high turnover rate and vulnerable to extreme environmental change compared to rhizome, which has long-live capability. Most root biomass of *Spartina* was in 0 – 10 cm in depth and 10 – 20 cm in depth for rhizome (Valiela et al. 1976, Darby and Turner 2008). My result showed that small size patches of *S. anglica* had significant higher rhizome in 0 – 10 cm in depth than medium and large size while p-value of root biomass in 0 – 10 cm in depth in different patch size was closed to 0.05 ($P < 0.05$). *S. anglica* which had short invasion history allocated resource to root and rhizome to adapt to harsh environment such as high salinity and tides. Rhizome biomass was around 1.35 times higher than root biomass. Under this condition, the patch would be tolerant to the harsh environment. Schubauer and Hopkinson (1984) also found that rhizome made up a greater portion of belowground biomass for a Georgia salt marsh. Investment of resources in rhizomes contributes to the ability of invasion clonal plant to establish in a wide range habitat by maintain soil volume (Schubauer and Hopkinson 1984, Petrone et al 2001). If the accumulation of organics in belowground is not sufficient, even a salt marsh with abundant aboveground plant growth might quickly become open water if sulfide accumulate and cause the demise of plants (Turner et al. 2004). BGB:AGB ratio also showed preparation of carbohydrates for harsh condition in hard marsh (Castillo et al. 2016). This Result showed that BGB:AGB ratio was significantly higher in small patch size, although average gap of BGB:ABG was small (0.13 – 0.16 gap ratio). In spring season, High root and rhizome might affected the leaf biomass. *Phragmites asturalis*, *Egertian densa*, and *Myriophyllum* showed depletion of carbonate reserves during rapid growth (Castillo et al. 2016). The shape of the rhizome in 6 to 9 cm in depth was often curve, and returns to the surface layer where it became a shoot (data not shown). It indicates that depth should be consider in eradication of *Spartina*. *S. densiflora* is a halophyte with a high tolerance to salinity, but its growth is limited in halosaline condition (Castillo et al. 2016). In my study, salinity was not directly related to biomass accumulation of *S. anglica* with different habitat. It showed that *S. anglica* might has more tolerance than *S. densiflora*.

### 4.4.3. *S. anglica* and macrofauna assemblage

The present study suggested that a significant association between *S. anglica* macrofauna assemblage. We observed macrofauna changes when *S. anglica* invaded mudflat or *S. japonica* vegetation. (1) Low macrofauna diversity and low macrofauna abundance and richness in mudflat; (2) more epifauna in *S. anglica* patches; (3) high abundance of *Perinereis linea* in *S. japonica* with *S. anglica* invasion.

The *S. anglica* invasion has altered the physico-chemical properties of the sediment habitat (Neira et al. 2007). In this study, the key environmental variables were water content, organic matter, and pH. Fallen debris from *S. anglica* can be an important organic matter source (Jackson et al. 1986).

Mudflat environment usually has high species richness, diversity, and abundance. Comparison of macrofauna assemblage in *S. anglica* versus no *S. anglica* invasion has yielded disparate trend by marsh. Species diversity was higher for macrofauna in the mudflat and native marsh compared to *S. anglica* patches. However, macrofauna biomass was not significantly different between habitats where *S. anglica* invaded or no *S. anglica* invaded. This result contrast with previous study that found negative correlation between root biomass and macrofauna biomass (Forbes and Lopez 1990, Wang et al. 2010). *S. anglica* have effect on macrofauna assemblages depending on invasion history. The period of invasion history was 7 – 8 years (Neira et al. 2007, Cutajar et al. 2012). In the study sites, the period of invasion history was estimated to be 5 years (Kim et al. 2015), resulting that 5 years is not enough to change biomass. *S. anglica* patches yield low macrofauna diversity and low abundance and richness in mudflat (Hedge and Kriwoken 2000). However, infauna *P. linea* and epifauna *B. cumingi* and *L. takii* were enhanced in *S. anglica* patches. it might be the same with results that show an increase in dominance by shifting in feeding mode from surface microalgal feeders to subsurface detritus (Neira et al. 2007, Bouma et al. 2009) and creating areas of *Spartina* not present on the open mudflat (Grosholz et al. 2009). In my site, there was no burrows with 2 cm in diameter in *S. anglica* patches, corresponding with no crustanean, and abundance of annelida was higher than molluca (Table 3.6). *S. anglica* appears to facilitate the colonization of oligochaetes at higher elevation and at the same time to inhibit other taxa such as crustacean and bivalves (Neira et al. 2006). CCA result showed that root and rhizome biomass were key factor of zonation. Macrofauna species could have been depleted by belowground biomass of roots and rhizomes compared to both the native marsh and mudflat (Bouma et al. 2009, Cutajar et al. 2012).

Based on my result, when sufficient belowground biomass was sufficient, macrofauna diversity, abundance, richness and biomass decrease more in *S. anglica* patches or meadow while a few of species , *Spartina* feeder and epifauna, were dominant.

# Chapter Ⅳ. General discussion

Mudflat and saltmarsh are valuable habitats that have diverse ecosystem services, providing food to various animal fauna such as zoobenthos, birds, and fish (Adam et al. 1985, Costanza et al. 1997, Barbier et al. 2011). The west coast of Korea has high large area (2,487 $km^2$) and biodiversity per the area (Ministry of Oceans and Fisheries 2013). Therefore, it is ranked as one of the top five tidal flats in the world. Kim et al. (2015) found *S. anglica*, an invasive weed, in the Dongmak-ri, Ganghwa Island in the western coast of Korea in 2012. The adaptation, growth, and propagation of seeds of *Spartina* are very active, and the problem of destroying the existing vegetation and ecological environment arose around world (Daehler and Strong 1996, Xiao et al. 2010, Cutajar et al. 2012). Although it is hazardous species, there were a few studies on *S. anglica* settlement and effects on macrofauna.

The purpose of the first study was to investigate the effect of *S. japonica* structures on seed settlement of *S. anglica*. *S. japonica* occurs in middle which is 50 – 100 m far away from coastline. *S. anglica* from several patched in the *S. japonica* vegetation at study site in Donggeom-ri. The number of *S. anglica* seeds per unit area ($m^2$) was higher in *S. japonica* vegetation than mudflat. There was no significant difference in the number of seed in each habitat, mudflat and *S. japonica* vegetation. It can be assumed that *S. japonica* vegetation or other factor such as tides and gradient of mudflat catch *S. anglica* seeds.

*Spartina* propagates by seeds floating on the water. Floating times are critical component of hydrochloric behavior resulting in decision of habitat (Carthey et al. 2016). When seeds and fruit have no buoyancy of their own, they may be dispersed little by water (Huiskes et al. 1995). Propagules with no buoyancy not only travel shorter distances than floating propagules. It indicates that the inundation condition in my studies indirectly could show gradient of habitat. Buoyancy period of *S. anglica* is 4 – 60 days (Huiskes et al. 1995). March was appropriate to survey the number of *S. anglica* seed since the degree of seed spreading was considered to be the maximum.

The Cox Proportional-Hazard Model suggested that light treatment had significant effect on germination probability. However, under inundation condition, there were no significant differences between submerge times. *S. anglica* vegetation should have been formed along the gradient of mudflat if there was no *S. japonica* vegetation.

This first study that perform seed bank experiment and germination of *S. anglica* showed that *S. japonica* vegetation has an effect on settlement of *S. anglica*. For seed settlement, A simple physical structure such vegetation attached to land or floating has is important factor as the trap for the seed (Huiskes et al. 1995, Neff and Baldwin 2005). The positive association between extant vegetation and seed bank composition has also been observed and many propagules may be trapped in the vegetation (Parker and Leck 1985, Huiskes et al. 1995). The presence or absence of vegetation within a community affected the abundance of some species in the seed bank but had little effect on species composition (Smith and Kadlec 1985, Baldwin et al. 1996)

The second study was carried out to examine difference of *S. anglica* patch structure among invasion history within 5 years and the effect of *S. anglica* on benthic macrofauna.

The dead shoot height were significant difference in different patch size of *S. anglica*. Large (13 – 40 $m^2$) had higher dead shoot height. It is the same result with other study that large area of *S. anglica* has stronger patch structures against hydrodynamics

(Neira et al. 2006; Bouma et al. 2009).

The mean of live and rhizome biomass in small size patch of *S. anglica* was significantly higher than in medium and large size patch of *S. anglica* ($P$ < 0.05). This result contrast with previous study that small patches unlikely develop the organ structures. My results showed *S. anglica* which had short invasion history allocated resource to root and rhizome to adapt to harsh environment such as high salinity and tides. Rhizome biomass was around 1.35 times higher than root. Under this condition, the patch would be tolerant to the harsh environment. Schubauer and Hopkinson (1984) also found that rhizome made up a greater portion of belowground biomass for a Georgia salt marsh. Investment of resources in rhizomes contributes to the ability of invasion clonal plant to establish in a wide range habitat by maintain soil volume (Schubauer and Hopkinson 1984, Petrone et al. 2001). If the accumulation of organics in belowground is not sufficient, even a salt marsh with abundant aboveground plant growth might quickly become open water (Turner et al. 2004). My result showed that BGB:AGB ratio was significantly higher in small patch size, although average gap of BGB:ABG was small (0.13 – 0.16). BGB:AGB ratio also showed preparation of carbohydrates for harsh condition in hard marsh (Castillo et al. 2016). PCA analysis also showed that small *S. anglica* patches (1 – 4$m^2$) allocated more resource than larger size patches to root and rhizome to adapt to harsh environment.

*S. densiflora* is a halophyte with a high tolerance to salinity, but its growth is limited in halosaline condition (Castillo et al. 2016). In this study, salinity was not directly related to biomass accumulation of *S. anglica* with different habitat. It showed that *S. anglica* might has more tolerance than *S. densiflora*.

A total of 16 benthic macrofauna was identified from 4 habitats. Mudflat and *S. japonica* vegetation with *S. anglica* invasion yielded fewer species (4 and 5). Both annelida and mollusca were depleted with *S. anglica* invasion while epifaunal macrofauna, *Batillaria cumingi* and *Lactiforis takii*, were found in *S. anglica* patches. Richness was 70% lower in the mudflat with the *S. anglica* invasion compared to the mudflat with no invasion. *S. anglica* patches reduced richness of annelida than mollusca. Mean species richness was over 80% lower in the *S. anglica* patches compared to mudflat and *S. japonica* vegetation with no invasion. *S. anglica* patches reduced diversity of annelida than mollusca. Mean species abundance and species richness was low in the *S. anglica* patches while mudflat and *S. japonica* vegetation with no invasion did not differ from each other. *Spartina* invasion was accompanied with a substantial reduction in macrofauna species richness and diversity (Neira et al. 2007, Chen et al. 2007, Tang and Kristensen 2010). It has been shown *S. anglica* tends to have a negative impact on benthic diversity and diversity in invertebrates. My result showed that *S. anglica* has negative impact on macrofauna richness, diversity, and abundance.

However, infauna *P. linea* and epifauna *B. cumingi* and *L. takii* were enhanced in *S. anglica* patches. It might be the same with results that show an increase in dominance by shifting in feeding mode from surface microalgal feeders to subsurface detritus (Neira et al. 2007, Bouma et al. 2009) and creating areas of *Spartina* not present on the open mudflat (Grosholz et al. 2009).

There were no significant differences in macrofaunal biomass among the habitats. This results contrast with previous study that found negative correlation between root biomass and macrofauna biomass (Forbes and Lopez 1990, Wang et al. 2010). *S. anglica* have effect on macrofauna assemblages depending on invasion history. The period of invasion history to start to have an effect on macrofauna was 7 – 8 years (Neira et al. 2007; Cutajar et al. 2012). In my sites, the period of invasion history was estimated to be 5 years (Kim et al. 2015), resulting that 5 years is not enough to change biomass.

In conclusion, (1) *S. japonica* might have an effect on settlement of *S. anglica* seed. (2) The small size patch of *S. anglica* allocated more resource to rhizomes than larger patches to adapt the hazardous tidal environment. (3) *S. anglica* invasion in Dongmak-ri may reduce macrofauna richness, diversity, and abundance. (4) However, *Spartina* feeder and epifauna may be enhanced by *S. anglica*. (5) *S. anglica* patches within 5years invasion history has not significant different effect on macrofauna. (6) Habitat with *S. anglica* invasion may change the macrofaunal assemblages with negative effect and the result differ depending on the habitat.

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# Appendix Ⅰ

# Data of vegetation and soil analysis in Donggoem-ri

Result of vegetation survey and soil analysis in Donggeom-ri.

| Habitat | Distance from coastline | *S. japonica* Individual ($m^{-2}$) | *S. japonica* Coverage (%) | *S. japonica* Height (cm $m^{-2}$) | *S. japonica* Drymass (g m-2) | *S. anglica* Seed ($m^{-2}$) | Soil pH | Soil EC (mS $cm^{-1}$) | Soil WC (%) | Soil OM (%) | Soil $PO_4^-$ (mg $kg^{-1}$) | Soil $NH_4^+$ (mg $kg^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mudflat | 30 m | 0 | 0 | 0 | 0 | 4 | 7.29 | 7.90 | 39.65 | 4.04 | 25.4 | 43.0 |
| Mudflat | 30 m | 0 | 0 | 0 | 0 | 0 | 7.36 | 7.11 | 37.27 | 3.54 | NA | NA |
| Mudflat | 30 m | 0 | 0 | 0 | 0 | 0 | 7.42 | 7.03 | 38.26 | 4.44 | NA | NA |
| Mudflat | 30 m | 0 | 0 | 0 | 0 | 0 | 7.31 | 7.06 | 38.52 | 4.36 | NA | NA |
| Mudflat | 30 m | 0 | 0 | 0 | 0 | 0 | 7.31 | 8.45 | 41.28 | 4.50 | 27.1 | 51.9 |
| Mudflat | 30 m | 0 | 0 | 0 | 0 | 0 | 7.29 | 8.86 | 39.28 | 4.45 | NA | NA |
| Mudflat | 30 m | 0 | 0 | 0 | 0 | 4 | 7.29 | 8.28 | 44.90 | 5.04 | NA | NA |
| Mudflat | 30 m | 0 | 0 | 0 | 0 | 0 | 7.39 | 6.60 | 38.66 | 4.08 | NA | NA |
| Mudflat | 30 m | 0 | 0 | 0 | 0 | 0 | 7.52 | 5.98 | 44.74 | 4.60 | NA | NA |
| Mudflat | 30 m | 0 | 0 | 0 | 0 | 0 | 7.42 | 5.99 | 37.09 | 4.39 | 25.3 | 76.4 |
| Mudflat | 30 m | 0 | 0 | 0 | 0 | 0 | 7.53 | 6.35 | 42.75 | 4.89 | NA | NA |
| Mudflat | 30 m | 0 | 0 | 0 | 0 | 0 | 7.49 | 7.47 | 43.47 | 4.00 | NA | NA |
| Mudflat | 30 m | 0 | 0 | 0 | 0 | 0 | 7.5 | 7.81 | 43.16 | 4.01 | NA | NA |
| Mudflat | 30 m | 0 | 0 | 0 | 0 | 0 | 7.5 | 7.16 | 36.24 | 4.52 | NA | NA |
| Mudflat | 30 m | 0 | 0 | 0 | 0 | 0 | 7.47 | 8.17 | 43.37 | 4.27 | 32.2 | 65.9 |
| Mudflat | 30 m | 0 | 0 | 0 | 0 | 0 | 7.51 | 6.94 | 39.77 | 4.88 | NA | NA |
| Mudflat | 30 m | 0 | 0 | 0 | 0 | 0 | 7.28 | 9.46 | 39.14 | 4.77 | NA | NA |
| Mudflat | 30 m | 0 | 0 | 0 | 0 | 0 | 7.43 | 8.24 | 41.10 | 4.21 | NA | NA |
| Mudflat | 30 m | 0 | 0 | 0 | 0 | 0 | 7.35 | 9.79 | 45.42 | 5.13 | NA | NA |
| Mudflat | 30 m | 0 | 0 | 0 | 0 | 0 | 7.54 | 6.37 | 38.92 | 4.55 | 32.7 | 44.4 |

Continued.

| Habitat | Distance from coastline | *S. japonica* Individual ($m^{-2}$) | *S. japonica* Coverage (%) | *S. japonica* Height (cm $m^{-2}$) | *S. japonica* Drymass (g $m^{-2}$) | *S. anglica* Seed ($m^{-2}$) | Soil pH | Soil EC (mS $cm^{-1}$) | Soil WC (%) | Soil OM (%) | Soil $PO_4^-$ (mg $kg^{-1}$) | Soil $NH_4^+$ (mg $kg^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *S. japonica* | 60 m | 36 | 80 | 18.6 | 38 | 8 | 7.51 | 6.38 | 35.89 | 3.93 | 25.7 | 37.0 |
| *S. japonica* | 60 m | 28 | 25 | 23.6 | 48 | 44 | 7.49 | 7.49 | 40.19 | 3.48 | NA | NA |
| *S. japonica* | 60 m | 28 | 20 | 19.6 | 24 | 0 | 7.61 | 4.70 | 34.91 | 3.96 | NA | NA |
| *S. japonica* | 60 m | 16 | 25 | 21.5 | 34 | 4 | 7.57 | 4.89 | 34.01 | 4.12 | NA | NA |
| *S. japonica* | 60 m | 304 | 25 | 18.6 | 22 | 12 | 7.49 | 7.46 | 38.93 | 4.32 | NA | NA |
| *S. japonica* | 60 m | 32 | 50 | 21.4 | 40 | 12 | 7.53 | 6.86 | 37.47 | 3.46 | 32.7 | 46.2 |
| *S. japonica* | 60 m | 24 | 50 | 19.8 | 30 | 4 | 7.49 | 9.29 | 37.41 | 3.42 | NA | NA |
| *S. japonica* | 60 m | 24 | 40 | 20.5 | 40 | 4 | 7.55 | 7.35 | 41.72 | 3.64 | NA | NA |
| *S. japonica* | 60 m | 16 | 30 | 21 | 32 | 8 | 7.56 | 6.83 | 35.13 | 3.91 | NA | NA |
| *S. japonica* | 60 m | 44 | 80 | 19.2 | 56 | 8 | 7.63 | 5.85 | 36.67 | 3.60 | NA | NA |
| *S. japonica* | 60 m | 20 | 35 | 22.8 | 40 | 4 | 7.55 | 7.98 | 37.50 | 3.71 | 27.0 | 44.6 |
| *S. japonica* | 60 m | 44 | 50 | 20.6 | 66 | 8 | 7.61 | 7.02 | 41.32 | 3.78 | NA | NA |
| *S. japonica* | 60 m | 24 | 30 | 18.2 | 16 | 4 | 7.67 | 5.88 | 41.94 | 3.79 | NA | NA |
| *S. japonica* | 60 m | 24 | 40 | 23.2 | 32 | 0 | 7.65 | 7.03 | 36.47 | 3.53 | NA | NA |
| *S. japonica* | 60 m | 8 | 10 | 24 | 10 | 4 | 7.59 | 8.14 | 40.05 | 4.34 | NA | NA |
| *S. japonica* | 60 m | 80 | 60 | 19 | 60 | 4 | 7.61 | 6.82 | 35.67 | 3.29 | 31.4 | 44.3 |
| *S. japonica* | 60 m | 48 | 70 | 22.4 | 52 | 8 | 7.65 | 6.89 | 39.31 | 4.51 | NA | NA |
| *S. japonica* | 60 m | 40 | 60 | 25.8 | 36 | 0 | 7.59 | 8.80 | 40.30 | 4.36 | NA | NA |
| *S. japonica* | 60 m | 32 | 50 | 21.2 | 46 | 28 | 7.62 | 7.12 | 36.73 | 3.63 | NA | NA |
| *S. japonica* | 60 m | 20 | 20 | 18.6 | 26 | 8 | 7.6 | 6.65 | 38.25 | 3.98 | 31.4 | 42.1 |

Continued

| Habitat | Distance from coastline | *S. japonica* Individual ($m^{-2}$) | Coverage (%) | Height (cm $m^{-2}$) | Drymass (g $m^{-2}$) | *S. anglica* Seed ($m^{-2}$) | Soil pH | EC (mS $cm^{-1}$) | WC (%) | OM (%) | $PO_4^-$ (mg $kg^{-1}$) | $NH_4^+$ (mg $kg^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *S. japonica* | 90 m | 36 | 50 | 21 | 50 | 0 | 7.61 | 5.71 | 38.22 | 3.91 | 32.3 | 44.8 |
| *S. japonica* | 90 m | 20 | 30 | 16.8 | 12 | 0 | 7.59 | 6.24 | 38.77 | 3.82 | NA | NA |
| *S. japonica* | 90 m | 60 | 45 | 20.2 | 66 | 12 | 7.59 | 5.95 | 33.87 | 4.11 | NA | NA |
| *S. japonica* | 90 m | 28 | 40 | 19.6 | 42 | 4 | 7.53 | 7.23 | 41.55 | 3.35 | NA | NA |
| *S. japonica* | 90 m | 52 | 80 | 21.8 | 58 | 12 | 7.54 | 7.58 | 34.35 | 4.17 | NA | NA |
| *S. japonica* | 90 m | 20 | 25 | 22.4 | 34 | 4 | 7.65 | 5.51 | 39.18 | 4.14 | 18.1 | 22.3 |
| *S. japonica* | 90 m | 64 | 50 | 18.4 | 40 | 0 | 7.53 | 8.10 | 32.53 | 4.09 | NA | NA |
| *S. japonica* | 90 m | 28 | 45 | 20.6 | 36 | 8 | 7.67 | 5.41 | 34.66 | 4.07 | NA | NA |
| *S. japonica* | 90 m | 132 | 75 | 22.4 | 76 | 0 | 7.6 | 7.26 | 33.97 | 4.12 | NA | NA |
| *S. japonica* | 90 m | 20 | 40 | 20.8 | 46 | 16 | 7.64 | 7.08 | 35.62 | 3.54 | NA | NA |
| *S. japonica* | 90 m | 160 | 85 | 18.8 | 138 | 12 | 7.63 | 6.29 | 38.68 | 3.75 | 30.1 | 29.8 |
| *S. japonica* | 90 m | 24 | 35 | 20.4 | 24 | 4 | 7.61 | 7.75 | 34.29 | 3.40 | NA | NA |
| *S. japonica* | 90 m | 12 | 15 | 18.7 | 18 | 0 | 7.76 | 4.47 | 35.78 | 3.61 | NA | NA |
| *S. japonica* | 90 m | 36 | 40 | 20 | 26 | 4 | 7.68 | 5.91 | 34.71 | 3.80 | NA | NA |
| *S. japonica* | 90 m | 20 | 25 | 18 | 26 | 4 | 7.67 | 7.01 | 38.57 | 4.07 | NA | NA |
| *S. japonica* | 90 m | 20 | 35 | 17.6 | 28 | 8 | 7.67 | 7.81 | 39.98 | 3.53 | 27.8 | 31.2 |
| *S. japonica* | 90 m | 44 | 15 | 16.6 | 26 | 0 | 7.65 | 7.10 | 36.56 | 3.50 | NA | NA |
| *S. japonica* | 90 m | 20 | 30 | 13.6 | 16 | 8 | 7.61 | 6.96 | 34.87 | 3.96 | NA | NA |
| *S. japonica* | 90 m | 24 | 60 | 19 | 30 | 0 | 7.58 | 7.27 | 37.06 | 3.94 | NA | NA |
| *S. japonica* | 90 m | 16 | 10 | 18 | 18 | 16 | 7.55 | 8.16 | 34.34 | 3.14 | 24.3 | 27.5 |

Continued.

| Habitat | Distance from coastline | *S. japonica* Individual ($m^{-2}$) | Coverage (%) | Height ($cm\ m^{-2}$) | Drymass ($g\ m^{-2}$) | *S. anglica* Seed ($m^{-2}$) | Soil pH | EC ($mS\ cm^{-1}$) | WC (%) | OM (%) | $PO_4^-$ ($mg\ kg^{-1}$) | $NH_4^+$ ($mg\ kg^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mudflat | 120 m | 0 | 0 | 0 | 0 | 0 | 7.48 | 6.7 | 38.83 | 4.05 | 27.0 | 54.5 |
| Mudflat | 120 m | 0 | 0 | 0 | 0 | 0 | 7.58 | 7.26 | 38.64 | 4.14 | NA | NA |
| Mudflat | 120 m | 0 | 0 | 0 | 0 | 0 | 7.55 | 8.36 | 37.29 | 4.08 | NA | NA |
| Mudflat | 120 m | 0 | 0 | 0 | 0 | 8 | 7.64 | 6.71 | 39.83 | 3.26 | NA | NA |
| Mudflat | 120 m | 0 | 0 | 0 | 0 | 0 | 7.67 | 6.59 | 38.51 | 3.45 | NA | NA |
| Mudflat | 120 m | 0 | 0 | 0 | 0 | 0 | 7.72 | 5.65 | 32.71 | 3.66 | 23.1 | 91.9 |
| Mudflat | 120 m | 0 | 0 | 0 | 0 | 0 | 7.66 | 5.21 | 36.51 | 3.88 | NA | NA |
| Mudflat | 120 m | 0 | 0 | 0 | 0 | 0 | 7.68 | 6.43 | 36.00 | 3.06 | NA | NA |
| Mudflat | 120 m | 0 | 0 | 0 | 0 | 0 | 7.8 | 4.65 | 37.39 | 2.97 | NA | NA |
| Mudflat | 120 m | 0 | 0 | 0 | 0 | 0 | 7.59 | 6.53 | 38.68 | 2.97 | NA | NA |
| Mudflat | 120 m | 0 | 0 | 0 | 0 | 0 | 7.65 | 7.28 | 34.52 | 3.82 | 22.2 | 77.4 |
| Mudflat | 120 m | 0 | 0 | 0 | 0 | 0 | 7.72 | 5.93 | 34.07 | 3.28 | NA | NA |
| Mudflat | 120 m | 0 | 0 | 0 | 0 | 0 | 7.62 | 5.82 | 37.05 | 3.40 | NA | NA |
| Mudflat | 120 m | 0 | 0 | 0 | 0 | 4 | 7.57 | 5.82 | 31.82 | 3.20 | NA | NA |
| Mudflat | 120 m | 0 | 0 | 0 | 0 | 0 | 7.58 | 5.67 | 38.96 | 3.93 | 32.7 | 87 |
| Mudflat | 120 m | 0 | 0 | 0 | 0 | 0 | 7.55 | 5.82 | 36.87 | 3.71 | NA | NA |
| Mudflat | 120 m | 0 | 0 | 0 | 0 | 0 | 7.56 | 7.83 | 42.17 | 3.39 | NA | NA |
| Mudflat | 120 m | 0 | 0 | 0 | 0 | 0 | 7.61 | 7.05 | 38.96 | 3.93 | NA | NA |
| Mudflat | 120 m | 0 | 0 | 0 | 0 | 4 | 7.62 | 5.36 | 33.88 | 3.12 | NA | NA |
| Mudflat | 120 m | 0 | 0 | 0 | 0 | 0 | 7.61 | 5.31 | 35.19 | 3.521 | 29.9 | 57.5 |

# Appendix Ⅱ

# Data of vegetation and soil analysis in Dongmak-ri

Results of vegetation survey in Dongmak-ri.

| NO | Habitat | Size | Density_live (indi. $m^{-2}$) | Density_dead (indi. $m^{-2}$) | Height_live (cm) | Height_dead (cm) | Leaf_live (g $m^{-2}$) | Stem_live (g $m^{-2}$) | Leaf_dead (g $m^{-2}$) | Stem_dead (g $m^{-2}$) | Root (g $m^{-2}$) | Rhizome (g $m^{-2}$) | Cover_live (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| c1 | V | S | 182 | 161 | 33.2 | 99.8 | 44.58 | 20.39 | 35.03 | 137.35 | 88.72 | 200.93 | 45 |
| c2 | V | L | 132 | 172 | 42.4 | 134 | 24.42 | 17.14 | 58.88 | 440.90 | 94.05 | 72.12 | 50 |
| c3 | V | M | 145 | 172 | 46.8 | 123 | 34.11 | 11.17 | 37.71 | 278.45 | 101.80 | 105.09 | 70 |
| c4 | M | M | 117 | 77 | 35 | 122.4 | 29.07 | 14.63 | 10.65 | 146.70 | 119.44 | 98.62 | 65 |
| c5 | V | L | 205 | 155 | 38.8 | 118.6 | 29.46 | 29.91 | 48.96 | 342.44 | 83.62 | 70.78 | 55 |
| c6 | M | S | 316 | 259 | 37.6 | 65.4 | 53.74 | 22.58 | 24.57 | 182.89 | 96.82 | 96.32 | 75 |
| c7 | M | M | 202 | 168 | 33.4 | 91.2 | 18.75 | 10.36 | 20.08 | 225.23 | 124.67 | 107.02 | 60 |
| c8 | M | S | 232 | 237 | 37 | 73.2 | 45.38 | 16.80 | 33.73 | 329.73 | 208.45 | 214.48 | 70 |
| c9 | M | L | 208 | 122 | 35 | 117.2 | 18.52 | 11.94 | 21.00 | 226.35 | 128.41 | 109.99 | 40 |
| d1 | V | L | 323 | 162 | 33.2 | 127.4 | 30.55 | 9.36 | 48.61 | 266.46 | 92.33 | 134.35 | 60 |
| d2 | V | M | 336 | 252 | 34.4 | 113 | 50.32 | 28.68 | 52.66 | 429.77 | 90.94 | 136.52 | 70 |
| d3 | V | S | 286 | 249 | 38.6 | 101.4 | 35.50 | 19.45 | 96.08 | 405.73 | 64.56 | 143.43 | 50 |

M: mudflat; V: *S. japonica* vegetation; S: small size (1 – 4$m^2$) patch of *S. anglica*; M: medium size (5 – 11$m^2$) patch of *S. anglica*; Large: Large size (13 – 40$m^2$) patch of *S. anglica*

Continued.

| NO | Habitat | Size | Density_live (indi. $m^{-2}$) | Density_dead (indi. $m^{-2}$) | Height_live (cm) | Height_dead (cm) | Leaf_live (g $m^{-2}$) | Stem_live (g $m^{-2}$) | Leaf_dead (g $m^{-2}$) | Stem_dead (g $m^{-2}$) | Root (g $m^{-2}$) | Rhizome (g $m^{-2}$) | Cover live (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| d4 | V | M | 277 | 192 | 32.4 | 118.2 | 22.57 | 9.93 | 59.23 | 423.33 | 83.54 | 157.74 | 50 |
| d5 | V | S | 217 | 240 | 34.6 | 83.2 | 64.43 | 29.50 | 36.50 | 239.90 | 182.65 | 172.91 | 65 |
| d7 | M | L | 242 | 200 | 34.2 | 99.8 | 41.71 | 23.41 | 62.13 | 295.98 | 115.80 | 130.54 | 40 |
| d8 | M | S | 160 | 154 | 32.2 | 95.4 | 20.57 | 9.35 | 33.74 | 247.70 | 143.84 | 129.98 | 60 |
| e1 | V | M | 95 | 107 | 36 | 55.4 | 38.19 | 25.13 | 35.27 | 137.78 | 33.52 | 27.66 | 65 |
| e2 | V | S | 156 | 238 | 40.8 | 115 | 30.73 | 18.24 | 105.54 | 545.02 | 125.05 | 194.34 | 50 |
| e3 | V | L | 134 | 217 | 46.2 | 134.8 | 19.09 | 11.71 | 61.25 | 362.53 | 82.50 | 77.83 | 60 |
| e5 | M | M | 192 | 179 | 36.8 | 115.6 | 34.54 | 21.52 | 52.08 | 303.14 | 88.17 | 111.33 | 40 |
| e6 | M | L | 240 | 182 | 36.8 | 115.4 | 19.79 | 14.80 | 33.01 | 243.28 | 82.49 | 140.49 | 35 |
| e7 | M | S | 200 | 253 | 33.4 | 99.8 | 41.55 | 18.87 | 45.17 | 308.12 | 132.58 | 186.40 | 55 |
| e8 | M | L | 172 | 149 | 31.4 | 106 | 27.24 | 15.95 | 61.93 | 325.58 | 92.24 | 153.03 | 30 |
| e9 | M | M | 183 | 306 | 29 | 91.2 | 19.00 | 5.34 | 35.04 | 258.65 | 109.20 | 101.71 | 80 |

M: mudflat; V: *S. japonica* vegetation; S: small size (1 – 4$m^2$) patch of *S. anglica*; M: medium size (5 – 11$m^2$) patch of *S. anglica*; Large: Large size (13 – 40$m^2$) patch of *S. anglica*

Results of soil analysis in Dongmak-ri

| NO | Habitat | Size | pH | Salinity (ppt) | WC (%) | OM (%) | $PO_4^-$ (mg kg$^{-1}$) | $NH_4^+$ (mg kg$^{-1}$) |
|---|---|---|---|---|---|---|---|---|
| c1 | V | S | 6.52 | 4.02 | 39.4 | 4.78 | 15.81 | 25.12 |
| c2 | V | L | 6.55 | 4.58 | 41.67 | 4.94 | 21.37 | 25.13 |
| c3 | V | M | 6.54 | 4.62 | 39.82 | 4.49 | 15.92 | 22.47 |
| c4 | M | M | 6.63 | 3.9 | 37.9 | 3.58 | 25.65 | 20.87 |
| c5 | V | L | 6.54 | 3.92 | 36.07 | 3.97 | 29.43 | 16.73 |
| c6 | M | S | 6.59 | 3.92 | 34.17 | 3.43 | 14.55 | 22.26 |
| c7 | M | M | 6.72 | 3.16 | 34.13 | 2.92 | 12.79 | 38.57 |
| c8 | M | S | 6.69 | 3.55 | 36.4 | 3.99 | 21.41 | 29.27 |
| c9 | M | L | 6.68 | 4 | 39.24 | 4.35 | 17.67 | 39.02 |
| d1 | V | L | 6.67 | 3.61 | 33.29 | 4.23 | 10.04 | 24.52 |
| d2 | V | M | 6.66 | 3.73 | 34.47 | 4.3 | 15.5 | 35.32 |
| d3 | V | S | 6.66 | 4.25 | 38.7 | 4.89 | 16.57 | 27.6 |

M: mudflat; V: *S. japonica* vegetation; S: small size (1 – 4m$^2$) patch of *S. anglica*; M: medium size (5 – 11m$^2$) patch of *S. anglica*; Large: Large size (13 – 40m$^2$) patch of *S. anglica*

Continued.

| NO | Habitat | Size | pH | Salinity (ppt) | WC (%) | OM (%) | $PO_4^-$ (mg $kg^{-1}$) | $NH_4^+$ (mg $kg^{-1}$) |
|---|---|---|---|---|---|---|---|---|
| d4 | V | M | 6.56 | 3.98 | 34.45 | 4.12 | 33.1 | 17.18 |
| d5 | V | S | 6.67 | 3.76 | 36.47 | 3.78 | 16.9 | 13.27 |
| d7 | M | L | 6.71 | 3.76 | 33.44 | 3.7 | 30.87 | 21.17 |
| d8 | M | S | 6.53 | 3.32 | 29.07 | 6.71 | 11.06 | 20.66 |
| e1 | V | M | 6.65 | 3.67 | 36.36 | 4.68 | 53.14 | 23.03 |
| e2 | V | S | 6.56 | 3.95 | 34.71 | 4.41 | 12.02 | 27.65 |
| e3 | V | L | 6.52 | 4.4 | 36.77 | 4.56 | 14.24 | 31.23 |
| e5 | M | M | 6.59 | 3.44 | 33.73 | 3.74 | 24.04 | 36.63 |
| e6 | M | L | 6.7 | 4.01 | 35.47 | 4.12 | 16.64 | 23.59 |
| e7 | M | S | 6.65 | 3.65 | 35.11 | 3.76 | 15.65 | 18.22 |
| e8 | M | L | 6.67 | 3.9 | 38.26 | 4.02 | 13.65 | 31.98 |
| e9 | M | M | 6.62 | 3.95 | 39.31 | 4.38 | 35.76 | 49.33 |

M: mudflat; V: *S. japonica* vegetation; S: small size (1 – 4$m^2$) patch of *S. anglica*; M: medium size (5 – 11$m^2$) patch of *S. anglica*; Large: Large size (13 – 40$m^2$) patch of *S. anglica*

Continued.

| NO | Habitat | pH | Salinity (ppt) | WC (%) | OM (%) | $PO_4^-$ (mg $kg^{-1}$) | $NH_4^+$ (mg $kg^{-1}$) |
|---|---|---|---|---|---|---|---|
| A1 | V | 40.13 | 5.11 | 34.88 | 11.18 | 6.83 | 4.05 |
| A2 | V | 33.99 | 4.06 | 28.20 | 29.38 | 6.69 | 3.42 |
| A3 | V | 38.65 | 3.72 | 41.41 | 44.77 | 6.69 | 4.63 |
| B1 | V | 32.86 | 5.27 | 30.26 | 26.30 | 6.74 | 3.90 |
| B2 | V | 36.33 | 4.09 | 56.80 | 32.27 | 6.73 | 3.88 |
| B3 | V | 28.99 | 2.87 | 21.43 | 7.80 | 6.71 | 2.85 |
| 칠 C1 | V | 31.21 | 3.20 | 38.58 | 16.44 | 6.70 | 3.13 |
| 칠 C2 | V | 30.75 | 2.86 | 52.22 | 10.50 | 6.88 | 2.54 |
| 칠 C3 | V | 29.72 | 4.27 | 25.68 | 18.56 | 6.83 | 3.00 |
| 가 1 | M | 31.83 | 4.90 | 38.10 | 13.21 | 6.98 | 2.54 |
| 가 2 | M | 28.79 | 3.85 | 31.71 | 32.09 | 6.85 | 3.48 |
| 가 3 | M | 34.41 | 4.09 | 30.97 | 15.49 | 6.78 | 4.27 |
| 나 1 | M | 26.35 | 1.76 | 34.50 | 6.74 | 6.73 | 2.95 |
| 나 2 | M | 36.41 | 4.03 | 36.39 | 21.42 | 6.74 | 4.36 |
| 나 3 | M | 27.81 | 3.35 | 37.55 | 22.06 | 6.85 | 3.15 |
| 다 1 | M | 36.13 | 3.88 | 44.21 | 15.90 | 6.84 | 3.70 |
| 다 2 | M | 29.41 | 3.31 | 17.56 | 7.03 | 6.83 | 3.21 |
| 다 3 | M | 29.34 | 2.80 | 22.34 | 20.91 | 6.78 | 3.87 |

M: mudflat; V: *S. japonica* vegetation

Vegetation survey for *S. japonica* vegetation in Dongmak-ri.

| | Seedling | | | | Dead | | | |
|---|---|---|---|---|---|---|---|---|
| | **Density ($m^{-2}$)** | **Height (cm m-$^{2}$)** | **Coverage (% $m^{-2}$)** | **Biomass (g $m^{-2}$)** | **Density ($m^{-2}$)** | **Height (cm m-$^{2}$)** | **Coverage (% $m^{-2}$)** | **Biomass (g $m^{-2}$)** |
| ***S. japonica*** | | | | | | | | |
| **mean** | 71.25 | 6.5 | 14.5 | 1.01 | 87.25 | 13.05 | 35 | 22.71 |
| **SE** | (21.5) | (0.29) | (3.2) | (0.5) | (18.28) | (1.14) | (12.42) | (4.14) |

# 국문 초록

영국갯끈풀 (*Spartina anglica*)는 외래 다년생 습지식물로 토양을 안정화시켜 서식지를 변화시킨다. 미국, 캐나다, 그리고 중국에서 외래식물로 알려진 바가 있다. 한국에서는 2012년에 영국갯끈풀이 강화도에서 처음 발견되었으며 2016년에 환경부에서 '생태교란식물'로 지정하였다. 그러나, 영국갯끈풀의 종자정착, 패치의 구조와 저서동물에 미치는 영향에 대한 연구는 미미한 상황이다. 첫번째 연구는 종자정착에 기여하는 요소를 찾기위해 실내 발아연구와 실외연구를 진행하였다. 단위면적($m^2$) 당 발견된 영국갯끈풀 종자의 수는 맨 갯벌 보다 칠면초 군락에서 더 많이 발견되었다. 맨 갯벌에서는 일정 면적($m^2$) 당 0.15 ± 0.06개, 칠면초 군락에서는 1.78 ± 0.33m-2 개가 발견되었다. 종자정착에 미치는 외부요인을 파악하기 위해, 침수조건 (0시간, 1시간, 2시간, 3시간, 영구적 침수)에 대한 발아실험을 진행하였다. Cox Propotional-Hazard Model 분석에서 발아는 침수조건에 영향을 받지 않는 것으로 나타났다. 이는 구간별로 영국갯끈풀이 발아할 것을 의미하고 조사지에서 칠면초 군락에서만 패치를 형성하고 있으므로 칠면초 군락이 영국갯끈풀 종자의 정착에 미치는 것을 나타낸다. 두번째 연구는 영국갯끈풀 패치의 크기에 따른 구조와 영국갯끈풀 패치가 저서동물에게 미치는 영향을 파악하기 위해 실외연구를 진행하였다. 맨 갯벌과 칠면초 군락 서식지에 대해 조사를 실시하였다. 각

서식지 별로 영국갯끈풀 패치의 넓이가 1 – 4 $m^2$, 5 – 11 $m^2$, 13 – 40 $m^2$ 인 3개의 조건에 대하여 4번의 반복수로 패치를 선정하였다. 살아있는 잎과 뿌리의 무게가 작은 패치에서 가장 높게 나타났다. 또한, 영국갯끈풀이 침입한 서식지에서 저서동물의 종다양도와 풍부도가 모두 낮게 나타났다. 그러나 내생동물인 *Perinereis linea* 와 표재동물인 *Batillaria cumingi*, *Lactiforis* 는 영국갯끈풀 패치에서 더 많이 출현하였다. CCA분석결과 영국갯끈풀이 침입하지 않은 맨 갯벌과 칠면초 군락은 서로 겹치는 구간이 있으며, 영국갯끈풀이 침입한 맨 갯벌과 칠면초 군락은 서로 차이가 났다. 이는 영국갯끈풀 침입이 대형저서생물에 미치는 부정적인 영향은 서식지 별로 차이가 나타남을 보여준다. 결론적으로 칠면초 군락은 영국갯끈풀 종자정착에 영향이 있고, 초기 침입단계의 영국갯끈풀은 뿌리줄기에 에너지를 할당한다. 또한, 영국갯끈풀은 저서동물을 감소시키는 부정적인 영향을 나타낸다. 하지만 몇 표재동물은 영국갯끈풀이 있는 환경을 선호한다.

주요어: 종자정착, 영국갯끈풀, 대형저서동물, 갯벌, 패치구조, 침입기간

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