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ORIGINAL ARTICLE

Classification of Halophyte Community Growth and Its Relationship with Soil Chemical Properties in Saemanguem Reclaimed Land

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Abstract Halophyte communities have been established to reduce dust from the Saemangeum reclaimed land. Growth of large-scale artificial halophyte communities was assessed, and the relationship between halophyte community growth and soil chemical properties was examined through three-year halophyte monitoring and soil analysis. Halophyte community growth was classified in 230 quadrats from 2006 to 2008, and the statistical significance between halophyte community growth and soil chemical properties was determined by Duncan's multiple range test. Overall, the yearly percentage of Class1 and Class 2 quadrats increased from 40% in 2006 to 87% in 2008. Over 90% of the 29 common quadrats consecutively surveyed for three years belonged to Class 1 or Class 2. Soil electrical conductivity (EC) decreased from 3.3 dSm^{-1} in 2006 to 2.0 dSm^{-1} in 2008. Available phosphate content increased from 28 mg kg^{-1} in 2007 to 115 mg kg^{-1} in 2008. Among soil properties, soil EC had a significantly negative relationship with halophyte community growth. A significant relationship was also observed between halophytic height and soil EC (R^2=0.95). These results indicate that halophyte community growth could be classified into five classes based on plant height and coverage closely related to soil EC in the reclaimed land.

Keywords electrical conductivity · halophyte community growth · halophyte seeding · *Salicornia europaea* · *Suaeda asparagoides* · *Suaeda japonica*

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Introduction

The Saemangeum Reclamation Project, a large-scale reclamation of tidal flats in Korea, has been carried out since 1989 to develop 28,300 ha of agricultural land and 11,800 ha of freshwater reservoir for rice production.

Since 2006, halophyte community establishment methods, inclusive of halophyte seeding, have been applied to reduce dust, because a volume of dust originating from the open land surface could be dispersed by wind erosion under dry and windy conditions (Jung et al., 2004). They can be defined as a way to establish plant communities of halophytes adapting to windy and dry conditions on a vast, salty stretch of land.

Halophytes have been practically studied in relation with salt marsh restoration (Lindig-Cisnero and Zedler, 2002; Zedler, 2005), and recently, they started to attract public attention in Korea as a new technology for wetland restoration (MLTMA, 2008; Lee et al., 2009). Nevertheless, domestic studies on halophytes have concentrated on basic ecological understanding, physiologically active ingredient (Kim et al., 2008; Kong et al., 2008), and factors that can control their growth such as relative locationswithin a salt marsh (Ihm et al., 1995; Kim et al., 2006), tidal water table gradient (Lee, 1989), and soil properties (Ihm and Lee, 1998; Kim, 2005; 2007; 2009). Moreover, planning, implementation, monitoring, and assessment of halophyte seeding process have not yet been systematically organized or theorized from field experiences, for purposes not only of salt marsh restoration but also eco-friendly reclamation.

The present study was carried out to assess the growth of large-scale artificial halophyte communities and to examine the relationship between halophyte community growth and soil chemical properties by three-year halophyte monitoring and soil analysis.

Materials and Methods

Halophyte community establishment and spatial analysis. Candidate areas for planting during the period vulnerable to dust in the Saemangeum reclaimed land were determined in the preceding year by field surveys with GPS (Garmin) and with consideration of parameters such as water level, soil erodibility, natural seed source, and distance to town. Halophytic seeds were collected from natural habitats every fall from 2005 to 2007 and stored at room temperature until sowing. Planting was performed on 2,866 ha of candidate areas four times in three years using 10,653 kg of eight halophytic seeds (Table 1 and Fig. 1). Spatial analysis was facilitated by integrating GPS field data, topographic maps, and air photographs on Surfer 8.06.39 (ver.). All areas were calculated with Auto-CAD (Shin and Kim, 2010).

Halophyte community growth monitoring. Plant species, heights, individual numbers, density, and coverage were examined in the 230 quadrats (1 m × 1 m) placed in the halophyte-sown areas immediately after sowing (Fig. 1) by Braun-Blanquet's method (Braun-Blanquet, 1964) each October from 2006 to 2008. The number of entire quadrats was 79 in 2006, 75 in 2007, and 76 in 2008. Among the quadrats, 29 were monitored consecutively for three years. Halophyte community growth in the quadrats was classified into five classes (from 1 to 5 with smaller numbers indicating better growth) by the criteria listed in Table 2. It was necessary to design a new classification to assort the yearly growing condition of halophyte communities based on reasonable criteria, because few studies have been made on natural and constructed halophyte communities in terms of growth. The criteria in Table 2 reflect the comparative mean height and/or overall coverage range of all plant species observed in a quadrat.

Soil analysis. Concurrent with growth monitoring, a soil sample was taken from the surface to 10 cm in depth in a quadrat, air-dried, passed through a 2-mm sieve, and used for analysis. Soil physico-chemical properties were analyzed within two months after sampling by Rural Development Administration's method (NIAST, 2000). Clay content was obtained using hydrometer method, and sand content was measured by sieving method. Organic matter was determined by back titration with ammonium sulfate solution. Available phosphate was determined from absorbance at 720 nm with a spectrophotometer (Cintra40, GBC). Soil electrical conductivity ($EC_{1:5}$) of 1:5 soil to water was measured with a conductometer (Orion 3 star, Thermo). Total nitrogen was measured by a modified Kjeldahl digestion. Exchangeable cations in 1N ammonium acetate extract were measured by an inductively coupled plasma spectrophotometer (ICPS-7510, Shimazu, Japan).

Statistical analysis. All statistical analyses were performed with the SAS (ver. 9.2, SAS, USA) program. Acquired results were denoted as mean ± standard deviation, and statistical significance of means was determined by Duncan's multiple-range test with an alpha value of 0.05 (p <0.05).

Results and Discussion

Halophyte community growth. Upon comparison of the yearly percentages of quadrats to each class for the entire quadrats shown in Table 3, only 40% (30 out of the 79 quadrats) was classified to Class 1 or Class 2 in 2006. The percentage increased outstandingly to 60.0% in 2007 and 86.8% in 2008.

For common quadrats like the result of entire quadrats, 45% (13 out of 29 quadrats) was classified into Class 1 or Class 2 in 2006. In 2008, just three years after halophyte community construction started, more than 90% belonged to Class 1 or Class 2, and no

Table 1 Planting of halophyte in the Saemangeum reclaimed land from 2006 to 2008

Year	Sowing period	Halophyte species	Seed amount (kg)	Sown area (ha)
2006	Period 1 May 8-Jun.15	Sa, Sj	6,520	1,434
2007	Period 2 Mar.27-May 25	Sa, Sj, At, Zs, Ag, Ac	2,212	968
	Apr.16-Apr. 22	Se	280	150
	Period 3 Oct. 15	Lt	108	12
	Dec.10-Dec.14	Sa, Sj	437	146
2008	Period 4 Mar.31-Apr.10	Sa, Sj	1,000	106
	Apr.11-Apr.18	Se	96	50
Sum		8	10,653	2,866

Sa: *Suaeda asparagoides*, Sj: *Suaeda japonica*, Se: *Salicornia europaea,* At: *Aster tripolium*, Zs: *Zoysia sinica*, Ag: *Atriplex gmelini*, Lt: *Limonium tetragonum*, Ac: *Artemisia capillaries.*

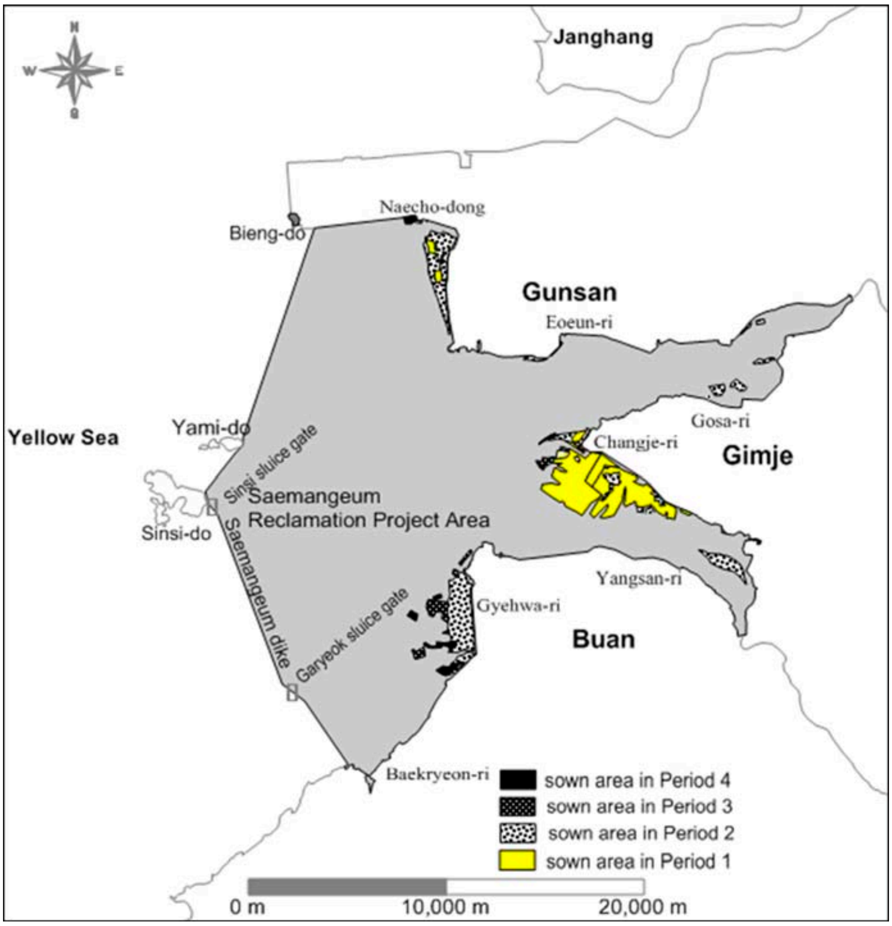

Fig. 1. Halophyte-sown areas in the Saemangeum reclaimed land from 2006 to 2008. Saemangeum Reclamation Project is an agricultural civil engineering work for development of 28,300 ha of agricultural land and 11,800 ha of freshwater lake administratively bordering on Gunsan-si, Gimje-si, and Buan-gun, Korea. Seeds (10,653 kg) were used through four-period seedings on 2,866 ha of the barren areas of Saemangeum reclaimed land from 2006 to 2008.

quadrat belonged to Class 5 (Table 4).

Soil properties. Regardless of class, soil texture was, on the whole, sandy loam with ≤5% of clay content (Table 5). This is thought to be the reason that levels of soil organic matter and available phosphate were very low, even when compared to levels in other earlier reclaimed lands (National Institute of Crop Science, 2007). Soil EC was greater than 3.1 dSm^{-1}, which is unsuitable for ordinary plants except halophytes. In 29 common quadrats, soil EC dropped from 3.3 dSm^{-1} in 2006 to 2.0 dSm^{-1} in 2008. Available phosphate content drastically increased from 28 mg kg^{-1} in 2006 to 115 mg kg^{-1} in 2008 (Table 5).

Table 2 Classification criteria of halophyte community growth in a quadrat based on plant height and coverage

Halophyte community growth	Criteria
Class 1	mean height ≥58 cm
Class 2	mean height of 30–57 cm or mean height of 20–30 cm and coverage 40%
Class 3	mean height of 10–30 cm and coverage 20%
Class 4	mean height of 10–20 cm and coverage 20%
Class 5	mean height ≤10 cm and coverage 20%

For *S. europaea*, Class 1 has a height ≥25 cm, Class 2 20–24 cm, Class 3 15–19 cm, Class 4 5–14 cm, and Class 5 ≤4 cm

As the tidal current was restricted by sea walls, the inner salt marsh can be steadily changed into reclaimed land through desalinization by precipitation (Kim et al., 2002) and salt contents in soil decreasing over time (Yoo et al., 1989). Glycophytes, absent in 2006 due to high EC and sodium content, were observed in 2008 as EC decreased to2.0 dSm^{-1}. In common quadrats, the decrease in soil EC and increase in phosphate content probably contributed to improvement of halophyte community growth such that most of the quadrats were Class 1 or Class 2 in 2008.

Relationship between halophyte community growth and soil chemical properties. A significantly negative relationship was observed between soil EC and halophyte community growth in 2006. The soil ECs in Class 1 and Class 2 quadrats measured 2.0

Table 3 Yearly distribution of halophyte community growth in the entire quadrats from 2006 to 2008

Year	Number (percentage) of quadrats to Class					
	Class 1	Class 2	Class 3	Class 4	Class 5	Sum
2006	14 (17.7%)	16 (20.3%)	22 (27.8%)	14 (16.5%)	13 (16.5%)	79 (100%)
2007	17 (22.7%)	28 (37.3%)	16 (21.3%)	9 (12.0%)	5 (6.7%)	75 (100%)
2008	26 (34.2%)	40 (52.6%)	6 (7.9%)	2 (2.6%)	2 (2.6%)	76 (100%)

Halophyte community growth of each quadrat was classified into five classes (from 1 to 5 with smaller numbersindicating better growth)

Table 4 Yearly distribution of halophyte community growth in the common quadrats consecutively surveyed from 2006 to 2008

Year	Number (percentage) of quadrats to Class					
	Class 1	Class 2	Class 3	Class 4	Class 5	Sum
2006	7 (24.1%)	6 (20.7%)	6 (20.7%)	6 (20.7%)	4 (13.8%)	29 (100%)
2007	4 (13.8%)	16 (55.2%)	7 (24.1%)	1 (3.4%)	1 (3.4%)	29 (100%)
2008	6 (20.7%)	21 (72.4%)	1 (3.4%)	1 (3.4%)	0 (0%)	29 (100%)

Halophyte community growth of each quadrat was classified into five classes (from 1 to 5 with smaller numbers indicating better growth)

Table 5 Soil physico-chemical properties in the quadrats from 2006 to 2008

Year	2006		2007		2008	
	A	B	A	B	A	B
Sand (%)	47±6	45±19	41±20	45±20	49±20	46±20
Silt (%)	48±7	50±18	54±19	51±19	48±19	52±19
Clay (%)	4.4±0.9	4.2±2.6	4.7±2.3	4.4±2.8	3.3±1.8	2.7±1.9
Organic matter (g kg^{-1})	3.0±0.5	3.1±1.7	4.0±2.2	3.4±1.7	2.8±1.6	2.3±1.1
Available P_2O_5 (mg kg^{-1})	29±4	28±9	86±24	81±25	104±29	115±28
$EC_{1:5}$ (dSm^{-1})	3.1±0.8	3.3±2.2	3.7±3.0	3.3±2.7	2.6±2.3	2.0±1.8

A: entire quadrats (79 in 2006, 75 in 2007, and 76 in 2008)
B: 29 common quadrats for three years.

Table 6 Soil physico-chemical properties in the quadrats for each Class in 2006

Class	Class 1	Class 2	Class 3	Class 4	Class 5
Sand (%)	58±25a	44±19b	42±9b	46±14ab	46±20ab
Silt (%)	38±24a	52±17b	55±8b	50±14ab	46±22ab
Clay (%)	4.5±2.1a	3.8±2.9a	3.8±1.6a	4.1±2.1a	5.8±2.3b
Organic matter (g kg^{-1})	0.32±0.16ab	0.24±0.16a	0.27±0.13ab	0.32±0.18ab	0.38±0.17b
Available P_2O_5 (mg kg^{-1})	30±8ab	25±9a	26±6a	30±9ab	34±8b
Total nitrogen (mg kg^{-1})	213±83ab	178±75a	166±25a	196±86ab	242±96b
$EC_{1:5}$ (dSm^{-1})	2.0±1.5a	2.7±2.6ab	3.1±1.3abc	3.6±2.1bc	4.2±1.5c
Exchangeable Ca^{2+} (cmol kg^{-1})	1.3±1.0a	0.7±0.4a	0.7±0.2a	1.4±1.8a	0.9±0.3a
Exchangeable Mg^{2+} (cmol kg^{-1})	3.6±2.2a	4.7±4.2ab	4.8±2.2ab	6.2±3.9bc	7.6±3.4c
Exchangeable K^{+} (cmol kg^{-1})	0.75±0.12a	0.76±0.15ab	0.86±0.11bc	0.92±0.21c	0.95±0.10c
Exchangeable Na^{+} (cmol kg^{-1})	8.8±5.6a	11.0±12.1a	10.7±8.3a	15.6±10.9ab	19.4±6.6b

Each value represents mean ± SD. Means with different letters in a row are significantly different according to Duncan's multiple-range test (p <0.05).A significantly negative relationship was observed between soil EC and halophyte community growth in 2006.

dSm^{-1} and 2.7 dSm^{-1} respectively (Table 6). Along with EC, halophyte community growth improved with decrease in soil magnesium, potassium, and sodium contents. In Class 1 quadrats, levels of soil magnesium, potassium, and sodium contents were 3.6 cmol, 0.75, and 8.8 cmol kg^{-1} respectively. On the other hand, clay, organic matter, available phosphate, and calcium contents did not have a significant relationship with halophyte community growth (Table 6).

The soil ECs in Class 1 and Class 2 quadrats increased year-to-year to 3.8 and 3.3 dSm^{-1} in 2007 respectively due to higher levels of exchangeable cations. Levels of soil magnesium, potassium, and sodium contents considerably increased on a yearly basis in all classes. In Class 1 quadrats, levels of soil magnesium, potassium, and sodium contents were 10.6, 0.97, and 28.7 cmol kg^{-1}

Table 7 Soil physico-chemical properties in the quadrats for each Class in 2007

Class	Class 1	Class 2	Class 3	Class 4	Class 5
Sand (%)	31±13[a]	39±19[a]	48±23[a]	50±28[a]	46±19[a]
Silt (%)	64±12[a]	56±17[ab]	48±22[ab]	44±27[b]	48±18[ab]
Clay (%)	4.5±1.8[ab]	4.9±2.8[ab]	3.7±2.0[a]	5.9±1.4[b]	5.2±1.8[ab]
Organic matter (gkg^{-1})	0.46±0.26[a]	0.36±0.23[a]	0.34±0.16[a]	0.45±0.15[a]	0.51±0.22[a]
Available P_2O_5 (mg kg^{-1})	90±15[a]	91±23[a]	74±30[a]	82±19[a]	90±26[a]
$EC_{1:5}$ (dSm^{-1})	3.8±2.7[ab]	3.3±2.9[ab]	3.0±2.3[a]	4.5±4.3[ab]	5.8±3.5[b]
Exchangeable Ca^{2+} (cmol kg^{-1})	1.2±0.6[a]	1.1±0.6[a]	1.3±0.6[a]	2.1±1.9[b]	1.1±0.6[a]
Exchangeable Mg^{2+} (cmol kg^{-1})	10.6±6.5[ab]	8.8±7.0[ab]	7.2±4.8[a]	10.9±8.0[ab]	13.8±7.4[b]
Exchangeable K^+ (cmol kg^{-1})	0.97±0.28[a]	0.98±0.23[a]	0.92±0.21[a]	1.04±0.27[a]	1.18±0.13[a]
Exchangeable Na^+ (cmol kg^{-1})	28.7±23.0[a]	28.2±24.6[a]	25.5±21.2[a]	34.2±24.7[a]	41.2±21.7[a]

Each value represents mean ± SD. Means with different letters in a row are significantly different according to Duncan's multiple-range test (p <0.05). The soil ECsin Class 1 and Class 2 quadrats increased year-to-year because of higher levels of exchangeable cations.

Table 8 Soil physico-chemical properties in the quadrats for each Class in 2008

Class	Class 1	Class 2	Class 3	Class 4	Class 5
Sand (%)	50±23[a]	47±19[a]	50±16[a]	41±3[a]	49±32[a]
Silt (%)	46±22[a]	49±18[a]	47±16[a]	54±6[a]	48±32[a]
Clay (%)	3.0±1.9[a]	3.0±1.8[a]	3.0±1.9[a]	5.0±2.8[a]	4.0±0[a]
Organic matter (g kg^{-1})	0.28±0.16[a]	0.26±0.14[a]	0.35±0.30[a]	0.33±0.09[a]	0.34±0.01[a]
Available P_2O_5 (mg kg^{-1})	96±29[ab]	111±26[a]	103±40[ab]	104±6[ab]	64±9[b]
$EC_{1:5}$ (dSm^{-1})	1.7±2.1[a]	2.7±2.1[a]	3.4±2.8[ab]	6.4±1.4[b]	6.0±0.2[b]

Each value represents mean ± SD. Means with different letters in a row are significantly different according to Duncan's multiple-range test (p <0.05). Exchangeable cations were not analyzed. Soil EC decreased compared with ECs for 2006 and 2007 and presented a significantly negative relationship with halophyte community growth.

respectively (Table 7). This result indicates that halophyte communitiesbecame more salt-tolerant, having adapted to saline conditions and well established in those conditions. Clay, organic matter, available phosphate, and calcium contents did not have a significant relationship with halophyte community growth as was found earlier.

In 2008, soil EC decreased compared with ECs for 2006 and 2007 showing a significantly negative relationship with halophyte community growth (Table 8). Soil ECsin Class 1 and Class 2 quadrats dropped from those of the year ago to 1.7 and 2.7 dSm^{-1}, respectively. Clay, organic matter, and available phosphate contents remained not to have a significant relationship with halophyte community growth.

Averaging the soil ECs and heights in the quadrats where a particular species existed, plant height representing halophyte growth was found to have a significantly negative relationship ($y=36.52x^{-0.8}$, R^2=0.95) with soil EC (Fig. 2). Whereas halophyte community growth improved from Class 5 to Class 1, soil EC decreased (4.6 dSm^{-1} to 1.8 dSm^{-1}) and plant height increased on the contrary (14.5 to 47.7 cm).

Matching existent plants with soil EC values in the 230 quadrats demonstrated a close plant species-soil EC relationship such that annual halophytic S*uaeda asparagoides*, S*uaedajaponica*, and *Salicornia europaea*, principal species planted for dust reduction, were categorized into the upper EC group (2.4–3.0 dSm^{-1}) (Fig. 3). On the other hand, annual or perennial halophytes

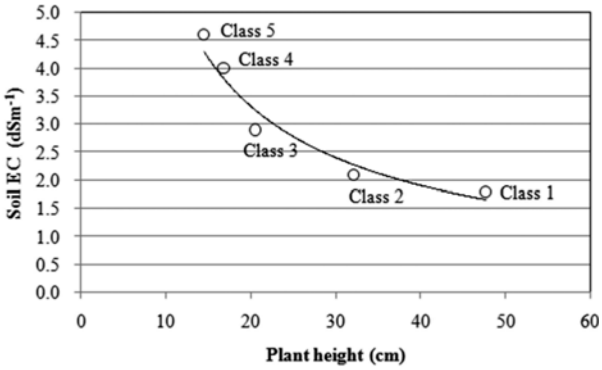

Fig. 2. Regression curve between plant height and soil EC. Plant height had a significantly negative relationship with a critical abiotic factor, soil EC (R^2=0.95). As halophyte community growth improved from Class 5 to Class 1, soil EC decreased and plant height increased.

(*Atriplex gmelini*, *Aster tripolium*, *Chenopodium album*, and *Phragmites communis*) and glycophytes (*Cyperus polystachyos*, *Echinochloa crusgalli*, *Echinochloa crusgalli* var. oryzicola, and S*anchus oleraceus*) were classified into the middle EC group (0.9–1.4 dSm^{-1}) and the lower EC group (0.1–0.2 dSm^{-1}) respectively.

Explaining patterns of species distributions along environmental gradients has been a dominant subject in ecological research for decades as indicated by Engels et al. (2011). Although many

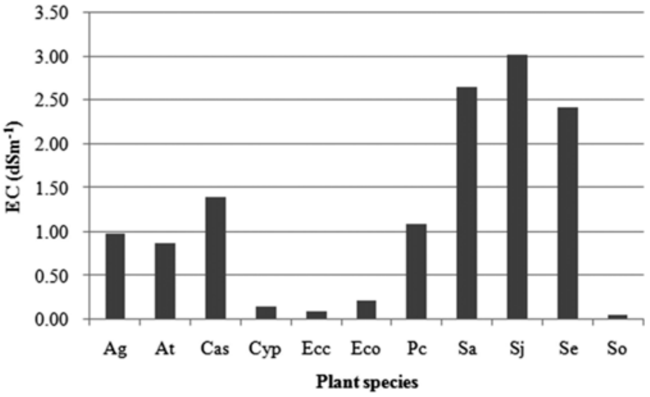

Fig. 3. Soil EC values for the existence of a particular plant species in a quadrat. Ag: *A. gmelini*, At: *A. tripolium*, Cas: *C. album*, Cyp: *C. polystachyos*, Ecc: *E. crusgalli*, Eco: *E. crusgalli var. oryzicolai*, Pc: *P. communis*, Sa: S. *asparagoides*, Sj: *S. japonica*, Se: *S. europaea*, So: S. *oleraceus.* All values were averaged from the soil ECs in the quadrats where a particular species existed. Annual halophytes (S. *asparagoides*, *S. japonica*, and *S. europaea*) were categorized into the most salt-tolerant group (2.4–3.0 dSm^{-1}).

abiotic factors affect halophytic growth, soil EC has been the most vigorously examined, and its close connection with halophytic distribution has been reported (Shumway and Bertness, 1992; Nam et al., 2007). The three-year soil analysis results show that soil EC has a significantly negative relationship with halophyte community growth, especially in 2006 when it is probable that the effect of soil EC on halophytes had the least interference from other factors. Magnesium, potassium and sodium contents showed a significant relationship with the growth. In 29 common quadrats, sand and silt contents increased over time due to the deposition of sand or silt and the erosion of clay by wind. Min (1986) classified plants in coastal reclaimed lands into four groups based on soil EC and moisture, and Lee et al. (2003) suggested EC ranges for emergence of halophytes and glycophytes. In the present study, detailed comparison of existing plant species and soil ECs in the 230 quadrats allowed categorization of halophytes into three groups depending on EC values. Especially, S. *asparagoides*, *S. japonica*, and *S. europaea* planted in volume on the reclaimed land turned out to have broad and high salt-resistance for halophyte seeding in the earlier reclaimed lands with high soil EC.

In conclusion, halophyte community growth could be classified into five classes according to the classification based on height and coverage in the reclaimed land. Among soil properties, soil EC showed a significantly negative relationship with halophyte community growth.

Apart from land covering, halophytes have other potential uses in bioremediation, food, medicines, bioenergy, and CO_2 sequestering (Glenn et al., 1998; Kong et al., 2008). The methods and results of the present study, therefore, would be continuously applied to biological dust reduction in reclaimed lands including Saemangeum. They could also play a basic role in developing halophyte farms to actualize other uses, with further related researches and a policy switch on reclaimed lands.

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References

Braun-Blanquet J (1964) In *Planzon Soziologie*. Springer, Wein, USA.

Engels JS, Rink F, and Jensen K (2011) Stress tolerance and biotic interactions determine plant zonation patterns in estuarine marshes during seedling emergence and early establishment. *J Ecology* **99**, 277–87.

Glenn EP, Brown JJ, and O'Leary JW (1998) Irrigating crops with seawater, *Scientific American* **279**, 56–61.

Ihm BS and Lee JS (1998) Soil factors affecting the plant communities of wetland on southwestern coast of Korea. *Korean J Ecol* **21**, 321–8.

Ihm BS, Lee JS, Woo HS, KwakAK, and Ihm HB (1995) Distribution of coastal plant communities at the salt marshes of Mankyung and Donjin River estuary. *Bull Inst Litt Environ* **12**, 11–28.

Jung YS, Joo JH, Kwon, SC, Im JN, Shin MH, and Choi KW (2004) Wind erodibility of the Saemangeum tideland reclamation project area. *Korean J Soil Sci Fer* **37**, 207–11.

Kim CH, Lee KB, Cho DS, and M H (2006) The study on the flora and vegetation of salt marshes of Mankyeong River estuary in Jeonbuk. *J Environ Sci* **20**, 288–98.

Kim EK, Jung YS, Jeong HG, Joo YK, and Chun S (2007) Vegetation distribution of intertidal zone and estuary area on Anseo Port in Saemangeum reclamation zone. *Korean J Env Ecol* **21**, 494–505.

Kim EK, Jung YS, Joo YK, Jung HG, Chun S, and Lee SH (2009) Vegetation distribution and soil salinity on Daeho reclaimed tidal land of Kyonggi-Bay in the Midwest coast of Korea. *Korean J Soil Sci Fer* **42**, 447–53.

Kim HS, Yoon YS, and Cho JW (2008) Quantitative analysis of flavonoids from *Salicornia herbacea* L. extract by LC-MS. *Korean J Medical Crop Sci* **16**, 231–7.

Kim JY, Son JG, Koo JW, and Choi JK (2002) Changes of physic-chemical properties in the reclaimed tidal land soils by precipitation. *J Korean Sci Rural Planning* **8**, 3–14.

Kim SH (2005) A study on the relationship between the physico-chemical properties of soil and the distribution of vegetation on reclaimed Deaho tidal flat. *Geography Research* **39**, 337–45.

Kong CS, Um YR, Lee JI, Kim YA, Lee JS, and Seo YW (2008) Inhibition effects of extracts and its solvent fractions isolated from *Limonium tetragonum* on growth of human cancer cells. *Korean J Biotechnol Bioeng* **23**, 177–82.

Lee JS (1989) On establishment of halophytes along tidal level gradient at salt marshes of Mangyeong and Donjin river estuaries. Ph.D. Thesis. Seoul National University, Seoul, Korea.

Lee JS, Lim BS, Myeong HH, Park JW, and Kim HS (2009) Soil environment analysis and habitat of halophyte for restoration in the salt marshes of southern and western coasts of Korea. *Korean J PlantResources* **22**, 102–10.

Lee SH, Ji KJ, A Y, and Ro HM (2003) Soil salinity and vegetation distribution at four tidal reclamation project areas. *J Environ Agric* **22**, 79–86.

Lindig-Cisnero R and Zedler JB (2002) Halophyte Recruitment in a salt marsh restoration site. *Estuaries and Coasts* **25**, 1174–83.

Min BM (1986) Changes of soil and vegetation in coastal reclaimed lands, West Coast of Korea. Ph. D. Thesis. Seoul National University, Seoul, Korea.

Ministry of Land, Transport and Maritime Affairs (2008) Survey and long-term planning of tidal flat restoration. Ministry of Land, Transport and Maritime Affairs, Seoul, Korea.

Nam YK, Baik JA, and Chiang MH (2007) Effects of different NaCl concentrations on the growth of *Suaeda asparagoides, Suaeda maritime,*

and Salicornia herbacea. *Korean J Soil Sci Fer* **40**, 349–53.
National Institute of Agricultural Science and Technology (2000) Methods of soil and pant analysis. Sammi Press, Suwon, Korea.
National Institute of Crop Science (2007) Managing techniques of rice paddy soils in reclaimed lands. Geumsung Graphic, Iksan, Korea.
Shin MH and Kim CH (2010) Traits of water level control by sluice gates and halophyte community formation in Saemangeum. *Korean J Environ Ecol* **24**, 186–93.
Shumway SW and Bertness MD (1992) Salt stress limitation of seedling recruitment in a salt marsh plant community. *Oecologia* **92**, 490–7.
Yoo CH, Cho GH, Choi JW, Park KH, and Kim YH (1989) Studies on change of physic-chemical properties due to ripening degrees in the reclaimed tidal deposits. *Korean Soil Sci Fert* **22**,180–90.
Zedler JB (2005) Restoring wetland plant diversity: a comparison of existing and adaptive approaches. *Wetlands Ecol Manage* **13**, 5–14.