J. Ecol. Field Biol. 32 (2): 115～121, 2009

Characteristics of Plant Distribution in the Reclaimed Dredging Area in Gwangyang Bay, Korea

Nam, Woong[1], Young-Se Kwak[2]*, Deok-Beom Lee[1] and Sang-Suk Lee[3]

[1]*Gwangyang Landscape Co., Ltd., Gwangyang 545-090, Korea*

[2]*Department of Environment Research, Research Institute of Industrial Science & Technology (RIST), Gwangyang 545-090, Korea*

[3]*Department of Landscape Architecture, Sunchon National University, Sunchon 540-742, Korea*

ABSTRACT: In order to elucidate the mechanisms affecting plant distributions in the reclaimed dredging area in the Gwangyang steelworks, in the Gwangyang Bay, Korea, we examined soil characteristics and plant distributions in four study sites and a control site in the study area. Desalination occurring along a gradient with increasing elevation, resulting in decrease of soil pH, EC, P, K, Cl, Ca, Mg, and salt and an increase in soil T-N, silt, clay contents. From site 1 (the lowest-elevation site) to site 5 (the highest-elevation site), halophytes decreased in abundance and nonhalophytes increased. The dominant species in each site were: *Phragmites communis*, *Limonium tetragonum*, and 12 additional species at site 1, *Carex pumila*, *Suaeda japonica*, and 15 additional species at site 2, *Spergularia marina*, *Scirpus planiculmis*, and 22 additional species at site 3, *Miscantus sinensis, Lespedeza bicolor*, and 26 additional species at site 4 and *Pinus thunberii*, *Rhododendron mucronulatum*, and 39 additional species at site 5, which resembled a naturally-occurring *P. thinbergii* community. Cluster analysis of the vegetation data matrix grouped the 35 plots into 5 major groups, and cluster analysis using the soil environment data matrix revealed 4 major groups. CCA of the floristic and environmental data matrix showed a positive relationship of SAR, EC, Na, Cl, and Ca, which are related to salt, in the 1st axis and 2nd axis, but negative relationships for altitude, organic contents, silt, and clay contents. Notably, plant species in the reclaimed dredging area that were separated along the 1st axis showed strong relationships with factors that related to salt. Long-term exposure to natural rainfall in the reclaimed dredging area changed the soil characteristics, such as salinity. This change in soil characteristics might alter the SAR, which affects plant survival strategies in a given habitat. These results strongly indicated that factors related to salt and elevation play important roles in determining the overall plant distribution in the reclaimed dredging area.

Key words: CCA, Distribution, Halophytes, Reclaimed dredging land, Salinity, SAR, Site

INTRODUCTION

The soil of reclaimed dredging areas is not suitable for the tree growth; hence, to introduce trees into these areas, it is necessary to build and manage man-made ground layers. Recently, ecological forestation by the introduction of natural vegetation has been proposed as an alternative method for artificial plantation. As a result, interest in the wild plants found in reclaimed dredging areas has increased (Kwak et al. 2004). From an ecological point of view, these plants can be regarded as useful natural resources, as the plants have already demonstrated an ability to adapt to the altered environment without artificial management or support. However, to date, the value of native plants and the potential of vegetation community in reclaimed dredging areas have not been fully appreciated. Research on the characteristics of landfill soil and the ecological value of the natural vegetation community in the area have not been sufficient. Research to date in the salt marsh has mainly examined the distribution patterns of halophytes (Bertness et al. 1992, Penning and Callaway 1992, Richard and Chumura 2000, Sally and Zedler 2000), survival strategies of halophytes based on soil environmental factors (Lee et al. 1996, Ajimal and Aziz 1998, Min and Kim 1999b, Bouma et al. 2001, Selislkar et al. 2002), and community analysis of the possible utility of halophytes (Christopher et al. 2002, Silvestri et al. 2005). Considerable research has been conducted on the succession of vegetation and the relationship between coastal landfill vegetation and soil characteristics. However, studies in reclaimed dredging areas are rare. We observed the process of vegetation change in a reclaimed dredging area without artificial disturbance within 10～20 years of the reclamation period, examined changes in the physico-chemical properties of soil and the plant distribution in the reclaimed dredging area over time, and elucidated the relationship between soil and plant characteristics.

* Corresponding author; Phone: +82-61-790-8754, e-mail: kwakys@rist.re.kr

MATERIALS AND METHODS

Materials used for the analyses of vegetation and soil characteristics were obtained from the reclaimed dredging area in Gwangyang Bay, South Korea (Fig. 1), which has been described in detail elsewhere (Nam et al. 2008a). The reclaimed dredging area was created along the shoreline in 1980. It is located from sea level to 15 meters altitude and exhibits typical characteristics of a salt marsh. The area is divided into five different sites (1, 2, 3, 4, and 5) with increasing altitude and distance from the waterline. We chose four sites in the filled reclaimed area of Gwangyang Bay (1, 2, 3, 4) with different vegetation conditions and no history of artificial disturbance for the last 10 to 20 years for our study. We established eight plots at each site and three control plots at site 5, for a total of 35 plots. We examined the physicochemical characteristics of the topsoil 0～20 cm from the surface.

We collected samples from communities of salt marsh and *P. thunbergii* from April 2007 to September 2007 using the methods described by Nam et al. (2008b) (Fig. 1). The 35 plots were established at scattered intervals in the dredging area in order to cover the various forms of vegetation. Plant communities were classified subjectively on the basis of dominant species, in the plots with a relatively homogeneous physiognomy. The presence or absence of each sampled plant species was then tallied within a 2 × 2 m quadrat in each plot. Constancy of species was calculated from the species table and species were placed into classes in intervals of 20%: species with constancy of 1～20%, 21～40%, 41～60%, 61～80%, and 81-100% were designated as class Ⅰ, Ⅱ, Ⅲ, Ⅳ, and Ⅴ, respectively (Mueller-Dombois and Ellenberg 1974). Topsoil 0～20 cm from the surface was collected from 35 plots and the physicochemical characteristics of the soil samples were analyzed using the procedure of Allen et al. (1986). We used cluster and canonical correspondence analysis (Orloci 1978) to examine the relationships between plant distributions and soil factors.

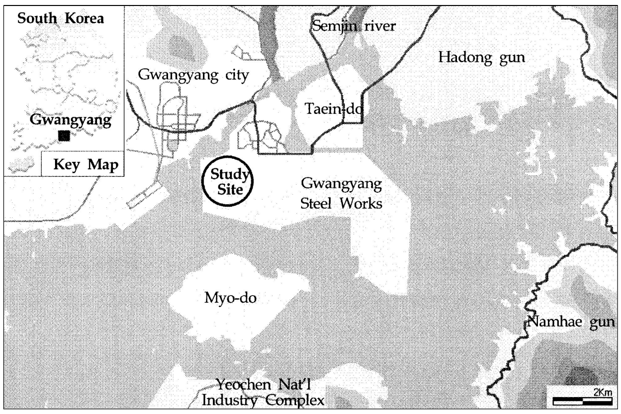

Fig. 1. The study site.

RESULTS AND DISCUSSION

The physicochemical characteristics in each site's topsoil varied with site elevation, site vegetation, and the type of reclaimed dredging soil. Soil pH, EC, P, Cl, Ca, Mg, Na, and sodium adsorption ratio (SAR) tended to decrease gradually from site 1 to site 4, while the total nitrogen tended to increase (Table 1).

Analysis of the physicochemical characteristics of soil in sites 1 to 4 suggested that long-term exposure to rainfall in the reclaimed dredging area changed soil characteristics, including salinity, and that the area exhibited the typical characteristics of a salt marsh. As desalination in the reclaimed dredging area occurred, each site developed a different plant distribution. After dredging, the sediments became naturally-occurring soils in the area as the soil leached over time. The rate of leaching is affected by rain intensity, soil texture, and topography (Min and Kim 1997a).

A total of 12, 15, 22, 27, and 35 different plant species were found in sites 1, 2, 3, 4, and 5, respectively (Table 2). Species appearing with high constancy in the five study sites were classified into six groups. Species group A was composed of *Limonium tetragonum* and *Sonchus brachyotus,* species occurring at 0.34 m elevation, preferably with inundating seawater. Species group B, which occurred at 1.51 m elevation, was composed of 5 species: *Suaeda japonica, Aster tripolium, Setaria viridis* var. *pachystachys, Vicia angustifolia* var. *segetilis,* and *Medicago lupulina.* Species group C, which occurred at 1.78 m elevation, was composed of two species: *Scirpus planiculmis* and *Spergularia marina.* Species group D, which occurred at 3.34 m elevation, was composed of seven species: *Miscanthus sinensis, Lespedeza bicolor, Populus alba, Oenothera odorata, Alopecurus aequalis,* and *Cerastium holosteoides* var. *hallaisanense*. Species group E, occurring only in a granite area at 15.15 m elevation, was composed of seven species: *Pinus thunbergii, Celtis sinensis, Oplismenus undulatifolius, Carex lanceolata, Rosa multiflora, Smilax china,* and *Rubus parvifolius* for. *Parvifolius.* Species group F consisted of species that were distributed throughout the site communities as dominant species (Table 2).

The representation of halophytes, which can grow more than 0.2% salt concentration (Barbour 1970), decreased from site 1 to site 5, and the representation of non-halophytes increased (Fig. 2). Halophytes growing in the reclaimed dredging area differ in their inherent salt tolerance (Bertness et al. 1992, Min and Kim 1999b, Christopher et al. 2002). Some halophytes can tolerate extraordinarily high salt concentrations. For example, *Suaeda maritime* can grow in 500 mol/m^3 NaCl (Greenway and Munns 1980). Salt-tolerant plants display one or more of the following traits: 1) selec

Table 1. Physicochemical properties of top soil at the study sites (data: mean ± 1 S.D.)

Environmental factors	Salt marsh				Vicinity
	Site 1	Site 2	Site 3	Site 4	Site 5
Elevation (m)	0.34	1.51	1.78	3.44	15.15
pH	7.62 ± 0.20	7.36 ± 0.20	7.33 ± 0.15	7.10 ± 0.10	6.04 ± 0.12
O.M. (%)	1.59 ± 0.15	2.29 ± 0.16	1.81 ± 0.33	1.51 ± 0.42	4.39 ± 0.77
EC (dS/m)	2.16 ± 0.32	1.05 ± 0.30	0.11 ± 0.02	0.12 ± 0.04	0.11 ± 0.02
T-N (mg/g)	0.27 ± 0.05	0.32 ± 0.06	0.46 ± 0.07	0.50 ± 0.09	0.86 ± 0.13
PO_4^{3-} (ppm)	13.7 ± 1.7	12.4 ± 1.3	7.8 ± 0.5	7.3 ± 0.4	1.1 ± 0.2
K^+ (ppm)	167.5 ± 14.9	182.6 ± 13.1	145.0 ± 14.8	118.2 ± 21.1	77.7 ± 9.3
Ca^{2+} (ppm)	1,918 ± 217	1,834 ± 184	1,085 ± 112	1,104 ± 106	1,069 ± 211
Mg^{2+} (ppm)	280.4 ± 21.4	269.1 ± 18.2	155.7 ± 11.7	117.5 ± 20.1	56.8 ± 10.3
Cl^- (ppm)	3,016 ± 679	1,042 ± 100	83 ± 11	48 ± 7	6 ± 1
Na^+ (ppm)	1,227 ± 136	65.1 ± 11.3	37.4 ± 5.3	13.4 ± 1.7	2.4 ± 0.6
SAR	6.94 ± 1.60	3.75 ± 0.77	0.29 ± 0.08	0.10 ± 0.01	0.02 ± 0.01
Sand (%)	80.0 ± 4.6	80.5 ± 3.1	93.4 ± 2.3	66.6 ± 2.9	53.5 ± 2.1
Silt (%)	10.6 ± 3.2	9.7 ± 3.8	2.4 ± 1.5	19.2 ± 1.8	23.7 ± 2.8
Clay (%)	9.4 ± 2.8	9.8 ± 4.3	4.2 ± 0.9	14.2 ± 2.5	22.8 ± 4.6

tion, 2) extrusion, 3) accumulation, or 4) dilution of ions (Chapman 1977). In sea coasts and inlets area composed of unstable sand, the effect of wave action prevent the establishment of vascular plants on the lower parts of the beach. Desalination at each site in the reclaimed dredging area was a driving force that affected the performance and distribution of halophytes and non-halophytes. Salt marsh macrophyte species may be associated with narrow ranges of soil topographic elevation (Silvestri et al. 2005). These distribution processes, involving the replacement of early, fast-growing species, showed strong relationships with the tolerance model (Connell and Slatyer 1977).

The results of the cluster analysis of the similarity in 15 soil characteristics in the 35 sample plots in Gwangyang Bay are shown Fig. 3. Site 3 (plots no.17～24) and site 4 (plots no. 25～32) showed 98% similarity in soil environmental factors, and sites 3 and 4 were clustered with site 5 (plots no 33～35) with 92% similarity. Site 2 (plots no. 9～16) was clustered with sites 3, 4, and 5 with 70% similarity. Finally, site 1 (plots no. 1～8) was clustered with site 2, 3, 4 and 5 with 65% similarity. Previous research has demonstrated that patch formation and growth of *Calamagrostis epigeios* plants in reclaimed coastal land are determined by differences in micro salt pan in the soil (Chung et al. 1991), and the density and distribution of halophytes in reclaimed land are also determined by micro soil factors and complex soil factors (Min 1985, Ajimal and Aziz 1998). Our results also showed a good correlation between soil characteristics and the distribution and performance of plants in the study plots (Fig. 3).

The cluster analysis based on the coverage of 73 plant species in the 35 sample plots in the reclaimed dredging area clustered the plots into 4 groups (Fig. 4). Site 2 had high similarity with site 3, which reflected their location in an ecotone. The cluster analysis produced similar results to the Releve method, as shown in Table 2. In ecological studies of halophytes in highly saline soil in Korea, the floristic composition of reclaimed land was affected by topography and the salt gradient at the sites (Hong et al. 1970, Min 2005, Nam et al. 2008a), and the distribution and performance of halophytes were determined by these environmental gradients (Pennings and Callaway 1992, Bouma et al. 2001, Christopher et al. 2002, Silvestri et al. 2005). Our results suggest that the distribution and performance of the dominant and differential species in the reclaimed dredging area in Gwangyang Bay were similarly affected by gradients in soil environmental factors.

The results of the canonical correspondence analysis (CCA) suggested that halophytes such as *Limonium tetragonum*, *Salicornia herbacea*, *Artemisia scoparia*, *Suaeda japonica*, *Aster tripolium*, *Scirpus planiculmis*, and *Spergularia marina* were established in areas

Table 2. Constancy table of different communities on the reclaimed dredging area in Gwangyang Bay

Scientific name	Layer	Site 1	Site 2	Site 3	Site 4	Site 5
Group A						
Limonium tetragonum	H	Ⅴ				
Sonchus brachyotus	H	Ⅲ				
Group B						
Suaeda japonica	H	Ⅰ	Ⅳ			
Aster tripolium	H	Ⅰ	Ⅴ			
Setaria viridis var. *pachystachys*	H	Ⅱ	Ⅲ			
Vicia angustifolia var. *segetilis*	H		Ⅲ			
Medicago lupulina	H		Ⅲ			
Group C						
Scirpus planiculmis	H			Ⅴ		
Spergularia marina	H	Ⅰ	Ⅰ	Ⅴ		
Group D						
Miscanthus sinensis	H				Ⅳ	Ⅰ
Lespedeza bicolor	S				Ⅲ	
Themeda triandra var. *japonica*	H				Ⅲ	
Populus alba	S				Ⅳ	
Oenothera odorata	H				Ⅲ	
Alopecurus aequalis	H			Ⅰ	Ⅲ	
Cerastium holosteoides var. *hallaisanense*	H		Ⅱ		Ⅳ	
Group E						
Pinus thunbergii	T					Ⅴ
Celtis sinensis	LT					Ⅴ
Oplismenus undulatifolius	H					Ⅲ
Carex lanceolata	H			Ⅰ		Ⅲ
Rosa multiflora	S		Ⅰ			Ⅲ
Smilax china	S					Ⅴ
Rubus parvifolius for. *parvifolius*	H		Ⅱ			Ⅲ
Group F						
Phragmites communis	H	Ⅴ	Ⅴ	Ⅴ	Ⅲ	
Imperata cylindrica var. *koenigii*	H	Ⅱ	Ⅱ		Ⅲ	
Vicia tetrasperma	H	Ⅱ	Ⅴ	Ⅰ	Ⅲ	
Celastrus orbiculatus	S			Ⅳ	Ⅲ	Ⅲ
Salicornia herbacea	H	Ⅴ	Ⅴ			
Artemisia scoparia	H	Ⅲ	Ⅴ		Ⅱ	Ⅰ
Total number of species		12	15	22	26	39

*Legend: H = Herb, S = Shrub, T = Tree, LT = Lower tree, Ⅰ = species with constancy of 1～20%, Ⅱ = species with constancy of 21～40%, Ⅲ = species with constancy of 41～60%, Ⅳ = species with constancy of 61～80%, Ⅴ = species with constancy of 81～100%.

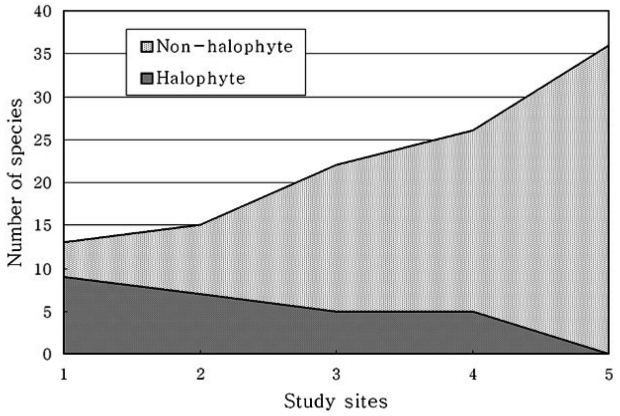

Fig. 2. Changes in the distribution of halophytes and non-halophytes within the plant community from this study.

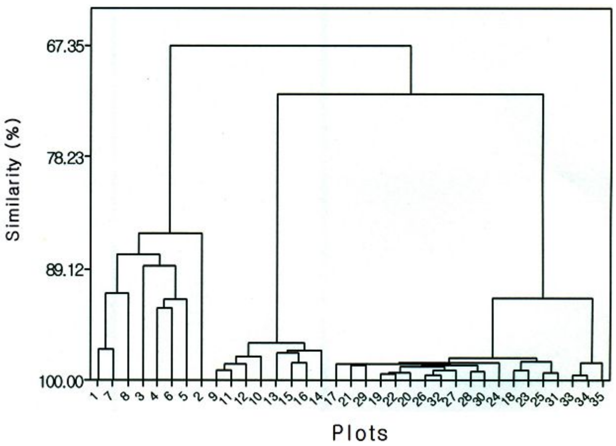

Fig. 3. Dendrogram of similarity in 15 soil characteristics in 35 plots in the reclaimed dredging area in the Gwangyang Bay produced by cluster analysis.

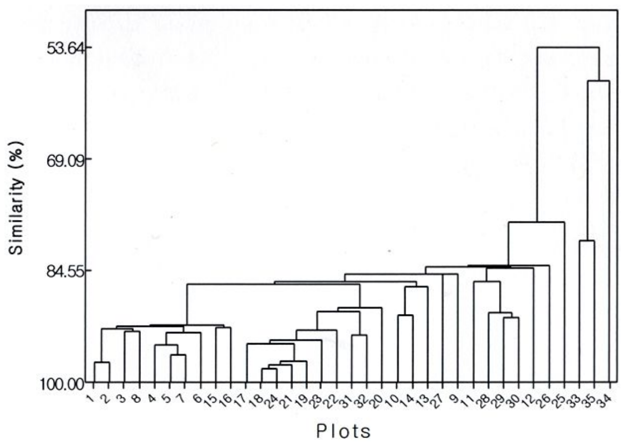

Fig. 4. Dendrogram of similarity in the coverage of 73 plant species among 35 plots in the reclaimed dredging area in Gwangyang Bay based on cluster analysis.

with high salinity and low elevation, in which electric conductivity (EC), the sodium adsorption ratio (SAR), sodium levels, chloride levels, and calcium levels were high, relative to those in areas inhabited by non-halophtes such as *Pinus thunbergii* and *Miscanthus sinensis.* In first axis based on the CCA, halophytes were positively correlated with salinity factors such as EC, Cl, Na, Ca, and SAR. In second axis, non-halophytes such as *Pinus thunbergii* and *Miscanthus sinensis* were positively correlated with elevation, total nitrogen, silt & clay, and organic matter (Fig. 5).

The succession of plant communities in the reclaimed area was not determined by the number of years following reclamation but by the topographical diversity of the land (Min et al. 1989). The principle factors affecting the distribution of halophytes in the reclaimed dredging area were the gradients of EC, Cl, Na, Ca, and SAR. The progression of plant species distribution was as follows; strongly halophyte → moderately halophyte → slightly halophyte & mixed non-halophyte → forest only, nonhalophyte (Fig. 6). Plant ecological research on reclaimed land in Korea has clarified the succession of plants that occurs with desalination and drying after reclamation as progressing through the following stages: *Salicornia herbasa* → *Suaeda japonica* · *Suaeda asparagoides* → *Aster tripolium* → *Sonchus brachyotus* → *Calamagrostis epigeios* → *Imperata cylindrica* (wet) · *Setaria glauca* (dry) → *Miscantus sinensis* (Min 1985). Salt marsh formation can be initiated by the colonization of bare tidal flats by pioneer halophytes such as *Salicornia herbasa* and *Limonium tetragonum* (Hong et al. 1971). Our results suggest that differences in the performance and distribution of halophytes at

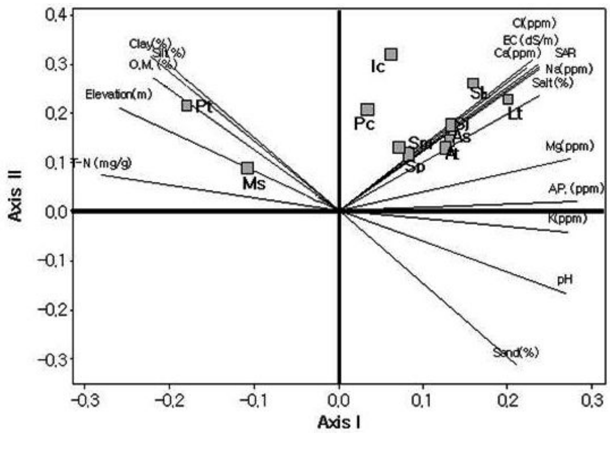

Fig. 5. CCA ordination diagram of the dominant species and soil environmental factors in the reclaimed dredging area in Gwangyang Bay. Pc: *Phragmites communis,* Ic: *Imperata cylindrica* var. *koengi*, Lt: *Limonium tetragonum*, Sh: *Salicornia herbacea*, As: *Artemisia scoparia*, Sj: *Suaeda japonica*, At: *Aster tripolium*, Sp: *Scirpus planiculmis*, Sm: *Spergularia marina,* Ms: *Miscanthus sinensis*, Pt: *Pinus thunbergii.*

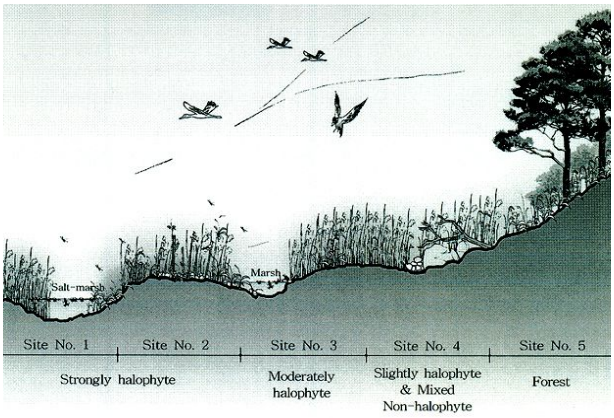

Fig. 6. Cross-sectional diagram of the study area showing the typical plant communities in the reclaimed dredging area in the Gwangyang Bay.

our study site were due to the SAR in the reclaimed soil, which contained high sodium, calcium and magnesium contents.

CONCLUSIONS

As desalination in the reclaimed dredging area (Gwangyang Bay, Korea) developed, the pH, Na, Cl, P, K, Ca, Mg and EC of the soil tended to decrease gradually. However, the total nitrogen, organic matter, silt and clay content tended to increase. Analysis of the physicochemical characteristics of the soil showed that long-term exposure to rainfall in higher-elevation areas in the reclaimed dredging area changed the soil characteristics, mostly salinity. The dominance of halophytes decreased with increasing elevation (i.e., from site 1 to site 5) and the dominance of non-halophytes increased. Species appearing with a high constancy in the reclaimed dredging sites were *Phragmites communis*, *Imperata cylindrica* var. *koeniggii*, *Vicia terasperma*, and *Celastrus orbiculatus*, and those appearing with high constancy in the salt marsh vicinity were *Pinus thunbergii* and *Celtis sinensis*. Cluster analysis and CCA of the sampling sites using floristic and environmental data clearly showed the differences in the vegetation in the reclaimed area, and showed that the dominant and the differential species in each site in the reclaimed dredging area were affected by soil variables such as electrical conductivity, sodium adsorption ratio and salt content. The density of halophytes tended to decline with increasing soil organic matter, clay and silt contents and elevation, and with decreasing soil EC, SAR, and salinity. The plant communities in the reclaimed dredging area examined in this study were affected by site grading and the local water circulation system. Hence, the conventional method of restoration, artificially plantation with trees on sites covered with mountain soil, should be revised to develop a more site-appropriate ecological restoration method that considers the ecological features of plants already present in the study area. Ecological restoration to create natural plant communities and increase biodiversity would improve the landscaping in reclaimed areas. The creation of wetlands and water channels in the reclaimed dredging area would enhance biodiversity and provide water purification services. We recommend the establishment of a seaside ecological park in the Gwangyang Bay.

LITERATURE CITED

Ajimal KM, Aziz S. 1998. Some aspects of salinity, plant density and nutrient effects on *Cressa cretica* L. J Plant Nut 21: 769-784.

Allen SE, Grimshaw HM, Rowland AP. 1986. Chemical analysis. In Method in Plant Ecology (Moore PD, Chapman SB, eds). Blackwell Sci Publ, Oxford, pp 285-344.

Barbour HG. 1970. Is any angiosperm an obligate halophyte? Am Mid Nat 84: 106-119.

Bertness MD, Gough L, Shumway SW. 1992. Salt tolerance and distribution of fugitive salt marsh plants. Ecology 73: 1842-1851.

Bouma T, Bas J, Koutstaal P, Van Dongen M, Nielsen KL. 2001. Coping with low nutrient availability and inundation: root growth responses of three halophytic grass species from different elevations along a flooding gradient. Oecologia 126: 474-481.

Chapman VJ. 1977. Wet coastal ecosystems; ecosystems of the world. BUMBA Vol (1), Amsterdam.

Christopher C, Broome S, Campbell C. 2002. Fifteen years of vegetation and soil development after brackish-water marsh creation. Rest Ecol 10: 248-258.

Choung YS, Kim JH. 1991. Studies on the population biology of some clonal plants in a coastal reclaimed land. I. Rhizome architecture, patch formation and growth of *Calamagrostis epigeios* plants. Korean J Ecol 14: 327-343.

Connell JH, Slatyer RO. 1977. Mechanisms of succession in natural communities and their role in community stability and organization. Am Nat 111: 1119-1144.

Greenway H, Munns R. 1980. Mechanisms of salt tolerance in non-halophytes. Ann Rev Plant Physiol 31: 149-190.

Hong SW, Hah YC, Choi YK. 1970. Ecological studies of the certain halophyte on the high saline soil. Korean J Bot 13: 25-32.

Kwak YS, Hur YK, Song JH, Hwangbo JK. 2004. Quantification of atmospheric purification capacity by forestation impact assessment of Gwangyang steel works. J RIST 18: 334-340.

Lee SK, Goh KC, Yee SO. 1996. Natural regeneration of vegetation as an alternative for greening sand filled reclaimed land in Singapore. Land Degrad Develop 8: 59-70.

Min BM. 1985. Changes of soil and vegetation in coastal reclaimed lands, west coast of Korea. Ph.D. Thesis. Seoul Natl Univ, Seoul.

Min BM, Kim JH. 1999a. Plant community structure in reclaimed land on the west coast of Korea. J Plant Biol 42: 287-293.

Min BM, Kim JH. 1999b. Plant distribution in relation to soil properties of reclaimed lands on the west coast of Korea. J Plant Biol 42: 279-286.

Min BM, Kim JH, Kimura M, Kikuchi E, Suzuki K, Takeda S, Kurihara Y. 1989. Soil and plant community of reclaimed lands on the west coast of Korea. Ecol Rev 21: 245-257.

Muller-Dombois D, Ellenberg H. 1974, Aims and Methods of Vegetation Ecology. Wiley international edition, New York.

Nam W, Kwak YS, Jeong IH, Lee DB, Lee SS. 2008a. Plant distributions and physicochemical characteristics of topsoil on the reclaimed dredging area. J Korean Inst Landscape Architec 36: 52-62.

Nam W, Kwak YS, Jeong IH, Lee DB, Lee SS. 2008b. Physicochemical properties of depth-based soil on the reclaimed dredging area. J Korean Env Reveg Tech 11: 60-71.

Orloci L. 1978. Multi-variate Analysis in Vegetation Research. 2nd Ed. W- Junk, The Hague.

Pennings SC, Callaway RM. 1992. Salt marsh plant zonation: the relative importance of competition and physical factors. Ecology 73: 681-690.

Richard C, Chmura GL. 2000. Dynamic of above- and belowground organic matter in a high latitude macrotidal saltmarsh. Marine Ecol 204: 101-110.

Sally T, Zedler, JB. 2000. Site conditions, not parental phenotype, determine the height of *Spartina foliosa*. Estuaries 23: 572-582.

Seliskar DM, Gallagher JL, Burdick DM, Mutz LA. 2002. The regulation of ecosystem function by ecotypic variation in the dominant plant: a *Spartina alterniflora* salt marsh case study. J Ecol 90: 1-11.

Silvestri S, Andrea D, Marco M. 2005. Tidal regime, salinity and salt marsh plant zonation. Estuar Coast Shelf Sci 62: 119-130.

(Received April 6, 2009; Accepted May 6, 2009)