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Studies on Plant Succession of Sand Bars at the Nagdong River Estuary

I. Vegetation and Soil Environment

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洛東江 河口 砂洲植生의 遷移에 관한 硏究

I. 植生과 土壤環境

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ABSTRACT

Plant succession and subsequent changes of soil properties were studied in sand bars at the Nagdong River estuary in Korea. By old maps, ages of sand bars such as Namusitdeung, Galmaegideung, Baeghapdeung and Ogryudeung were estimated about 10, 15, 25 and 60 years old, respectively. The dominance-diversity curves and plant species diversity indices among the sand bars showed increasing trend of stability from Galmaegideung toward Ogryudeung. The soil acidity, contents of organic matter and total nitrogen of soil increased significantly from Galmaegideung toward Ogryudeung. The order of successional degree among the sand bars on the basis of the number of plant species, the results of vegetation analysis and changes of soil properties almost coincide with the order of age among the sand bars. However, the order of successional degree between Namusitdeung and Galmaegideung was more or less obscured because of cyclic succession driven by allogenic processes.

INTRODUCTION

The initial studies of succession were focused on the changes of structural aspect of community (Cowles, 1899; Cooper, 1939). Since Lindeman (1942) attempted to systematize the succession from the trophic dynamic aspect, many ecologists have studied in point of view of functional aspect of succession such as energy accumulation and transfer among the trophic levels. The energetic concept of succession was elaborated by ecosystem ecologists such as Margalef (1963, 1968), Odum (1962, 1968, 1969) and Whittaker (1975).

They have suggested general trends in community development and the changes of ecological attributes with time elapsed. Especially, Odum (1969) provided a table of 24 trends to be expected in succession. Their synthetic treatment have helped the efforts of subsequent workers examining the empirical and experimental basis of succession theory.

Recently, there are many reports conflicting with Odum's (1969) generalization in point of view of maximum productivity and biomass (Horn, 1974; Major. 1974; Bormann and Likens, 1979) and species diversity and nutrient cyclings (Auclair and Goff, 1971; Peet, 1978; Bormann and Likens, 1979).

Numerous examples of succession can be classified into several categories such as primary succession (Cooper, 1939; Crocker and Major, 1955; Crocker and Dickson, 1956; Tayor, 1956: Olson, 1958; Ishizuka, 1962; Kumler, 1969), secondary succession (Keever, 1950; Roux and Warren, 1963; Lee *et al.*, 1979; Peet and Christensen, 1980; Aweto, 1981a, 1981b; Kang and Lee, 1982) and successional hypothesis (Vitousek and Reiners, 1975; Valk, 1981).

Many workers have studied on successional stages of sand dune vegetation in relation to the development of the soil (Crocker and Dickson, 1956; Olson, 1958; Willis *et al.*, 1959; Ishizuka, 1962; Ranwell, 1960, 1972; Kumler, 1969; Hewett, 1970).

At the estuary of the Nagdong River, there are several sand bars which were formed by sediment from both the stream and wave action. Because the ages of sand bars are different from one another, they are suitable places to examine the vegetational changes with time and subsequent changes of soil environmental factors. Several reports on these bars are available on the vegetation and soil properties (Oh, 1970; Park and Lee, 1970; Kim *et al.*, 1982), and geomorphological characters (Kwon, 1973; Choi, 1978, 1979). However, there is no work of ecological succession. We, therefore, intend to present with a series of papers on the formation process of vegetation, changes of structure and function of plant communities with time elapsed, and subsequent changes of soil properties.

In the present paper, we report on historical background of the formation processes of the sand bars and soil properties coupled with succession.

STUDY AREA

The Nagdong River, originating from Samcheug-gun, Gangwon Province in Korea, is about 525km long and the stream water flows with a great quantity of particulate matter including soil and sand into the estuary. At the upper part of the Nagdong River estuary, there are several delta such as Ilungdo, Eulsugdo and Myeonghodo which are largely influenced by fluvial process. At the lower part of the estuary, there are sand bars such as Namusitdeung, Galmaegideung, Baeghapdeung, Ogryudeung and Daemadeung which are influenced by wave action (Fig. 1). At the upstream site about 5km apart from Gupo, the Jugrim River, a tributary, branches from the Nagdong River. Because there are Daejeur and Nagsan floodgates at the Jugrim River, most particulate matter in the stream water

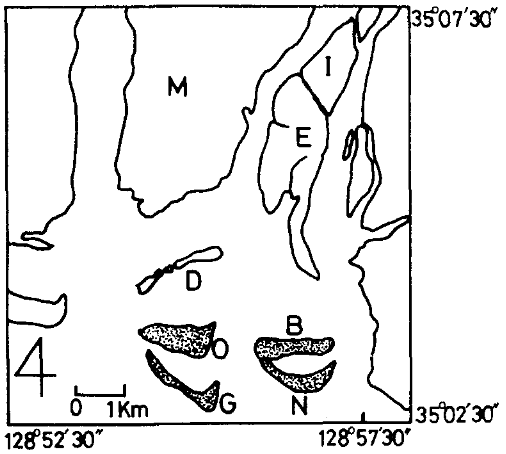

Fig. 1. A map showing the studied sand bars (dotted) at the Nagdong River estuary. I; Ilungdo, E; Eulsugdo, M; Myeonghodo, D; Daemadeung, O; Ogryudeung, B; Baeghapdeung, G; Galmaegideung, N; Namusitdeung.

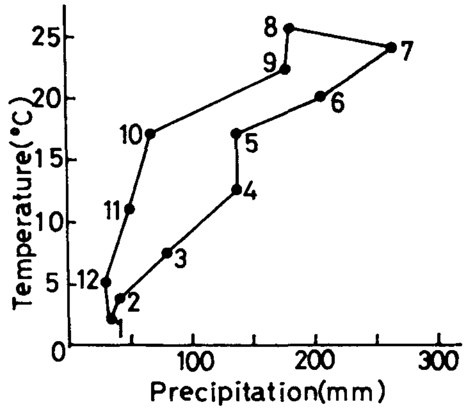

Fig. 2. Hythergraph based on the climatic data of Busan Meteorological Station located in the vicinity of the study area. Temperature is for the period of 78 years (1905~1982) and rainfall is for the period of 52 years (1931~1982).

flows into the Nagdong River estuary as main stream.

The most areas of Myeonghodo, Ilungdo, Eulsugdo and Daemadeung are under cultivation. Namusitdeung, Galmaegideung, Baeghapdeung and Ogryudeung without man's impact were selected for study sites.

The hythergraph of Busan, in the vicinity of study area, is depicted in Figure 2. Annual mean precipitation for period of 78 years from 1905 to 1982 and annual mean temperature for period of 52 years from 1931 to 1982 were 1,418 mm/yr and 14.14C, respectively.

FORMATION PROCESS OF SAND BARS

Atlhough there is no correct record on the ages of sand bars, it could be inferred by old maps collected and a testimony of the residents at Myeonghodo. According to the old map published in 1918 (Fig. 3), Daemadeung was situated at the forefront of the esturine delta and a submerged tidal marsh, assumed as origin of Ogryudeung at present, was being emerged. Ogryudeung, therefore, seemed to be formed since early of 1920s. From 1918 through 1954, there is no available maps of the study area. On the map published in 1956, outline of Ogryudeung appeared clearly even if the shape was quite different from that of the present (Fig. 4-1). As shown in the Figure, it extended slenderly parallel with the coastal line with time advanced. On the map of 1964 Baeghapdeung appeared at the east side of Ogryudeung and at the same time another submerged tidal marsh, assumed as origin of Galmaegideung, was being emerged at the south side of Ogryudeung. On the map of 1977, on one hand, Ogryudeung was divided into two

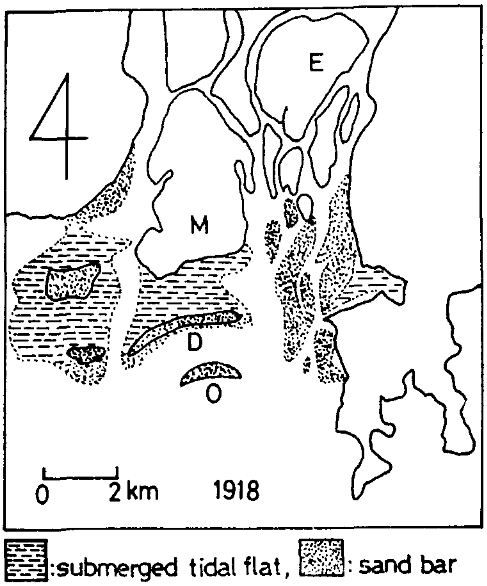

Fig. 3. A map of delta and sand bars at the Nagdong River estuary published in 1918 by the Government-General of Korea. See symbols in legend of Fig. 1.

pieces and the west piece gradually disappeared with time, on the other hand, Namusitdeung began to grow attached to Baeghapdeung in 1970s. Namusitdeung, the most recently formed, was not included in the papers by Oh (1970) and Kwon (1973). From the formation process of sand bars mentioned above, Namusitdeung, Galmaegideung, Baeghapdeung and Ogryudeung were estimated 10, 15, 25 and 60 years old, respectively.

Among these sand bars, Namusitdeung and Galmaegideung occasionally change their overall shape owing to wave action and their vegetation, therefore, is quite poor. As shown in the map of 1980, Galmaegideung was divided into two parts, one was very small size and its vegetation flourished in comparison with the other. Namusitdeung was disconnected from Baeghapdeung in 1980, however, connected with each

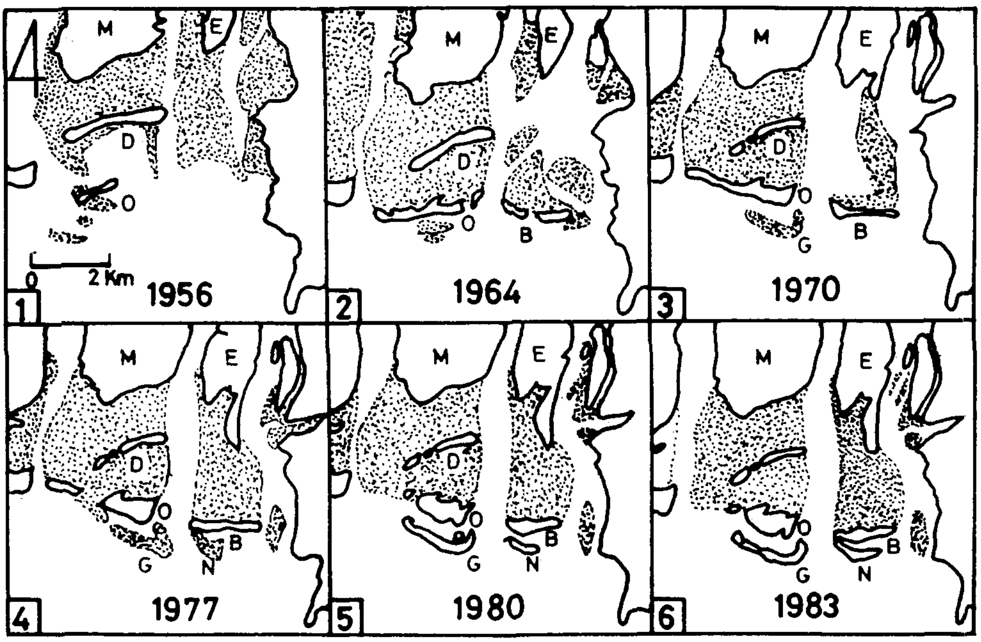

Fig. 4. Maps showing the developmental stages of sand bars at the Nagdong River estuary. Dotted area means submerged tidal flat. See symbols in legend of Fig. 1.

other in 1982. The two parts of Galmaegideung united in 1982. On these unstable sand bars the vegetation was washed away by wave, or burried in sand owing to the windstorm of the previous year. Their vegetation, therefore, became similar with one another.

In 1982, the sand bars were surveyed with a plane table outfit. The areas of Baeghapdeung and Ogryudeung were 304 ha and 615 ha respectively, and most part of them were covered with plants. The areas of Namusitdeung and Galmaegideung were 144 ha and 343 ha, respectively, and only small area of central part of them were covered with plants. The west edge of Ogryudeung was being eroded continuously.

METHODS

Plant and soil samples of each sand bar were collected from 1980 to 1983 by line transect sampling procedure. Sampling sites were set along the line transect across the sand bar from north to southward except for Ogryudeung (Fig. 5). Aboveground samples of plant were collected quantitatively within 200×200mm quadrat to calculate the index of plant species diversity by the method of Pielou (1966). Similarity indices among sand bars were calculated after Søensen (1948) based on a list of plant species surveyed intensively on August from 1981 to 1983 (Mun, 1984).

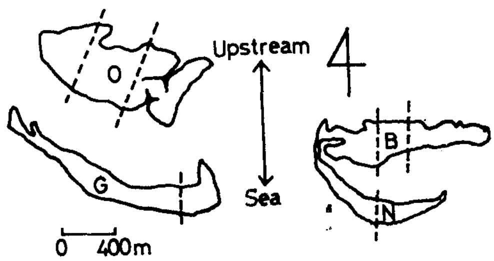

Fig. 5. The line transects (broken lines) showing the main sampling sites at the studied sand bars. See symbols in legend of Fig. 1.

To investigate the nutrients status along the soil depth, soil samples were collected every 20cm interval in each sampling site. Physico-chemical analyses of soil, after dried under the shade, were carried out as follows. Soil texture was determined by Kühn method. Soil pH was measured with a glass electrode pH meter (1 part of soil : 2.5 parts of distilled water) after shaking. for 1 hour. Organic matter content in soil was determined by loss on ignition at 450C for 3 hours. Total nitrogen content in soil was determined by micro-Kjeldahl method. Sodium and potassium were extracted with 2N ammonium acetate solution and measured by flame photometer. Phosphorus was determined after Allen *et al.* (1974) and electrical conductivity was measured by conductivity meter.

RESULTS

Vegetation analysis. From the results of floral surveys for the period from 1981 to 1983, plant species were identified as follows: 9 families and 17 species in Namusitdeung, 8 families and 14 species in Galmaegideung, 25 families and 83 species in Baeghapdeung and 26 families and 88 species in Ogryudeung. The structures of plant communities in Namusitdeung and Galmaegideung were simple in comparison with those of Baeghapdeung and Ogryudeung, and the dominant species of them were *Cynodon dactylon*, *Carex pumila* and *Salsola komarovi* which are typical at sand dune. The dominant species of Baeghapdeung and Ogryudeung were nearly identical. At salt marshes, the pure stands of *Phragmites longivalvis*,, *Carex scabrifolia* and *Zoysia sinica* were developed with distinct zonation, however, mixed plant communities dominated with *Imperata cylindrica* var. *koenigii*, *Calystegia soldanella*, *Lathyrus japonica*, *Carex pumila* and *Cynodon dactylon* were developed at sand dune (Tables 1, 2, 3 and 4).

The dominance-diversity curve for each sand bar at the study area was shown in Fig. 6. The dominance-diversity curve for Galmaegideung is almost a vertical straight line, however, that for Ogryudeung describes parabola as the same of "S" shape. The diversity index of each sand bar based on the Tables 1, 2, 3 and 4 was depicted in Fig. 7. The diversity index of Galmaegideung was the lowest among the sand bars with a value of 0.74 and that of Ogryudeung was the highest with 1.13.

Table 1. Plant community structure of Galmaegideung

Species	Relative frequency	Relative density	Importance value
Carex pumila	35	37	72
Salsola komarovi	20	18	38
Cynodon dactylon	17	19	36
Carex kobomugi	13	12	25
Calystegia soldanella	9	10	19
Phragmites longivalvis	7	5	12
Atriplex gmelini	6	2	8

Table 2. Plant community structure of Namusitdeung

Species	Relative frequency	Relative density	Importance value
Cynodon dactylon	25	22	47
Carex pumila	19	20	39
Salsola komarovi	17	19	36
Phragmites longivalvis	13	13	26
Calystegia soldanella	8	9	17
Sueada maritima	9	7	16
Carex kobomugi	5	7	12
Atriplex gmelini	2	3	5
Messerschmidia sibirica	2	2	4

Table 3. Plant community structure of Baeghapdeung

Species	Relative frequency	Relative density	Importance value
Phragmites longivalvis	18	15	33
Imperata cylindrica var. *koenigii*	14	12	26
Zoysia sinica	6	10	16
Carex scabrifolia	7	8	15
Oenothera odorata	6	8	14
Carex pumila	5	8	13
Cynodon dactylon	5	8	13
Calystegia soldanella	8	4	12
Phacelurus latifolius	6	6	12
Lathyrus japonica	5	5	10
Ixeris repens	3	3	6
Erigeron annuus	3	2	5
Hemarthria sibirica	3	2	5
Salsola komarovi	1	2	3
Calamagrostis epigeios	1	2	3
Miscanthus sacchariflorus	1	2	3
Limonium tetragonum	1	1	2
Carex kobomugi	1	1	2
Artemisia capillaris	1	1	2
Cyperus polystachyos	1	1	2
Aster trifolium	1	1	2
Melandryum firmum	1	1	2
Ixeris dentata	1	1	2
Metaplexis japonica	+	1	1
Sueada maritima	+	1	1
Rumex crispus	+	1	1
Artemisia princeps var. *orientalis*	+	1	1

The similarity and dissimilarity indices between the sand bars were shown in Table 5. Similarity indices between Namusitdeung and Galmaegideung, between Baeghapdeung and Ogryudeung were 90 and 84%, respectively. However, those between Namusitdeung and Ogryudeung, or Baeghapdeung were low with a range of 20～21%.

Physico-chemical properties of soil. The soil texture of each sand bar was shown in Fig. 8. In general, the overall soil textures of Namusitdeung and Galmaegideung were made up with pure sand and salt marshes were not developed in them. The overall soil textures of Baeghapdeung and Ogryudeung also made up largely with sand soil, however, contents of both silt and clay gradually increased from foreshore toward backshore

Table 4. Plant community structure of Ogryudeung

Species	Relative frequency	Relative density	Importance value
Imperata cylindrica var. *koenigii*	17	24	41
Phragmites longivalvis	14	12	26
Zoysia sinica	8	10	18
Carex scabrifolia	3	12	15
Lathyrus japonica	8	4	12
Carex pumila	5	6	11
Calystegia soldanella	6	3	9
Ixeris repens	6	1	7
Cynodon dactylon	3	4	7
Carex kobomugi	4	2	6
Calamagrostis epigeios	3	3	6
Oenothera odorata	4	1	5
Hemarthria sibirica	2	3	5
Limonium tetragonum	2	1	3
Aster trifolium	2	1	3
Erigeron annuus	2	1	3
Cnidium japonicum	1	1	2
Artemisia capillaris	1	2	3
Juncus krameri	1	1	2
Atriplex subcordata	1	1	2
Cyperus polystachyos	1	1	2
Miscanthus sacchariflorus	1	1	2
Setaria glauca	1	1	2
Metaplexis japonica	1	1	2
Equisetum ramosissimum	1	1	2
Ophioglossum vulgatum	+	1	1
Lepidium apetalum	+	+	+
Rumex crispus	+	+	+
Suaeda maritima	+	+	+
Kyllinga brevifolia var. *leiolepis*	+	+	+
Phacelurus latifolius	+	+	+
Digitaria sanguinalis	+	+	+

Table 5. Indices of similarity and dissimilarity among the sand bars

	Ogryudeung	Baeghapdeung	Namusitdeung	Galmaegideung	
Ogryudeung	—	16	80	86	Index of dissimilarity
Baeghapdeung	84	—	79	80	
Namusitdeung	20	21	—	10	
Galmaegideung	14	20	90	—	
	Index of similarity				

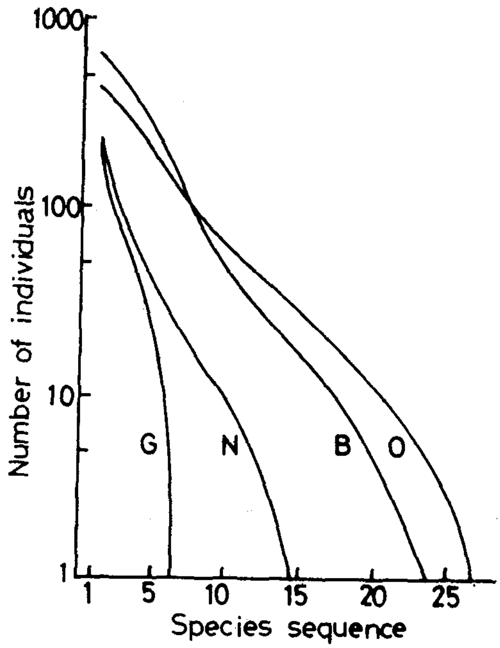

Fig. 6. Dominance-diversity curve of each sand bar at the study area. See symbols in legend of Fig. 1.

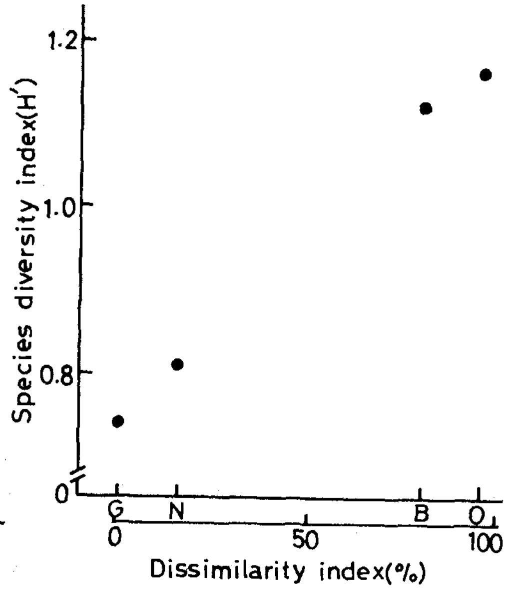

Fig. 7. Species diversity index of each sand bar at the study area. Abscissa is arranged by dissimilarity index of the other sand bars from Galmaegideung(G). See symbols in legend of Fig. 1.

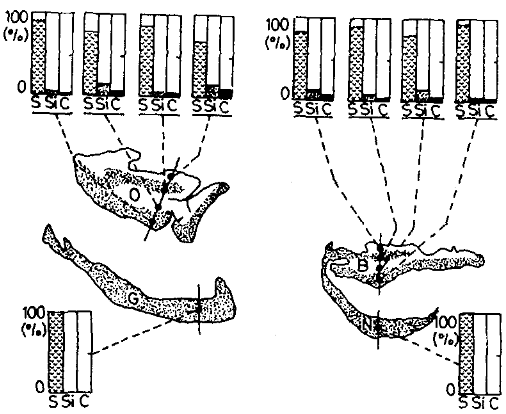

Fig. 8. The soil texture of each sand bar. C; clay, Si; silt, S; sand. See symbols in legend of Fig. 1.

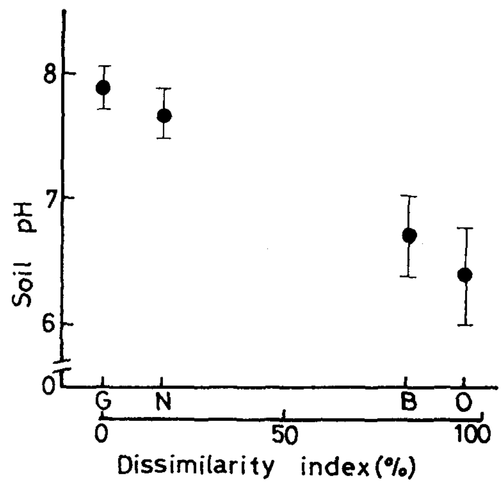

Fig. 9. Soil pH of each sand bar. Abscissa is arranged by dissimilarity index of the other sand bars from Galmaegideung(G). See symbols in legend of Fig. 1.

which developed into salt marshes.

The soil acidity of Namusitdeung and Galmaegideung was low with a range of pH 7.0~8.5, however, increased in Baeghapdeung and Ogryudeung with pH 5.5~7.0 (Fig. 9). Both sodium content and electrical conductivity of soil were closely related with both topographical feature and soil texture (Fig. 10). They were low at the high sand dune with a range of 0.1~0.2mg Na/g and 0.00~0.30 mmho, but high at the low salt marsh with range of 0.9~1.5mg Na/g and 1.50~2.80 mmho, respectively. Contents of organic matter, phosphorus and total nitrogen in Namus itdeung and Galmaegideung were low, but they increased obviously in Baeghapdeung and Ogryudeung (Fig. 11). Potassium content, however, was no consistent tendency among the sand bars.

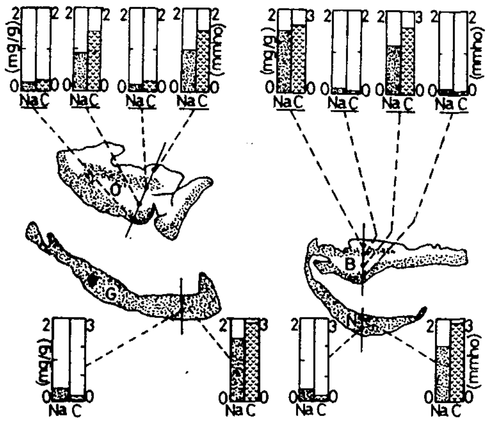

Fig. 10. Sodium content(Na) and electrical conductivity(C) of the soil at the study area. See symbols in legend of Fig. 1.

The changes of chemical properties of soil with soil depth in each sand bar were depicted in Fig. 12. Contents of organic matter and total nitrogen in Namusitdeung and Galmaegideung did not changed significantly with soil depth, however, those in Baeghapdeung and Ogryundeung decreased steeply from top to bottom. The soil acidity also showed decreasing tendency with soil depth.

DISCUSSION

The most conspicuous changes of ecosystem as primary succession proceed from the bare ground are increment of plant species and changes of chemical properties of soil. Foregoing results suggest that the number of plant species grown in Namusitdeung and Galmaegideung, which are in embryo dune phase and unstable condition, is much fewer than those in Baeghapdeung and Ogryundeung which are in grey dune phase and relatively stable condition. As the plant cover spreads on bare sand bar like Namusitdeung and Galmaegideung, the sand bar becomes stabilized and associated with changes in microenvironment as occurred in Baeghapdeung and Ogryudeung (Vasek, 1980). Park and Lee (1970) reported 23 families and 67 plant species in Ogryudeung, and 2 families and 6 plant species in Galmaegideung. So to speak, plant species increased 3 families and 21 species in Ogryudeung, and 6 families and 8 species in Galmaegideung for last 13 years. Kim *et. al.*, (1982), furthermore, collected 10 families and 24 plant species in Namusitdeung, and 8 families and 22 species in Galmaegideung in 1981. In our study, the number of plant species collected in Namusitdeung and Galmaegideung rather decreased in comparison with the report by Kim *et.*

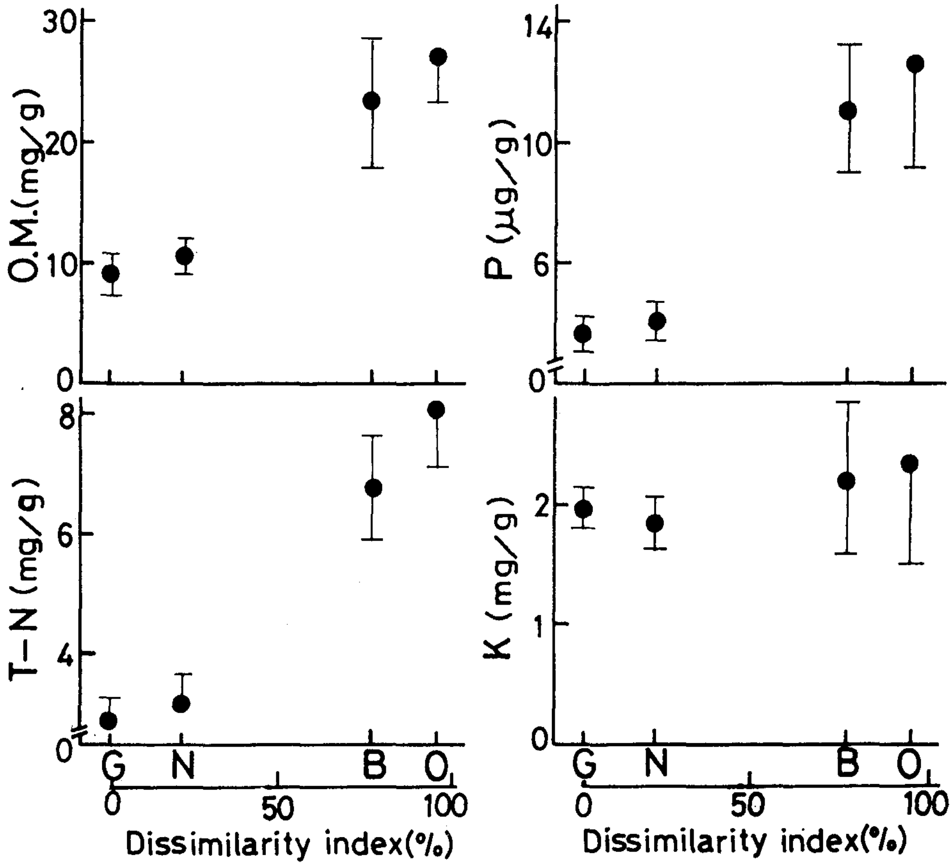

Fig. 11. Contents of organic matter(O.M.), total nitrogen(T-N), phosphorus(P) and potassium(K) of the soil at each sand bar. Abscissa is arranged by dissimilarity index of the other sand bars from Galmaegideung(G). See symbols in legend of Fig. 1.

al., (1982). This is because the most vegetation in Namusitdeung and Galmaegideung were burried in sand, or washed away by windstorm in 1981 and 1982. During the study period from 1980 to 1983, in fact, we could observe surprising changes in overall shape as well as topography in Namusitdeung and Galmaegideung. These allogenic processes force the cyclic succession to occur in them.

The dominance-diversity curves after Whittaker (1965) indicate that the stability of plant communities gradually strengthen in the order from Galmaegideung toward Ogryudeung (Fig. 6). In his hypothetical examples, Whittaker (1965) suggested that natural or anthropogenic stresses tend to steepen the curve. The diversity index of each sand bar attested to harsh environments and unstable plant communities in Namusitdeung and Galmaegideung (Fig. 7). Species diversity index is a considerable significant measure in the study of succession, since it is positively correlated with the stability of various biotic

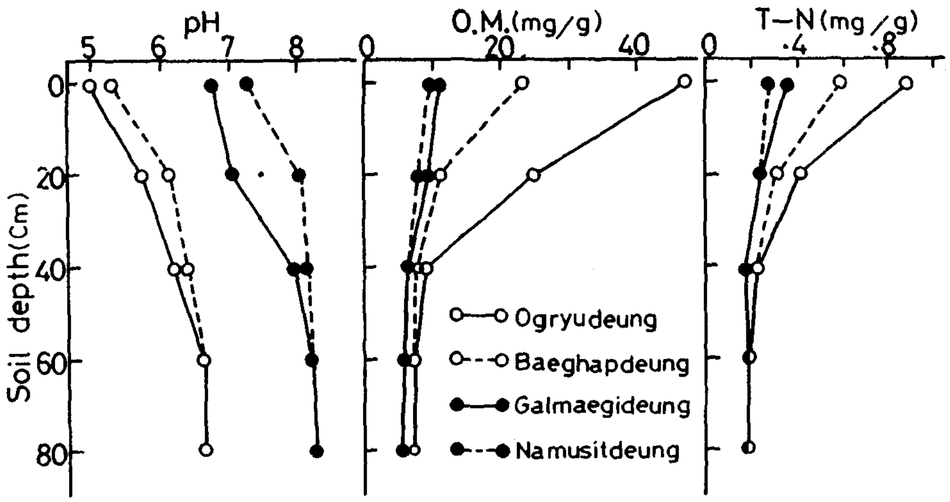

Fig. 12. Changes of soil pH, and contents of organic matter(O.M.) and total nitrogen(T-N) with soil depth.

and abiotic components of ecosystem (Tramer, 1975). Margalef (1968) and Odum (1969) suggested that species diversity index increase rapidly during the early successional stages. As shown in Fig. 7, diversity indices gradually increased from Galmaegideung toward Ogryudeung. Ogryudeung, therefore, should be later stage in a successional sequence than those other sand bars. This fact also coincides with the age of sand bars.

Many workers have studied the changes of soil properties during primary succession (Crocker and Major, 1955; Crocker and Dickson, 1956; Wilson, 1960; Vasek, 1980). The most significant changes of soil properties during the primary succession are increase of soil acidity, and contents of organic matter and total nitrogen. Crocker and Major (1955) and Wilson (1960) reported that the changes of soil acidity and organic matter content were closely related to the vegetational succession. Compared with that in Galmaegideung and Namusitdeung (Fig. 9), the decreasing soil pH in Baeghapdeung and Ogryudeng seems due to addition of humic substances to the soil, removal of NaCl by plant growth, and decreasing frequency of salt spray by seawater. The noticeable increases of contents of organic matter, total nitrogen and phosphorus in the soil in Baeghapdeung and Ogryudeung seem to relate to the reserve of them in the soil *via* litter decomposition.

The contents of organic matter and total nitrogen with soil depth in Baeghapdeung and Ogryudeung changed abruptly from top toward bottom (Fig. 12). This means that the soil profile began to be formed in them. In practical field observation, we could observe dark humus layer developing at some sampling sites in Baeghapdeung and Ogryudeung.

From the facts mentioned above, the overall order of successional degree among the sand bars based on the number of plant species, results of vegetation analysis and changes of soil properties corresponded well with the order of ages of them. That of Namusitdeung and Galmaegideung, however, was more or less obscured because of occurrence of cyclic succession in them.

摘 要

洛東江 河口에 형성되어 있는 砂洲의 植生遷移와 그에 따른 土壤性質의 변화를 조사하였다. 古地圖에 의해서 추정한 砂洲의 형성연령은 옥류등, 백합등, 갈매기등 및 나무싯등이 각각 60년, 25년, 15년 및 10년이었다. 각 砂洲에 生育하는 植物種數는 갈매기등, 나무싯등, 백합등 그리고 옥류등의 順으로 증가하였다. 優占度-多樣性 曲線과 種多樣性 指數에 의하여 판정된 植物群集의 安定性은 갈매기등, 나무싯등, 백합등, 옥류등의 順으로 높아졌다. 土壤의 酸度, 有機物과 全窒素 含量은 갈매기 등에서 옥류등으로 移行함에 따라 현저히 증가하였다. 生育植物의 種數, 植物群集의 安定性 및 土壤性質의 변화등을 근거로한 각 砂洲의 遷移程度는 그들의 나이와 대체로 일치하였으나 갈매기등과 나무싯등 처럼 아직도 모래가 불안정한 砂洲에서는 遷移程度와 砂洲의 나이가 일치하지 않았다.

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