WETLAND CONSERVATION OF RIVERINE WETLANDS IN THE LOWER NAKDONG RIVER, S. KOREA

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Introduction

The Nakdong River estuary (total area, ca. 125.4 km^2) had peculiar and diverse habitats formed by well-developed deltas, tidal marshes, and wetlands. However, losses of wetlands and riparian zones along the lower Nakdong River have accelerated due to rapid industrialization and urbanization since the 1980s. Almost 8 million people in the southeastern Korea depend on the Nakdong River for drinking water and industrial water supplies. Owing to the high demand on water resources, the river has been drastically modified during the last three decades with five multi-purpose dams in the major tributaries. The estuarine dam in the mouth of the river was built to prevent salt-water intrusion into the water intake facility at Mulgeum (27 km from the barrage).

After the construction of the estuary dam in 1987, changes in the structure and function of the estuarine ecosystem have accelerated. In addition, construction of industrial complexes and residential areas continued in the 1990s. Even though there are plenty of scientific reports on the ecosystem components of the estuary, changes in ecological characteristics such as biodiversity and habitat modification have not been systematically evaluated (Joo 1994, Busan Metropolitan City 2000). Recently, public awareness on the need for wetland restoration has been on the rise. In the middle of 1990s, three artificial wetlands were created to compensate for the loss of wetlands due to the development of industrial complexes and residential areas (total area: Noksan, 6.8 km^2; Myeongji, 16 km^2). Furthermore, restoration of agricultural fields on the physically modified Eulsukdo is now proceeding.

The purpose of this paper is 1) to analyze physical alterations of the wetland during the last two decades, 2) to evaluate changes of the physico-chemical and biological characteristics of the wetland, and 3) to provide a restoration plan for the Nakdong River estuary with an emphasis on Eulsukdo.

Study Area and Methods

Site description

The Nakdong River is the 2nd largest river system in Korea. The river, which runs down to the estuary dam, has a drainage area covering 23,817 km^2 and 521.5 km in length (Busan Metropolitan City 2000, Nakdong River Environmental Management Office 2002). The drainage area is situated at 35° 03`-37° 13`N and 127° 29`-129° 18`E (Fig. 1). The estuary, a part of the delta system of the river, consists of numbers of sandy islands, water channels, and mudflats. The reed (*Phragmites communis*) community dominates in the shallow area of the wetland.

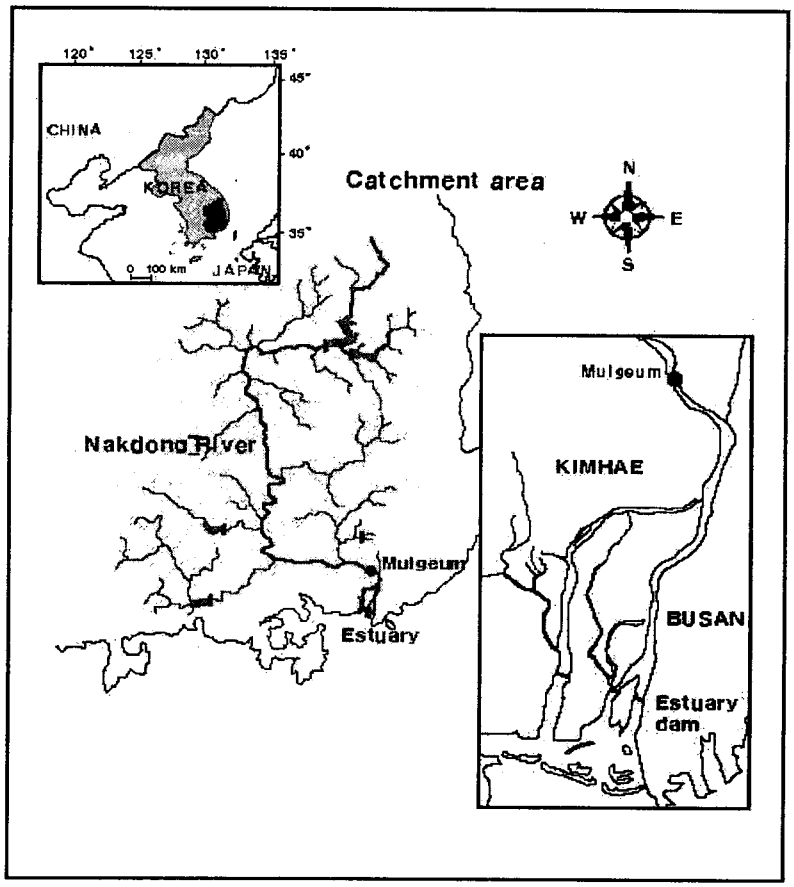

Fig. 1. Map of the basin of the Nakdong River and the estuary.

Data collection for the analysis

When analyzing the physical changes of the wetland in the Nakdong River estuary region, we examined various sources of information gathered

around the Nakdong River estuary Dam. Data on changes of land-use, water quality and changes of flora and fauna were collected from the publications of the Ministry of Environment, Korea Water Resources Cooperation and Busan Metropolitan City and scientific journals report and dissertations during the last three decades (Joo 1994). Long-term changes in water quality and biological components around the estuarine dam are from Joo *et al.* (1997), Ha *et al.* (1998), Kim *et al.* (1998), Ha *et al.* (1999), Kim *et al.* (2000), Kim *et al.* (2001) and Lee *et al.* (2000)

Results and discussion

Current status

Biodiversity Even though the ecologically sensitive area of estuary has declined dramatically during the last several decades, this wetland still maintains a high biodiversity. From the analysis of collected data, flora was a total of 397 species of 68 families, 225 genuses. Fauna was 236 species (mammals, 7 families 10 species; birds, 25 families 93 species; fishes, 37 families 72 species; benthos, 61 species). In particular, the estuary was an internationally important wetland, serving as a wintering ground and stopover site for birds in the East Asian-Australian flyway (Lee *et al.* 2000). Due to the construction of the barrage in the estuary, a large brackish zone has been lost. In addition, eutrophication of the freshwater zone of the estuary and loss of wetlands below the barrage caused a loss of biodiversity.

Protected area During the past three decades, the importance of the estuarine ecosystem of Nakdong River was well recognized by the various sectors of the government. In July of 1966, the Ministry of Culture and Tourism designated the estuary a Natural Monument (No. 179) Area (total area, 109.3 km^2). Currently, the Nakdong River estuary is one of five Natural Ecosystem Conservation Area (34.2 km^2) designated by the Ministry of Environment (1989). In addition to these two legal protections, the wetland was designated as the Coastal Pollution Management Area (129 km^2, 1982), Natural Environment Conservation Area (52.7 km^2, 1988) and Wetland Conservation Area (34.2 km^2, 1999). The legal protection status and area of the designated region are summarized in Table 1 and Fig. 2. Problems associated with the management of the estuary and responsible organizations are listed in Table 2.

Law enforcement and management plans for the designated area were poorly implemented. Therefore, illegal fishing activity and agricultural practice by

the local residents are widespread. The sustainability of harvesting natural resources should be evaluated.

Table 1. Legal protection status of the Nakdong River estuary

Name of Protected Area	Date of Designation	Area (Km^2)	Ministry
Natural Monument Area	1966. 7. 13.	109.3	Ministry of Culture and Tourism
Coastal Pollution Management Area	1982. 10. 21.	129.0	Ministry of Maritime Affairs and Fisheries
Natural Environment Conservation Area	1988. 12. 31.	52.7	Ministry of Construction and Transportation
Natural Ecosystem Conservation Area	1989. 3. 30.	34.2	Ministry of Environment
Wetland Conservation Area	1999. 8. 8.	34.2	Ministry of Environment

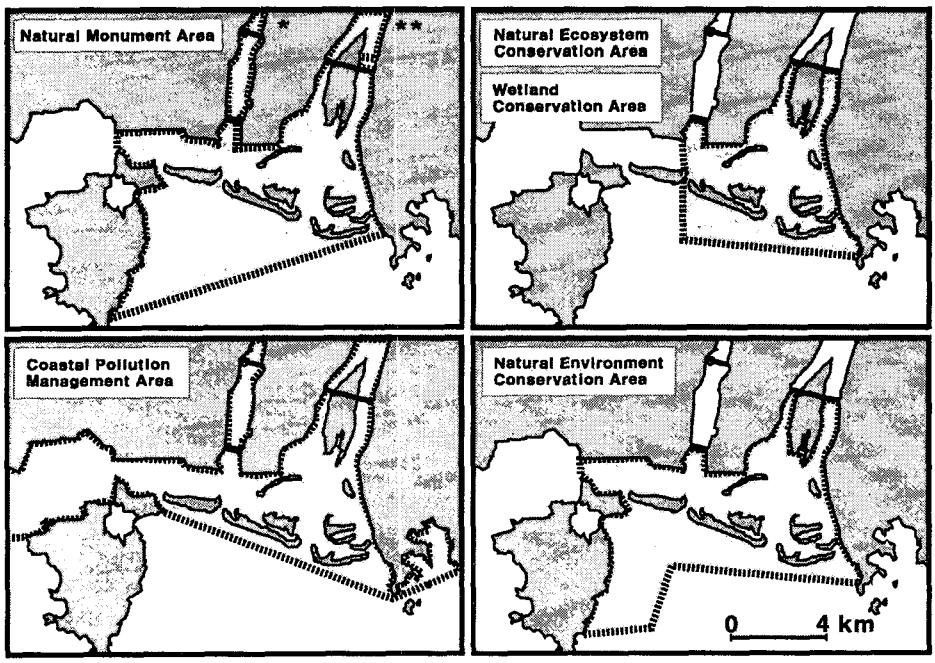

Fig. 2. Designations of a part of the Nakdong River estuary as a protected area (*, up to Bulamgyo (Bridge); **, up to 2nd Nakdonggyo (Bridge)).

Table 2. Responsible organizations for the management of the estuary and designated protected area and management needs

Problems	Responsible organizations	Remarks
Needs of the long-term management plan	Ministry of Environment (ME), Ministry of Maritime Affairs and Fisheries (MMAF), Ministry of Culture and Tourism(MCT), Busan Metropolitan City (BMC)	Ecosystem Monitoring Plan (2001, BMC)
Law enforcement for illegal fishery	BMC, MCT, ME	evaluation of sustainable fisheries
Lack of balance between conservation and development	BMC, MCT	shrinkage of designated area due to the development of industrial complex and residential areas in 1990's
Construction of poorly designed artificial wetlands	BMC, MCT	ecological monitoring of the restored habitat
Lack of support from the local and central government	BMC, MCT, ME, MMAF	physical facility (management and research), research funds (evaluation of ecosystem function and structure)

Physical alterations of the estuarine wetland The lower part of the estuary consisted of barrier sandy islands and tidal flats. Behind these barrier islands, extensive mudflats existed in the center of the wetland. Until the 1980s, the ecological integrity of the estuary was well maintained. Due to land reclamation for the Jangnim and Noksan Industrial Complexes and Myeongji Residential Area, a large land-water interface has been lost during the last 10 years (ca. 16 km^2; Fig. 3 and 4). The loss of these shallow, sensitive areas caused a decrease in the biodiversity and a reduction of migratory bird populations in the wetland.

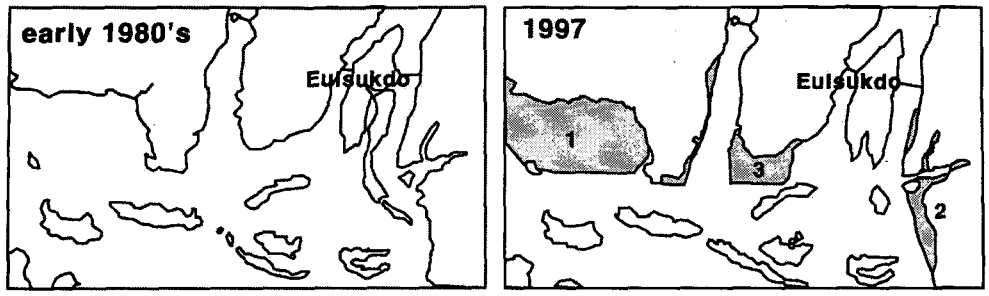

Fig. 3. Physical changes to the Nakdong River estuary (1 and 2, industrial complexes; 3, residential area).

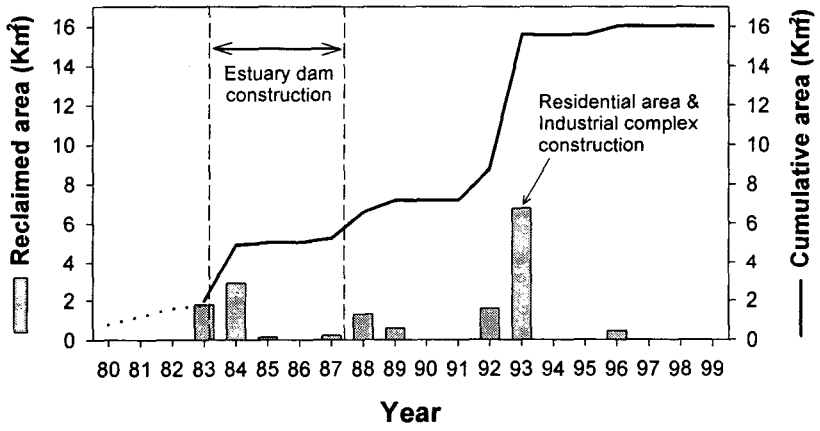

Fig. 4. Cumulative loss of wetland areas from 1983 to 1999 in the Nakdong River estuary (unit: km^2).

Changes in physico-chemical and biological characteristics

Changes of water quality and phytoplankton Physico-chemical characteristics have drastically changed after the construction of estuarine dam. The water body became stagnant in upper 40-50 km from the dam. Except during flooding, freshwater input into the estuary is minimal (about 2 to 3 months a year). Losses of a brackish zone and changes in hydrology caused by constant water intake along the lower part of Nakdong River have caused an excessive growth of phytoplankton and changes in the plankton community structure. The water body above the estuarine dam showed to

be hypertrophic in almost all basic water quality parameters. In particular, a several fold increase in phytoplankton biomass (chl. *a*) and nutrients were observed in the freshwater zone (Table 3 and Fig. 5)(Kim *et al.* 1998, Lee and Kwon 1992). There were dramatic changes in plankton species and community composition after the construction of the estuarine dam. Prolonged retention time caused by a low discharge and high nutrient loading induced algal bloom events in upper part of the dam since 1992: a *Stephanodiscus* (diatom) bloom in winter and a *Microsystis* (blue-green algae) bloom in summer (Ha *et al.* 1998).

Table 3. Changes of nutrient concentration in the freshwater zone of the Nakdonggang estuary during the last two decades (Kim *et al.*, 1998)

	1980's	1990's
NO_3-N (mg/l)	0.9	2.5
NH_4-N (mg/l)	0.6	1
PO_4-P (μg/l)	40	200
Chl. *a* (μg/l)	33	62

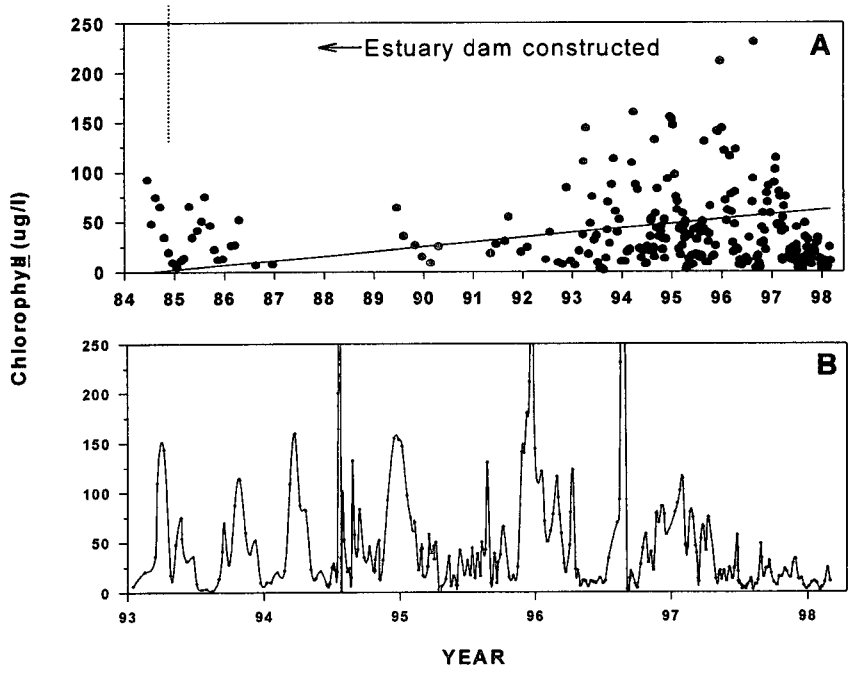

Fig. 5. Changes in phytoplankton biomass (chl. *a* concentration) in the freshwater zone of the Nakdong River estuary from 1984 to 1998 (a) and from 1993 to 1998 (b) (Joo *et al.* 1997).

Changes of fauna After the construction of the estuarine dam, brackish areas were divided into saltwater and freshwater habitats. Thus, many of the organisms adapted to the brackish zones in the wetland were decreased. In the early 1980s, marine and freshwater invertebrates have co-inhabited in the estuary. However, after the completion of the dam in 1987, the loss of brackish areas in the lower part of the dam has resulted in a significant decline of *Cobicula japonica*. Overall, it is thought that the construction of the estuary dam has caused the disappearance of many brackish species by the extreme division of the habitat to saltwater and freshwater zones. During the last decade, sharp decreases in bird communities were also observed (Table 4 and Fig. 6).

Table 4. Total bird species numbers and individuals in the Nakdong River estuary (Lee and Joo unpublished data, n=40)

Year	Number of species	Observed individuals
'68-'80	180	-
'81-'85	158	60,798
'86-'90	140	83,970
'91-'95	144	24,767
'96-'00	104	17,194

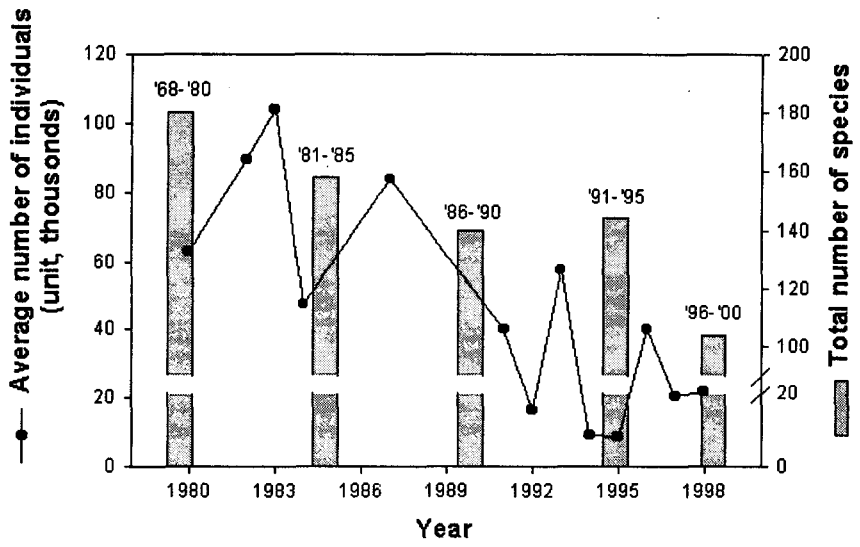

Fig. 6. Total number of bird species and individuals in the Nakdong River estuary (Lee and Joo unpublished data, n=40).

Restoration of the estuary

Phase 1: Construction of three artificial wetlands in the mid 1990s
Three artificial wetlands (South Eulsukdo, Daemadeung, and Shinho-dong) were constructed in the mid 1990s in order to compensate for the loss of wetlands caused by the reclamation of industrial complexes and residential areas (Fig. 7). The plan for the construction of the wetlands was to increase wetland area and to convert agricultural fields into wetlands. However, several problems associated with these wetlands have been identified. Because of the simple morphometry of the South Eulsukdo and Daemadeung wetlands, the interface between land and water is very narrow. In the case of the South Eulsukdo, a bird observation tower (height 14.8m) has not been utilized. Much of the original Shinho-dong wetland was a mudflat. During construction, an artificial dike was created in order to protect the wetland from the tidal movements. Overall, creation of the Shinho-dong wetland was not necessary and it was a result of the misguided practice of a "No Net Loss Concept". Even though three wetlands were constructed 6 years ago with a substantial budget (total cost of construction: about 12 billion won), ecological monitoring of these newly created habitats has not been conducted yet (Table 5).

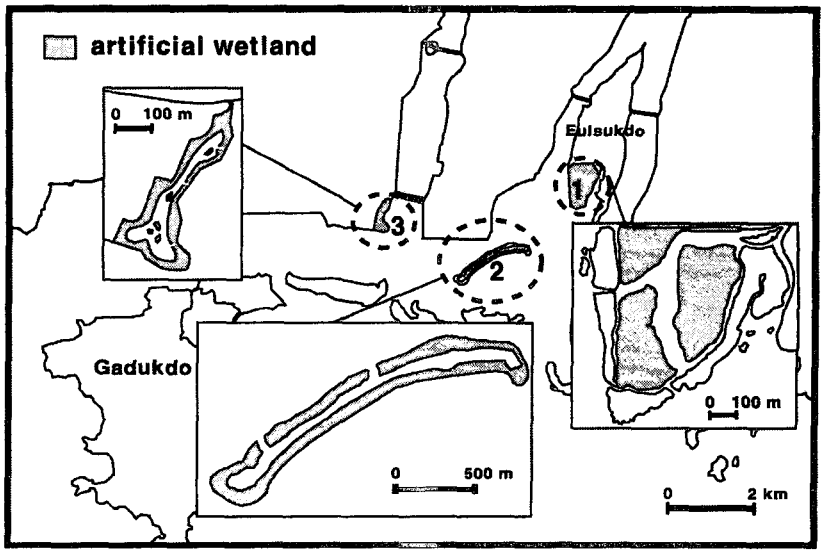

Fig. 7. Three artificial wetlands constructed in Nakdong River estuary (1, South Eulsukdo; 2, Daemadeung; 3, Sinho-dong).

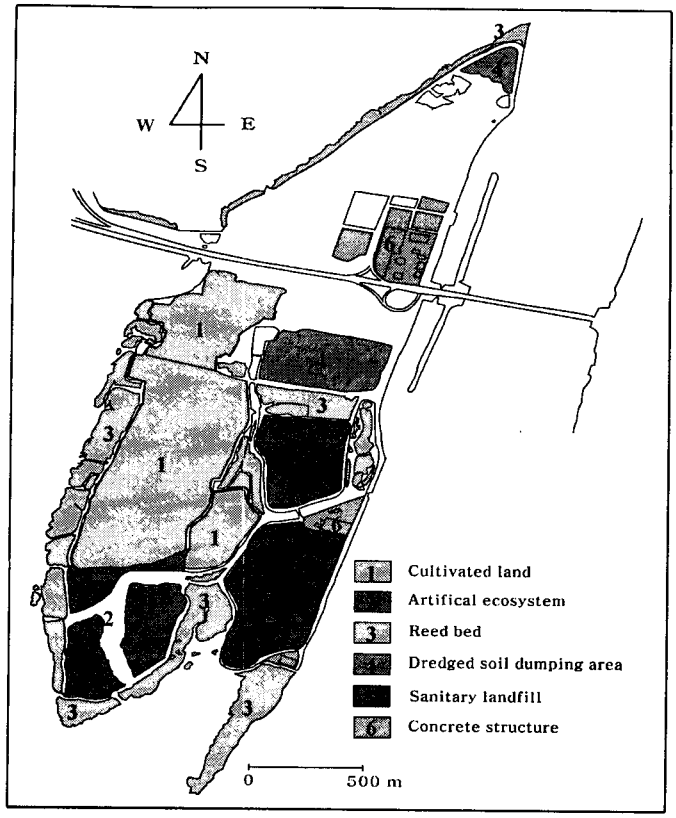

Fig. 8. Present land-use of the Eulsukdo.

Table 5. Previous land-use and present problems of three artificial wetlands

Name of wetland	Previous land-use	Present problems
South Eulsukdo	Agricultural practice	Uniform channel morphology Unutilized bird watching tower Lack of interface between land and water
Daemadeung	Agricultural practice	Uniform channel morphology Lack of interface between land and water
Shinho-dong	Mudflats	Uniform channel morphology Lack of interface between land and water

Phase 2: Restoration plans of Eulsukdo The basic concept for the

restoration of the Eulsukdo was prepared by the Busan Metropolitan City in 2001. This plan was developed with an emphasis on converting illegally cultivated area into a fully functioning wetland. During and after the construction of the estuarine barrage in 1983 to 1987, Eulsukdo has been physically modified. Only 7% of the reed belt on the island remains relatively intact. The dredging of the nearby river channel impacted most of the land area in the island. Completion of the restoration project is expected in 2005.

The objectives of this plan were 1) to enhance biodiversity through restoration of the habitats, 2) to convert illegally cultivated areas into estuarine wetlands, 3) to enhance public awareness of the conservation of the estuarine wetland (with the construction of an educational center), 4) to provide educational and recreational opportunities for the community, and 5) to improve and establish a management strategy for the Nakdong River estuarine wetland. The restoration plan was prepared according to the following principles. 1) Maximum use of natural topography and re-creation of the original habitat, 2) planning of a natural ecological design to exclude artificial design, 3) minimization of artificial buildings and use of natural materials, 4) creation of ecological space within the parameters of the estuarine ecosystem, 5) zones for restoration areas (utilization and education zones, buffer and limited education zones, and core and conservation zones) and core zones having a sufficient buffer area, 6) construction of an ecological area with economically independent control and management.

Currently, Eulsukdo is utilized for agriculture, a sanitary landfill, a park, an area for dredged materials, and an artificial wetland (Fig. 8). The remaining natural habitat is a reed bed area along the shoreline and water channels. The restoration is focused on the construction of wetlands in the illegally cultivated land and dumping area for dredged materials. The publicis allowed to enter the limited area of the island only for bird watching. We have separated the lower part of the island into three zones: A (Utilization and education), B (Buffer and limited education), and C (Core and conservation) zones (Fig. 8 and 9). Zone A is a public access zone for the utilization and education of tourists and citizens. Thus zone A includes facilities for eco-tourism and education. A visitor center with research facility will be located in this area. Zone B was set as a buffer for zone C.

After restoration of the wetland, the expected outcomes and benefits will be as follows: 1) change of land-use; illegal cropland to wetland ecosystem, 2) enhancement of biodiversity and public awareness, 3) increasing possibility of wetland education and management, and 4) establishment of integrated management plan for the Nakdong River estuary. Since the island is located in the heart of the wetland, the visitor center and restored

habitat will be a focal point in the wetland. Recently, Busan Metropolitan City announced a local city ordinance for the protection of the estuary. In addition, there is active NGO participation for surveys, eco-tourism and education of the wetland ecology. However, this plan poses several challenges: construction of a bridge across the lower part of Eulsukdo near the well preserved tidal flat and lack of experience in the restoration of the estuarine ecosystem. In order to maximize the benefits of newly restored habitats, various areas of expertise (wetland ecology, hydrology, restoration engineering etc.) are highly needed in the design and construction phase.

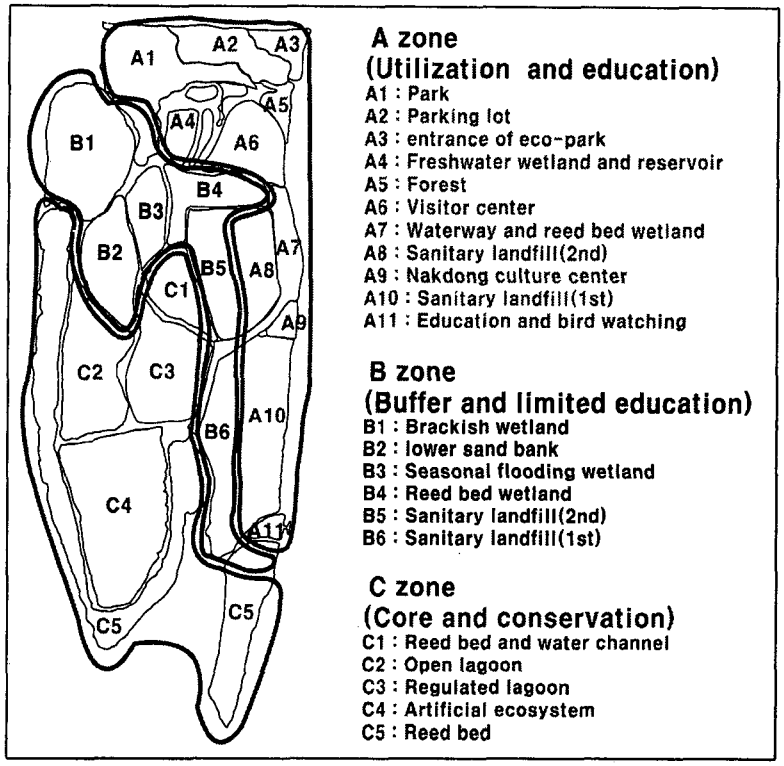

Fig. 9. Three zones after restoration (tentative).

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