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Changes in Fish Assemblages after Dike Construction in the Saemangeum Area

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Abstract – In the Saemangeum area, construction of a dike began in 1991 and was completed in 2006; desalination is currently being conducted. In order to investigate the influence of dike construction on fish assemblages, we analyzed the changes in fish assemblages using fish monitoring data accumulated before, during, and after construction of the Saemangeum Dike. Analysis of changes in the salinity of the Saemangeum Reservoir between 1997 and 2014 revealed that the overall salinity decreased, and this pattern became evident after completion of the dike. Long-term changes in fish assemblages were also confirmed in freshwater areas (Mankyeong and Dongjin Rivers) and the Saemangeum Reservoir. In freshwater areas, different fish assemblages were collected before and after dike construction according to NMDS analysis, and the proportion of freshwater fish continuously increased during analysis of ecological types. In the Saemangeum Reservoir, differences in fish assemblages were observed before, during, and after dike construction (PERMANOVA, $F = 2.5325$, $P = 0.017$). Moreover, the numbers of families and species decreased during dike construction; in terms of species composition, the proportion of brackish water fish increased, while that of marine fish decreased. Currently, a salinity gradient exists in the Saemangeum area between the rivers and the dike, and the M1-3 and D1-3 sites were classified as freshwater sites. Desalination is expected to increase freshwater areas in the future; as the change will happen over a very long period of time, differentiated management plans for each site of the Saemangeum area should be implemented through continuous monitoring.

Keywords – dike construction, ecological type, fish assemblage, salinity, Seamangeum Reservoir

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1. Introduction

Fish are influenced by various environmental variables and habitat characteristics (Buisson et al. 2007; Kouamélan et al. 2003; Matthews et al. 1992). Aquatic ecosystems are continuously changing because of global developments, and such changes alter the habitat environments of aquatic organisms, ultimately leading to changes in the aquatic organisms (Lucas and Baras 2001). Freshwater fish, which occupy a high trophic level in the aquatic ecosystem (Diana 1995), are directly and indirectly influenced by such conditions. In particular, the construction of instream structures, such as dams, weirs, or estuary barrages, not only influences the habitat environments of fish but also affects the movement of fish and substantially changes local fish assemblages (Barry 1990; Mallen-Cooper and Harris 1990).

Various physicochemical environmental factors, such as biological oxygen, biology oxygen demand, and salinity, influence the physiological characteristics of fish, such as spawning and oocyte maturation and the distribution and habitat selection of fish, along with physical factors (Matthews 2012). In particular, the response of fish to salinity distinguishes marine and freshwater fish and acts as a barrier to prevent each type of fish from trespassing into each other's habitat environments (Lucas and Baras 2001). Although some diadromous and brackish water species can physiologically adapt to wide salinity ranges, freshwater and marine species are completely isolated from each other in terms of their physiologies. Therefore, salinity reflects the fish distribution according to the fish category.

Dikes are embankments constructed along the coast in order to prevent seawater from flowing into the land when the land is lower than the surface of the sea or when the tides are high. Dikes are typically constructed in the Netherlands and Korea, and long-term large-scale developments are conducted after dike construction to secure the land through continuous reclamation projects. The construction of dikes can lead to the accumulation of water and prevention of salt damage. However, it can also cause overall changes in the environment and the organisms inhabiting the environment as the existing ecosystem is completely changed by desalination. Desalinization is conducted in areas that were previously part of the sea by decreasing seawater circulation with dikes. In particular, changes in salinity resulting from desalination greatly influence the overall biological assemblage, including fish assemblages and structures (Meng et al. 1994; Thiel et al. 1995).

The construction of dikes in Korea is concentrated in the West Coast where the tidal range is large and reclamation projects have been active. Large-scale dikes in Korea include Saemangeum Dike, Cheonsuman Dike, Asanman Dike, Seehwa Dike, and Sapgyocheon Dike. Among these, construction of the Saemangeum Dike began in 1991 and was completed in 2006; this dike is the longest in the world (Korea Rural Community Corporation). Dike construction causes substantial environmental changes; however, overall studies on dikes have been limited as dikes are constructed in few locations globally. Although estuary barrages have some characteristics that are similar to dikes, the scale and influence cannot be compared between the two types of instream structures. Therefore, in this study, we investigated long-term changes in fish assemblages caused by dike construction. Although multiple studies were conducted before construction, long-term changes have not been quantitatively analyzed; therefore, we used these previously reported long-term data in this study.

2. Materials and Methods

Study site

The Saemangeum Dike, included in the open sea of the Geum River Estuary, stretches over 33.9 km from Osik Island, Bieung Island, past the Mankyeong River and the Dongjin River to Gun Island of Gogunsan. This dike is 36 m high with a surface area of 40,100 ha, making it the largest dike in the world (Fig. 1a). Its construction began in 1991 and was completed on April 21, 2006. At the time of the construction, two sluices were constructed for the circulation of seawater and the passages of ships, and since then, seawater only passes through the sea dike sluices. Fig. 1b shows the annual process of dike construction. As observed in the photograph taken in 2001, which was taken before the dike was completed, seawater circulated freely at that time. After completion of the dike, desalination, which was intended for internal development plans promoted by the government, was initially conducted by preventing the complete circulation of seawater; however, because the water quality inside the reservoir declined, seawater is now being circulated through the sluices. Plans were developed to improve the water quality of the Saemangeum Reservoir until 2020 through seawater circulation, and complete desalination is planned afterwards. However, because circulation of the seawater is conducted irregularly, salinity levels are maintained at various sites in the reservoir.

Data collection and sampling methods

In order to investigate changes in fish assemblages at the site of dike construction, we analyzed the results of previously conducted studies and analyzed the current conditions. A literature search was conducted separately for freshwater areas (Mankyeong and Dongjin Rivers) and Saemangeum Reservoir. In the M1 and D1 freshwater areas before dike construction, seawater infiltrated into these areas, but these areas now completely contain freshwater. For freshwater areas, we used previously reported data collected at the same sites by Lee (1990), Kim and Lee (1998), NIER (2009). For the reservoir, we used previous data reported by Jeon (1992), Kim and Lee (1993), Ryu and Choi (1993), Sim and Lee (1999), Lee et al. (2003), RRI (2003, 2004, 2005).

Methods of investigation differed according to the studies. In previous studies of freshwater areas, fish were collected using a kick net (5-mm mesh) and cast net (7-mm mesh), while an otter trawl was used in previous studies of Saemangeum Reservoir. The present study was conducted in 2013 and 2014 inside the reservoir (M4–M9, D4–D8) and in the Mankyeong and Dongjin Rivers (M1–M3, D1–D3). The investigation was conducted four times per year in each season, for a total of eight times. In the Mankyeong and Dongjin Rivers, a kick net (5-mm mesh), cast net (7-mm mesh), gill nets (30- and 70-mm mesh; length 50 m), and fyke net (5-mm mesh) were used to collect the fish. Cast nets were used 10 times at each site, and gill nets and fyke nets were set in the

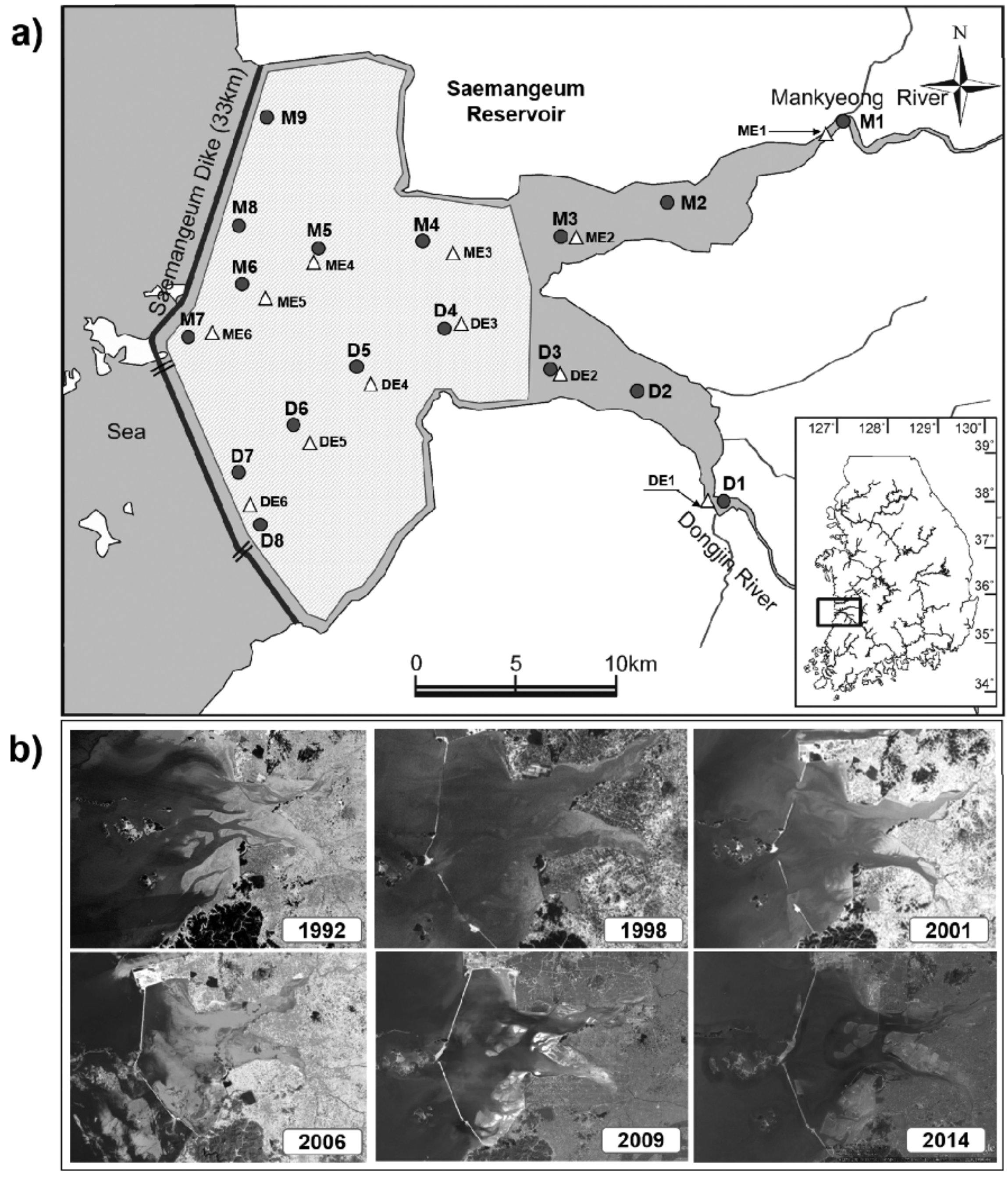

Fig. 1. (a) Map showing the study sites. Circles refer to the sites of fish investigation (17 sites) conducted in 2013–2014 and triangles show sites of salinity measurement (10 sites). The gray-colored area inside the dike is the reservoir area. (b) Yearly changes in the physical environment of Saemangeum area observed using satellite images (Korea Rural Community Corporation). The images show changes between 1992 and 2014 after the beginning of dike construction

afternoon before sunset and then retrieved the next morning after sunrise (approximately 12 h, including two crepuscular periods). Kick nets were used for approximately 20 min in areas with water plants at each site. In sites within the reservoir, an otter trawl was used to collect the fish. Using a fishing boat with an otter trawl (length 20 m; width 8 m, wings mesh 3.5 cm, cod end mesh 1.5 cm), 1-km sections at each site were investigated at a velocity of 2.5 knots for 20 min, and the results were quantified. Collected fish were released immediately after counting and identification.

Environmental factors

Environmental factors (water temperature, total nitrogen [TN], total phosphorus [TP] and salinity) were investigated at twelve sites, including ten sites (ME2–ME6, DE2–DE6) within the reservoir and two sites (ME1 and DE1) in the Mankyeong and Dongjin Rivers. Salinity data were obtained from the Saemangeum Area Integrated Environmental Management System, which is managed by Ministry of Environment (https://www.eariul.go.kr/smg/cont010100/cont010102.do). The data were measured each month; data from the two sites in the rivers have been accumulated since 2007, and we used monthly data measured since 1997 for sites within the reservoir.

Data analysis

The purpose of a dike is to desalinate water in the reservoir; thus, salinity can be considered as the most important factor affecting water environment after the dike construction. Subsequently, we investigated the ecological type changes that are most relevant to salinity in analyzing the fish assemblage variation. Fish were classified into four types (freshwater [primary and secondary], diadromous, brackish water, and marine fish) depending on the ecological type. Classification was conducted based on Kim et al. (2005) and the internet website FishBase (http://www.fishbase.org). In addition, the analysis data for long-term variations were examined by numerous researchers by various means (gears, frequency, time, etc.), which made detailed analysis regarding aspects such as individuals and biomass rather difficult. The analysis was performed based on the presence/absence data of fish species to reduce the error introduced by different methods as much as possible.

Variation in fish assemblages by year and between two rivers and the reservoir were analyzed using nonmetric multidimensional scaling (NMDS). NMDS constructs two-dimensional ordination in a manner that best represents the relationships between samples in a similarity matrix (Field et al. 1982). Similarity matrices were generated by the presence/absence data of fish assemblages and by calculating Bray-Curtis similarity indices for each pairwise assemblage comparison. The robustness of the ordination is indicated by its stress value, ranging from < 0.2 (fair) to < 0.05 (excellent) (Clarke and Warwick 1994). The permutational multivariate analysis of variance (PERMANOVA; Anderson 2001) based on the same similarity matrix was used to detect fish assemblage differences before, during, and after dike construction and between freshwater and downstream areas. NMDS and PERMANOVA were performed using Primer 6 software (Primer-E Ltd. Plymouth, UK).

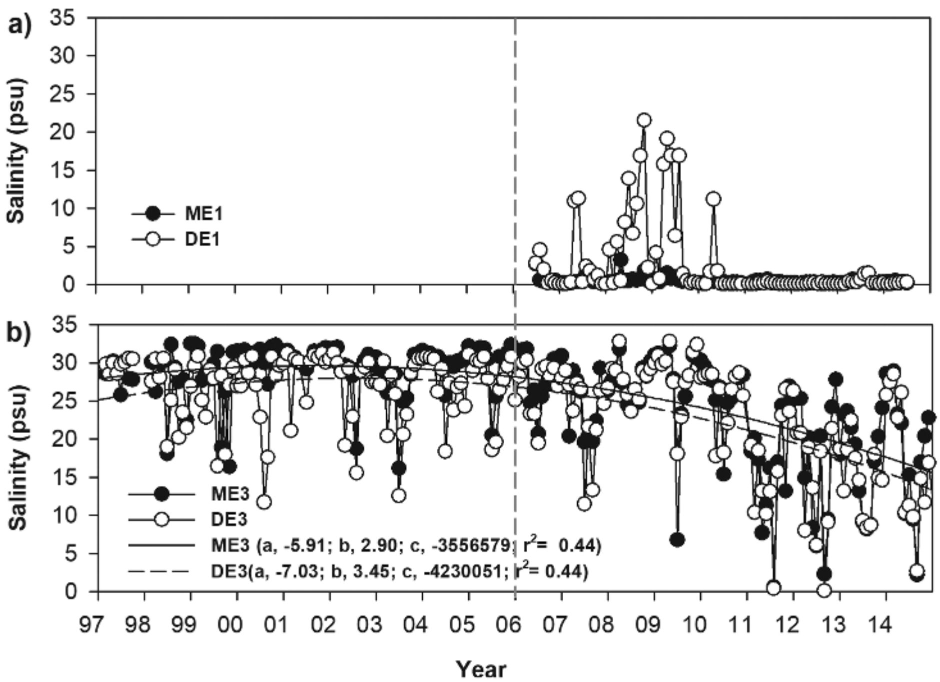

Fig. 2. Patterns of long-term salinity changes in the Mankyeong and Dongjin Rivers (a) and the reservoir (b). Patterns of salinity changes in locations within the reservoir were confirmed by regression analysis ($y = ax^2 + bx + c$). The dotted line indicates the year in which dike construction was completed

3. Results

Changes in environmental factors from 1997 to 2014

Almost no salinity was detected in DE1 and ME1, which were located in the Mankyeong and Dongjin Rivers. Salinity increased temporarily in 2008 and 2009 in both rivers and salinity exceeded 20 psu, particularly at ME1 in the Mankyeong River. However, the measurements stabilized after 2011 and most measurements were 0 psu (Fig. 2a). A decreasing pattern in salinity was observed at sites within the reservoir, and the decrease became evident after dike completion (Fig. 2b). In DE3 and ME3, which were adjacent to the Mankyeong and Dongjin Rivers, the average salinity between 1998 and 2005 was around 26.7–29.3 psu before the dike construction while it decreased significantly after 2006 when the dike was built. In 2014, approximately 8 years after the dike construction, the average salinity was 17.4–19.0 psu which was about a 10 psu reduction.

The Saemangeum Reservoir water temperature was examined from 2008 to 2014. The water temperature varied seasonally but did not increase over the years (Fig. 3a). TN and TP have been surveyed since 2005 and 2002, respectively. The TN mean of DE3 was 1.171 mg/L and that of ME3 was 1.763 mg/L, but the nutrient concentration on the lower Mankyeong River was higher than that of the lower Dongjin River. The mean TP was 0.091 mg/L in ME3, downstream of Mankyeong River, which was higher compared to the 0.071 of DE3. Yearly nutrient variation pattern was not observed, but the nutrients increased in summer along with the water temperature (Fig. 3b, c).

Long-term changes in fish assemblages

Long-term changes were observed in fish assemblages. In M1 and D1 located in the Mankyeong and Dongjin Rivers, fish assemblages changed before and after dike construction. Before dike construction, 42 species of fish in 21 families were observed, and the proportion of freshwater fish was only 38.1%. In contrast, the proportion of marine and

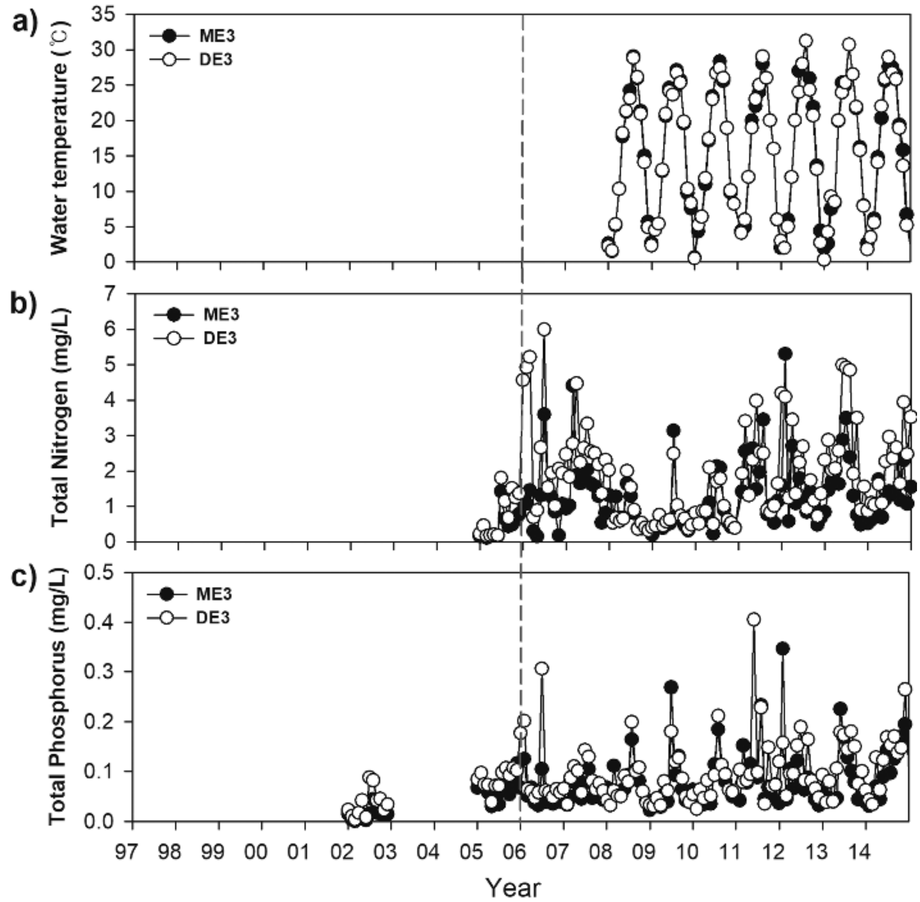

Fig. 3. Patterns of long-term changes of environmental factors (water temperature, total nitrogen and total phosphorus) in the Saemangeum reservoir (ME3, DE3). The dotted line indicates the year in which dike construction was completed

Table 1. Yearly changes in the numbers of families and species observed in freshwater areas (M1 and D1 in Mankyeong and Dongjin Rivers). Changes in the percentage of species classified according to four ecological types

Dike construction		Before	After				
Sampling year		1989–1990	2007	2008	2009	2013	2014
Number of family		21	8	4	9	12	10
Number of species		42	24	19	33	24	32
Ecological types (Species percentage)	Freshwater	38.1	58.3	68.4	57.6	75.0	81.3
	Diadromous	2.4	0.0	0.0	0.0	3.1	3.1
	Brackish water	31.0	41.7	26.3	39.4	21.9	15.6
	Marine	28.6	0.0	5.3	3.0	0.0	0.0

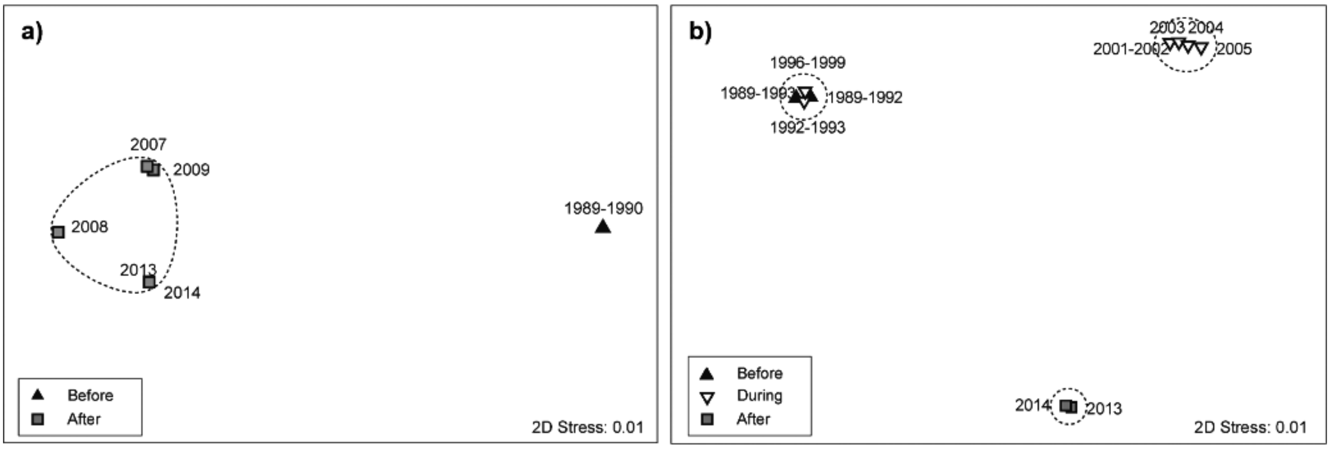

Fig. 4. Non-metric multidimensional scaling of freshwater areas (a) and reservoir (b) based on Bray-Curtis similarities. Sampling years are grouped based on a cluster analysis at a similarity level of 50

brackish water fish, which was higher, reached 59.6%. Such tendencies changed dramatically after dike completion. The number of observed families and species decreased, and marine fish were rarely observed. In contrast, 16 freshwater fish species appeared for the first time and the proportion of freshwater fish increased (Table A1; Table 1). After completion, this trend became more evident over time, and the proportion of freshwater fish exceeded 81% in 2014. Additionally, based on the NMDS results, we confirmed that the collection trends differed before and after dike construction (Fig. 4a).

Fish assemblages in sites within the reservoir were statistically confirmed to change depending on dike construction condition (before, during, and after) (PERMANOVA, $F = 2.5325$, $P = 0.017$). Before construction of the dike and during the early stages of construction, the numbers of observed families and species were 40 and 85, respectively, and marine fish were the major species (Table A2; Table 2). The numbers of observed families and species began to decrease in 2001. Compared to previous data, the numbers of families and species decreased by more than half. However, the proportion of marine fish remained dominant. After completion of the dike, in 2013 and 2014, the number of observed species was

Table 2. Yearly changes in the numbers of families and species observed in Saemangeum Reservoir (M4–M9 and D4–D8 for 2013 and 2014). Changes in the percentage of species classified according to four ecological types were also investigated

Dike construction		Before	During							After	
Sampling year		1989–1992	1989–1993	1992–1993	1996–1999	2001–2002	2003	2004	2005	2013	2014
Number of family		40	49	44	45	26	23	20	14	20	21
Number of species		86	96	89	98	43	39	30	27	34	27
Ecological types (Species percentage)	Freshwater	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.8	0.0
	Diadromous	3.5	1.0	2.2	0.0	2.3	2.6	0.0	0.0	2.9	7.4
	Brackish water	25.6	18.8	20.2	19.4	30.2	23.1	26.7	29.6	47.1	37.0
	Marine	70.9	80.2	77.5	80.6	67.4	74.4	73.3	70.4	41.2	55.6

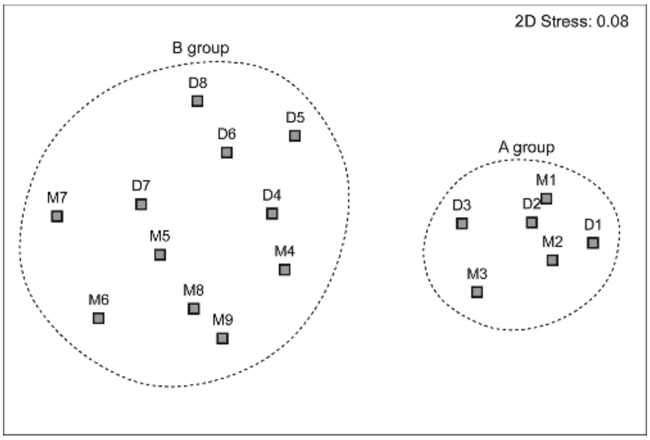

Fig. 5. Non-metric multidimensional scaling of 2013–2014 fish assemblages at each study site based on Bray-Curtis similarities. The sites are classified into two groups based on cluster analysis at a similarity level of 40. A Group includes 6 sites in the Mankyeong and Dongjin Rivers, and B Group includes 11 sites within the reservoir

similar to previous values; however, the proportion of marine fish decreased to approximately 50% and the proportion of brackish water fish increased. In 2013, freshwater fish were also observed. According to the results of NMDS, although the collection of fish species differed depending on the time of investigation, fish assemblages observed during the early stages of construction were similar to those observed before construction (Fig. 4b).

Fish assemblage and salinity distribution in Saemangeum Area in 2013 and 2014

When NMDS was conducted on fish assemblages observed at each site in 2013 and 2014, M1, 2, 3, and D1, 2, and 3 were classified as A Group, and the remaining sites within the reservoir were classified as B Group (Fig. 5). Sites in the Mankyeong and Dongjin Rivers were included in the A Group and the proportion of freshwater fish was high at most sites (Table A2). In sites included in the B Group, the proportion of marine and brackish water fish was high. M1, 2, and 3 are adjacent to ME1 and ME2 among sites where salinity was measured and D1, 2, and 3 are adjacent to DE1 and DE2; the proportion of freshwater fish was found to be high at these sites, as the salinity in these sites was lower than in other areas (Fig. 6).

4. Discussion

Completion of dikes caused two main changes in fish assemblages. First, structures divided and isolated the areas across which fish moved freely in the past; second, seawater circulation was blocked. Although the two sluices constructed in the dike maintained the movement of fish and circulation of seawater, the situation is not the same as in the past, as events that occurred previously across wide areas are now limited to certain areas. In particular, decreased salinity

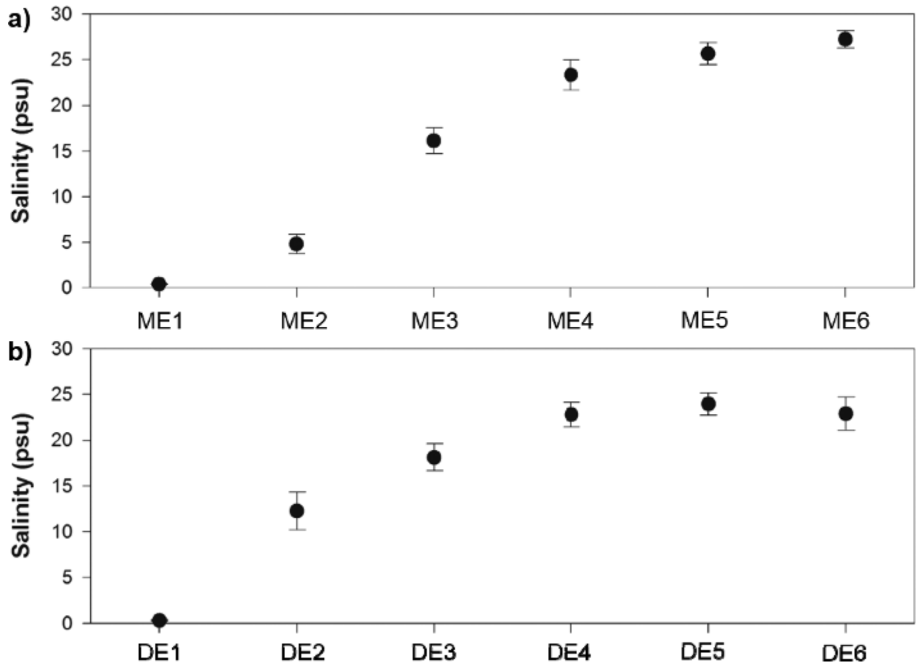

Fig. 6. Salinity gradient in 2013–2014 at each site of Saemangeum area. Linear salinity gradients were observed between the Mankyeong River (a) and Dongjin River (b) and the reservoir

within the reservoir after dike completion caused changes in fish assemblages by limiting the distribution of fish from a physiological perspective.

Long-term changes in fish assemblage caused by the construction of the dike were observed in this study, and the transition in fish assemblages according to the construction was also evident. Until the late 1990s, during the early stages of construction, although structures were being built, they were only partially completed (Fig. 1b). Therefore, the circulation of seawater or movement of fish was not limited and was similar to the pre-construction states. This was supported by the observation that fish assemblages showed no large differences compared to pre-construction fish assemblages until this period (Fig. 4). Subsequently, transitions in fish assemblages were observed with the progression of dike construction (in particular, a decrease in marine fish was evident), and fish assemblages changed again after dike completion. Generally, construction induces environmental changes after the structure is completed. In contrast, in this study, the environmental and physical changes in areas around the sites of investigation occurred simultaneously with construction progress, which was large-scale and extensive, resulting in the first transition in fish assemblages. During the first transition, the overall number of observed species decreased, but changes in the assemblage structure (changes in ecological type) did not occur.

Changes in fish assemblages observed after 2006, or the completion of the dike (second transition), were thought to have been caused by decreased salinity related to construction. The first transition involved a decrease in the overall number of observed species because of the construction, while the second transition resulted from changes in species compositions. After completion of the dike, the circulation of seawater was blocked for desalination purposes, which continuously decreased intra-reservoir salinity (Fig. 2). Decreased salinity led to an increased proportion of freshwater fish among the fish observed in inflow streams by changing the inflow streams to completely freshwater environments, which decreased brackish water fish. In sites within the reservoir (certain levels of salinity were maintained in these sites), the proportion of marine fish, which was previously relatively high, decreased to 50%, and the proportion of brackish water fish that can adapt to wide ranges of salinity increased.

Salinity is highly associated with the distribution of fish (Meng et al. 1994). An overall decrease in salinity resulting from desalination expanded the freshwater fish habitat and caused the retreat of marine and brackish water fish. Expansion of freshwater areas, which is expected to continue, will further expand the freshwater fish habitat (Park et al. 2013; Thiel et al. 1995). As shown in studies from 2013 and 2014, the distribution of freshwater fish expanded with the expansion of freshwater areas. Moreover, although it was temporary, freshwater fish were observed in 2013 in reservoir sites adjacent to the Mankyeong and Dongjin Rivers. In contrast, marine fish are now observed only in certain areas (M6 and 7, D7 and 8) where seawater is circulated. The appearance of marine fish in the reservoir appears to be closely related to the temporary operation of sluices, and marine fish are expected to disappear from the reservoir in the absence of seawater circulation. The appearance of brackish water fish, which can tolerate wide ranges of salinity, was expected to increase with desalination, and the distribution areas of brackish water fish did not decrease substantially. Therefore, brackish water species are not expected to disappear after desalination, however, their appearance is expected to become greatly limited.

Such trends are expected to continue in the future. For marine fish that enter the reservoir through sluices, the Saemangeum area cannot provide suitable habitats, and it is rather a sink habitat where the fish may die under severe conditions. In particular, except areas near sluices with high salinity, environments in other areas are not suitable for marine fish. Therefore, these species should be prevented from entering the reservoir or plans should be implemented to return these species back to the sea, such as through the sluices.

Changes in the biota caused by environmental changes resulting from development or construction have been discussed in multiple studies from various perspectives (Dudgeon 2000; Harding et al. 1998; Poff et al. 2007). However, although the relationship between increases in lentic areas due to construction of dams and changes in fish assemblages was investigated in multiple studies, studies examining the construction of dikes involving both seawater and freshwater have been limited worldwide. Discontinuation of seawater circulation because of dike construction causes environmental changes in the existing ecosystem, and this in turn not only changes the existing biota, but also changes the overall environment (Kim et al. 2011). Various problems, such as the continuous death of fish and clams and eutrophication, occur not only in Saemangeum, which was the site investigated in the present study, but also in other dikes. Although it is not a dike, similar problems were observed in the Chilika Lagoon in India - the overall productivity of the lagoon decreased and eutrophication continuously occurred when seawater circulation was stopped; these problems were resolved after seawater circulation was resumed (Ghosh et al. 2006). Increased seawater circulation would also solve problems in the Saemangeum Dike area; however, it would be difficult to continue seawater circulation, as this would cause problems for future projects, including reclamation projects. Therefore, during the progression of desalination, existing seawater-based management strategies should be changed to freshwater-based strategies. Moreover, as organisms in the reservoir cannot be moved to areas outside Saemangeum at once, desalination should be conducted with stepwise goals.

In this study, we examined areas planned to undergo desalination. Although monitoring was conducted only for changes in fish assemblages, we confirmed the influences of desalination on fish assemblages. Therefore, our results will be a useful reference on desalination, and the results of this study can be used to suggest management strategies to minimize problems associated with environmental changes and enable stable and continuous development by providing long-term data on seawater circulation and desalination.

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Appendix

Table A1. Fish fauna observed in M1 and DI in Mankyeong and Dongjin Rivers in 1989–2014. Fish were classified four Ecological types (Fre, freshwater fish; Dia, diadromous fish, Bra, brackish water fish, Mar, marine fish)

Family	Species	Lee (1990)	NIER (2009)			This study		Ecological types
		1989–1990	2007	2008	2009	2013	2014	
Anguillidae	*Anguilla japonica*	+				+	+	Dia
Congridae	*Conger myriaster*	+						Mar
Engraulidae	*Coilia mystus*	+						Bra
	Coilia nasus	+		+		+	+	Bra
	Engraulis japonicus	+						Mar
	Setipinna tenuifilis	+						Mar
	Thryssa kammalensis	+						Bra
	Thryssa hamiltoni	+		+				Mar
Clupeidae	*Sardinella zunasi*	+	+		+			Bra
	Konosirus punctatus	+	+			+		Bra
Cyprinidae	*Cyprinus carpio*	+	+	+	+	+	+	Fre
	Carassius auratus	+	+	+	+	+	+	Fre
	Carassius cuvieri		+	+	+	+	+	Fre
	Rhodeus ocellatus				+			Fre
	Acheilognathus lanceolatus	+						Fre
	Acheilognathus rhombeus	+	+		+		+	Fre
	Acanthorhodeus macropterus			+	+	+	+	Fre
	Acanthorhodeus gracilis			+	+	+	+	Fre
	Pseudorasbora parva	+	+		+		+	Fre
	Sarcocheilichthys variegatus				+		+	Fre
	Sarcocheilichthys nigripinnis morii					+	+	Fre
	Squalidus japonicus coreanus			+		+	+	Fre
	Squalidus chankaensis tsuchigae		+	+	+	+	+	Fre
	Hemibarbus labeo		+	+	+	+	+	Fre
	Hemibarbus longirostris						+	Fre
	Pseudogobio esocinus	+			+	+	+	Fre
	Abbottina rivularis	+	+		+	+		Fre
	Microphysogobio jeoni		+	+	+	+	+	Fre
	Aphyocypris chinensis	+						Fre
	Opsariichthys uncirostris amurensis	+	+	+	+	+	+	Fre
	Squaliobarbus curriculus			+	+	+	+	Fre
	Erythroculter erythropterus		+	+	+	+	+	Fre
	Culter brevicauda					+		Fre
	Hemiculter eigenmanni	+	+	+	+	+	+	Fre
Cobitidae	*Misgurnus anguillicaudatus*	+						Fre
Bagridae	*Pseudobagrus fulvidraco*	+				+	+	Fre
	Leiocassis ussuriensis					+	+	Fre
	Leiocassis nitidus					+	+	Fre
Siluridae	*Silurus asotus*	+				+	+	Fre
Mugilidae	*Mugil cephalus*	+	+	+	+	+		Bra
	Chelon haematocheilus		+	+	+	+	+	Bra
Hemiramphidae	*Hyporhamphus intermedius*	+			+		+	Bra
	Hyporhamphus sajori		+			+	+	Bra

Table A1. Continued

Family	Species	Lee (1990)	NIER (2009)			This study		Ecological types
		1989–1990	2007	2008	2009	2013	2014	
Platycephalidae	*Platycephalus indicus*	+						Mar
Sciaenidae	*Collichthys lucidus*	+						Mar
Cottidae	*Trachidermus fasciatus*		+		+			Bra
Moronidae	*Lateolabrax japonicus*				+			Bra
	Lateolabrax japonicus		+			+	+	Bra
Centrarchidae	*Lepomis macrochirus*		+			+	+	Fre
	Micropterus salmoides		+		+	+	+	Fre
Leiognathidae	*Leiognathus nuchalis*				+			Mar
Belontiidae	*Macropodus ocellatus*	+					+	Fre
Channidae	*Channa argus*	+				+		Fre
Gobiidae	*Acanthogobius flavimanus*				+			Bra
	Synechogobius hasta	+	+	+	+	+		Bra
	Rhinogobius giurinus				+			Bra
	Rhinogobius brunneus	+						Fre
	Tridentger trigonocephalus	+	+		+			Bra
	Tridentiger obscurus			+	+			Bra
	Tridentiger barbatus	+						Bra
	Periophthalmus modestus	+	+		+			Bra
	Periophthalmus magnuspinnatus				+			Bra
	Taenioides rubicundus	+						Bra
Zoarcidae	*Zoarces gilli*	+						Mar
Pholidae	*Pholis fangi*	+						Mar
Pleuronectidae	*Pleuronichthys cornutus*	+						Mar
Cynoglossidae	*Cynoglossus semilaevis*	+						Mar
	Areliscus hollandi	+						Mar
Monacanthidae	*Stephanolepis cirrhifer*	+						Mar
Tetraodontidae	*Takifugu niphobles*	+						Bra
	Number of species	42	24	19	33	32	32	

Table A2. Fish fauna observed in 17 study sites of Saemangeum area in 2013–2014. Fish were classified four Ecological types (Fre, freshwater fish; Dia, diadromous fish, Bra, brackish water fish, Mar, marine fish)

Family	Species	M1	M2	M3	M4	M5	M6	M7	M8	M9	D1	D2	D3	D4	D5	D6	D7	D8	Total	Ecological types
Anguillidae	*Anguilla japonica*		7	2							4			1	1				15	Dia
Ophichthidae	*Conger myrister*						4												4	Mar
Engraulidae	*Coilia nasus*	31	8	68							17	39	8	1	1				173	Dia
	Engraulis japonicus				186	771	674	1532	13	25				459	311	515	464	747	5697	Mar
	Thryssa adelae				10	2		33	1				1	4	65	31		2	149	Mar
	Thryssa kammalensis					1	7	36								3		565	612	Mar
Clupeidae	*Konosirus punctatus*	1		4	138	116	266	198	158	121		1	96	21	15	4	5	68	1212	Bra
	Sardinella zunasi				14		11	104	16	1				5					151	Bra
Cyprinidae	*Carassius auratus*	259	321	32	8						90	117	223						1050	Fre
	Carassius cuvieri	2	6	5							18	1	11						43	Fre
	Cyprinus carpio	21	57	10	4						12	6	64						174	Fre
	Acanthorhodeus gracilis	61	11								6	1							79	Fre
	Acanthorhodeus macropterus	225	287	17							2								531	Fre
	Acheilognathus rhombeus	1									2								3	Fre
	Abbottina rivularis	9																	9	Fre
	Hemibarbus labeo	60	52	110	1						198	31	23						475	Fre
	Hemibarbus longirostris										2								2	Fre
	Microphysogobio jeoni	193	950								8	4	1						1156	Fre
	Pseudogobio esocinus	10									31	3							44	Fre
	Pseudorasbora parva	22	62	4							2	7	159						256	Fre
	Sarcocheilichthys nigripinnis morii	4	7																11	Fre
	Sarocochеilichthys variegatus wakiyae	3																	3	Fre
	Squalidus chankaensis tsuchigae	11	36								31	4							82	Fre
	Squalidus japonicus coreanus	63	1088								25	4	2						1182	Fre
	Opsariichthys uncirostris amurensis	29	52								6	3	1						91	Fre
	Squaliobarbus curriculus	5	5																10	Fre
	Zacco platypus		1																1	Fre
	Culter brevicauda	1																	1	Fre
	Erythroculter erythropterus	179	80	1							39	382	73						754	Fre
	Hemiculter eigenmanni	58	827	12							48	21	33						999	Fre
Cobitidae	*Misgurnus mizolepis*			1								1							2	Fre
Siluridae	*Silurus asotus*		11	1							2	1	2						17	Fre
Bagridae	*Leiocassis nitidus*	10									21	3	1						35	Fre
	Leiocassis ussuriensis	2																	2	Fre
	Pseudobagrus fulvidraco	8	92	1							8	8	2						119	Fre
Salangidae	*Neosalanx anderssoni*		4				1		1										6	Dia
Mugilidae	*Chelon haematocheilus*	135	195	429	1						194	99	357	1331	700	10	1	2	3454	Bra
	Mugil cephalus		1	2						1	1	2	7						14	Bra
Hemiramphidae	*Hyporhamphus intermedius*	5	1									2	16	1	1	2	64	12	104	Bra
	Hyporhamphus sajori	9	109	6	1	2			3	2			14						146	Bra
Syngnathidae	*Syngnathus schlegeli*						1												1	Mar
Scorpaenidae	*Sebastes schlegeli*					8	2										60		70	Mar
Platycephalidae	*Onigocia spinosa*					1											1		2	Bra
	Platycephalus indicus					1	2	4	1								2		10	Bra
Hexagrammidae	*Hexagrammos otakii*						1	1									3		5	Mar
Cottidae	*Trachidermus fasciatus*			5															5	Bra
Hemitripteridae	*Semitripterus villosus*																1		1	Mar
Moronidae	*Lateolabrax maculatus*	3	1	6					2			4		4	3				23	Bra
Centrarchidae	*Lepomis macrochirus*	1	4	2							9	1							17	Fre
	Micropterus salmoides	4	1								9	3	1						18	Fre

Table A2. Continued

Family	Species	M1	M2	M3	M4	M5	M6	M7	M8	M9	D1	D2	D3	D4	D5	D6	D7	D8	Total	Ecological types
Sillagnidae	*Sillago japonica*						1	2									9		12	Mar
Leiognathidae	*Leiognathus nuchalis*				14	1	489	929	11	4				21	11	282	478	7	2247	Bra
Haemulidae	*Plectorhinchus cinctus*							11											11	Mar
Sciaenidae	*Collichthys lucidus*						8		1	1									10	Mar
	Larimichthys polyactis															1			1	Mar
Pholididae	*Pholis nebulosa*								1										1	Mar
Gobiidae	*Acanthogobius flavimanus*																1		1	Bra
	Favonigobius gymnauchen					5	4		7	11				2			165		194	Bra
	Gymnogobius heptacanthus						1												1	Bra
	Leucopsarion petersii														16				16	Dia
	Rhinogobius giurinus											1							1	Fre
	Synechogobius hasta	2	10	150	17	8	1		19	4	6	41	121	7	2	1	9		398	Bra
	Tridentiger nudicervicus														1		3		4	Bra
	Tridentiger obscurus		1																1	Bra
	Tridentiger trigonocephalus			9	4	1			8	23			1	23		1	1		71	Bra
Sphyraenidae	*Sphyraena japonica*							3											3	Mar
Trichiuridae	*Trichiurus lepturus*							1											1	Mar
Scombridae	*Scomberomorus niphonius*					1		1									1		3	Mar
Belontiidae	*Macropodus ocellatus*	1																	1	Fre
Channidae	*Channa argus*										1								1	Fre
Paralichthyidae	*Paralichthys olivaceus*															1			1	Mar
	Pseudorhombus cinnamoneus																1		1	Mar
pleuronectidae	*Pleuronectes yokohamae*				1	140	4	1	2								1		149	Mar
Soleidae	*Zebrias fasciatus*													1					1	Mar
Cynoglossidae	*Cynoglossus Joyneri*						1											1	2	Bra
Tetraodontidae	*Takifugu niphobles*																1		1	Bra
	Number of species	33	30	22	13	14	18	14	15	10	27	27	23	14	12	11	20	8	76	
	Number of individuals	1428	4287	877	399	1058	1478	2856	244	193	792	790	1217	1881	1127	851	1271	1404	22153	