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Drastic change of bivalves and gastropods caused by the huge reclamation projects in Japan and Korea

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Abstract: In this study, I compared faunal change of bivalves and gastropods after the construction of the reclamation dike in case studies in Japan (Isahaya Bay) and South Korea (Saemangeum). In April 1997, the inner part of Isahaya Bay was isolated from the rest of Ariake Bay by a reclamation dike. In the inner part of this bay, 15 species of marine bivalves and gastropods were collected in large numbers before the dike was completed. These species were still alive in May 1997, but most of them had died by August 1997. However, a brackish bivalve species, *Potamocorbula* sp. that was not found prior to isolation of this bay, replaced the pre-isolation bivalve community from August 1997. In the outer part of Isahaya Bay, hypoxic water masses appeared around the mouth of the bay in June 1997, and most of the bivalve species distributed near the hypoxic regions decreased rapidly from 1997 to 1999. Thereafter, only a few bivalve species such as *Modiolus* (*M.*) *comptus* increased rapidly in abundance from June 2002. These faunal changes were strongly influenced by environmental changes, such as occurrence of hypoxic water and decrease of grain size of bottom sediments, and those are caused by isolation of Isahaya Bay. In Saemangeum area, *Potamocorbula* sp. and a few other species of bivalves and gastropods also increased temporarily after the dike construction. These results suggest that drastic changes of bivalves and gastropods after isolation are very similar in the Yellow Sea and Ariake Bay.

Key words: Ariake Bay, bivalves, Isahaya Bay, reclamation dike, Saemangeum area

Introduction

Recently, huge reclamation projects have resulted in large impacts on the natural environment around the coasts in Japan and Korea (Fig. 1A). In Japan, more than 800 km^2 of tidal flats existed once, but more than 40% of them have been lost during the past 50 years (Tsutsumi et al. 2000). Thus, many bivalves such as hard clam, *Meretrix lusoria* (Röding 1798) and short neck clam, *Tapes* (*Ruditapes*) *philippinarum* Adams & Reeve (1850), which were formerly abundant in the tidal flats of western Japan, are now decreasing rapidly (Wada et al. 1996, Tsutsumi 2006). Especially, tidal mud flats, which usually adjoined the big cities, disappeared rapidly from the Japanese coasts, and then almost all benthic animals inhabiting tidal mud flats are now threatened with extinction (e.g. Wada et al. 1996, Yamashita et al. 1997, Sato & Takita 2000).

In Ariake Bay, western Kyushu, the tidal range is more than 6 m at maximum spring tide, and there are huge tidal flats which account for ca. 40% of the total area of the Japanese tidal flats (Sugano 1981, Sato & Takita 2000). Large area of tidal mud flats also existed in Isahaya Bay, where is the western part of Ariake Bay, and many species threatened with extinction in Japan used to live there (Yamashita & Tominaga 1995, 1996, Fukuda 2000, Sato 2000b). However, the inner part of Isahaya Bay was isolated from the rest of Ariake Bay by the construction of a dike in April 1997, and most areas (ca. 29 km^2) of tidal mud flats have been lost (Fig. 1D). After this isolation, all of the benthic animals inhabiting tidal mud flats died by dry and starvation in the inner parts of dike (Sato 1997, 2000a,

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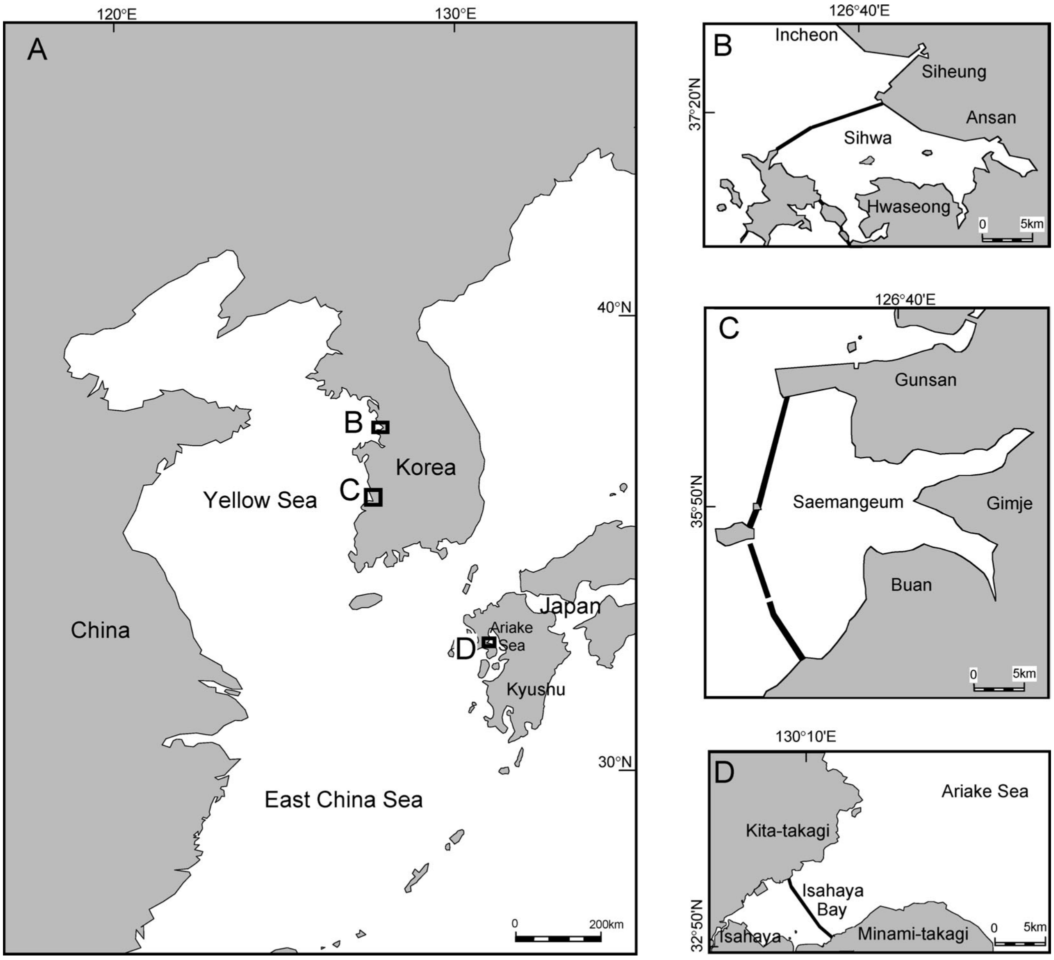

Fig. 1. A: Location of the huge reclamation projects in Korea and Japan (modified from Sato 2002). B–D: Location of the reclamation area in (B) Sihwa, (C) Saemangeum and (D) Isahaya Bay. Black bars represent the dike completed in each area. Maps from B to D are same scale.

2000b, 2001). Moreover, in the outer part of Isahaya Bay, environmental conditions suddenly changed, and fauna of bivalves was replaced on a drastic scale (Sato & Kanazawa 2004, Kanazawa et al. 2005).

In Korea, large-scale tidal flats exist around the western coasts facing the Yellow Sea. The tidal range in western Korea is the greatest in Asia (more than 9 m in maximum), and the total area of the tidal flats in South Korea is 3,905 km^2 in 1964 (Hong 2000, Sato & Koh 2004). However, many reclamation projects are also being carried out in South Korea (Fig. 1). One of the hugest projects is the Saemangeum Reclamation Project (Fig. 1C). The construction of the reclamation dike in Saemangeum area was started in 1991 and is scheduled to be completed in 2011. If this project is completed, 401 km^2 of tidal flats and shallow sea will be lost.

In these reclamation projects, we can see the drastic changes of benthos fauna, that is, the dominant species rapidly disappear after the construction of the dike, and then a few species increase temporarily and then decrease rapidly. The Yellow Sea and Ariake Bay have a common geological history (Shimoyama 2000), so we can see the common response of benthos animals to large-scale environmental changes such as isolation. In the present paper, I review the faunal changes of bivalves and gastropods after the construction of the reclamation dike in Japan and South Korea and discuss the common responses between them.

"Holocaust" occurred on the tidal mud flat of Isahaya Bay after the dike's completion

On April 14, 1997, the inner part of Isahaya Bay was isolated from the rest of Ariake Bay by a reclamation dike (Fig. 2). The reclamation area is 35.5 km^2, and the length of the dike is 7,050 m. After the dike's completion, seawater in the inner area was occasionally drained into the outer part of this bay through two gates in the dike, and the water level of the reclamation area has been kept at -1 m of average sea level (Fig. 2C).

The intertidal zone of the inner bay dried up completely by a few months later, and then numerous dead shells were exposed on the dried mud flat (Fig. 3). In July 1997, I col-

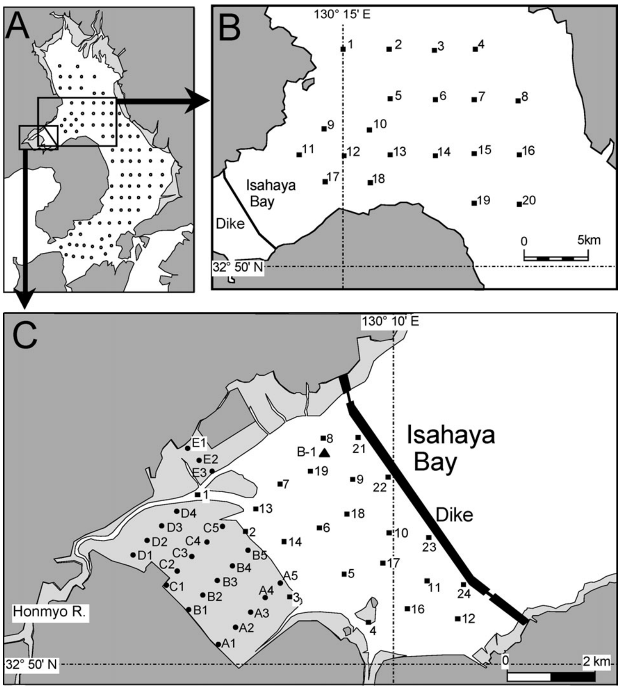

Fig. 2. Locality map showing Ariake Bay, western Kyushu, southern Japan (modified from Kanazawa et al. 2005). A: 92 fixed stations for sediment sampling conducted in June 1997 and June 2002. B: 20 fixed stations in and around the mouth of Isahaya Bay for sediment sampling conducted from June 1997 to November 2003. C: Locality of each fixed stations for quadrat sampling on the dried mud flat (black circle: A1–E3) and sediment sampling in the adjustment pond (black square: 1–24 without 15 and 20). A black triangle (B-1) in the adjustment pond means the station for water quality measuring set up by the Japanese Ministry of Agriculture, Forestry and Fisheries. A black bar is the reclamation dike in Isahaya Bay shut off from Ariake Bay.

Fig. 3. Numerous dead shells of *Tegillarca granosa* exposed on the dried mud flat in Isahaya Bay on August 23, 1997.

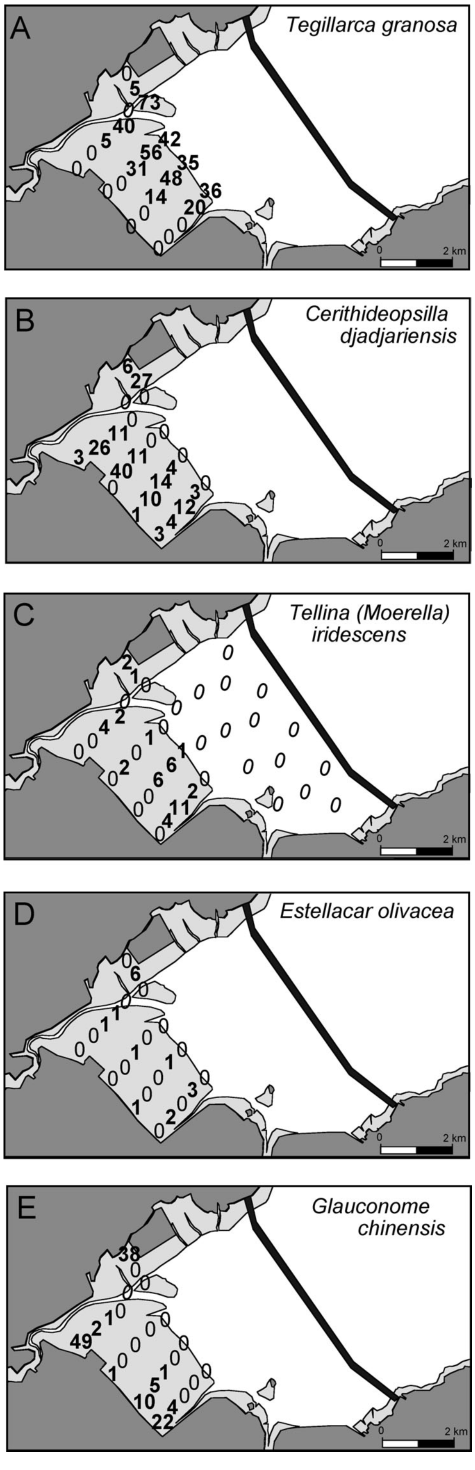

Fig. 4. Distribution patterns (indiv. m^{-2}) in (A) *Tegillarca granosa*, (B) *Cerithideopsilla djadjariensis*, (C) *Tellina* (*Moerella*) *iridescens*, (D) *Estellacar olivacea* and (E) *Glauconome chinensis* on the dried mud flat in Isahaya Bay (from Sato 2001).

lected all the specimens of bivalves and gastropods from a quadrat area (1 m×1 m) at the 22 stations (black circles A1–E3 in Fig. 2C). The major study area was located on the former tidal mud flats ca. 3 km in length along the coast and ca. 2 km in width from the former mean high water of spring tide (MHWS) to the present shoreline (Fig. 2C). This survey made it clear that *Tegillarca granosa* (Linnaeus 1758) (bivalve) was very dense (30–70 indiv. m^{-2}) at the lower part of the dried mud flat of ca. 1 to 2 km distance from the former MHWS (Fig. 4A). 50 years ago, this species was distributed widely in tidal mud flats around the western Japanese coasts, but now it is designated as an endangered species (Wada et al. 1996, Sato 2000b). Nevertheless, in Isahaya Bay, a total of 100 million individuals of *Tegillarca granosa* at least were destroyed by the reclamation project (Sato 1997, 2001).

In addition to *Tegillarca granosa*, many threatened species such as *Cerithideopsilla djadjariensis* (K. Martin 1899) (gastropod), *Tellina* (*Moerella*) *iridescens* (Benson 1842) and *Estellacar olivacea* (Reeve 1844) (bivalves) were also distributed in abundance at the middle part of the dried mud flat of ca. 0.5 to 1 km from the former MHWS (Fig. 4B–D). By contrast, *Glauconome chinensis* Gray (1828) (bivalve) was especially crowded at the uppermost part of the dried mud flat near the former MHWS and ranged to the former mean high water of neap tide (Fig. 4E). These facts suggest that there were three separate zones of mollusks arranged parallel to the water level on the tidal mud flat of Isahaya Bay. Usually spatial distribution analysis of benthos inhabiting tidal mud flats is very difficult, because it required hard work and much water to wash the samples. It is ironic that the reclamation project made it possible for us to find such clear zonations of benthos on the tidal mud flat of Isahaya Bay.

Most individuals of the gastropod *Cerithideopsilla djadjariensis* had lived at the middle part of the dried mud flat for a long time after isolation (Sato 1997, 2001). The survival ratio of this species was 95.5% in July 1997, but it decreased to 12.6% in March 1998 and 0% in July 1998 (Sato 2001). Moreover, many individuals of gastropods distributed in reedy marshes such as *Cerithidea rhizophorarum* A. Adams (1855) and *Pseudomphala miyazakii* (Habe 1943) had lived until October 1999, that is 2.5 years after isolation (Sato 2001). In bivalves, a few living individuals of *Glauconome chinensis* and *Estellacar olivacea* were also found on the upper part of the dried mud flat in July 1997 (Sato 1997, 2001). However, in *Tegillarca granosa*, all individuals had died by July 1997, although they were distributed on the lower part of this mud flat, which was much wetter than the upper part during the same time period (Sato 2001). These facts suggest that in both gastropods and bivalves, the species distributed on the upper part of the tidal mud flat were more tolerant to dry and starvation than those on the lower part.

Faunal change of bivalves and gastropods in the adjustment pond of the Isahaya Reclamation Project

In the subtidal zone of the inner bay (an adjustment pond at present), salinity of the bottom water layer decreased suddenly to $<$5 psu within 4 months after isolation, and then the bivalve and gastropod fauna was drastically altered (Sato S et al. 2001, Sato & Azuma 2002). According to the data that was measured at the station B-1 of Fig. 2C by the Ministry of Agriculture, Forestry, and Fisheries, the salinity of the surface water layer of the adjustment pond also decreased from $>$30 psu to 9.0 psu between May 6 and May 19, 1997. Although salinity of the surface water temporarily increased to $>$10 psu in October 1997, it did not exceed 2 psu during 1998 and 2002.

We periodically collected sediment samples from the fixed stations (black squares 1–24 in Fig. 2C), 15 times between March 1997 and August 2005. Each sampling station was located by GPS (Sony IPS-760, accuracy $\pm<30$ m), and 2 to 11 repeated samples were taken at each station using an Ekman-Birge grab (sampling area: 0.02 m^2). The samples were passed through a sieve of 1 mm mesh size. The remnants were preserved in 10% formalin, and living benthic animals were removed from the debris and identified in the laboratory.

Our results suggest that, in March 1997, before isolation of Isahaya Bay, 15 species of gastropods such as *Iravadia* (*Fluviocingula*) *elegantula* (A. Adams 1863), *Odostomia* sp. and *Salinator takii* Kuroda (1928), and bivalves such as *Modiolus* (*Modiolus*) *metcalfei* (Hanley 1843), *Musculista senhousia* (Benson 1842), *Scapharca kagoshimensis* (Tokunaga 1906) and *Theora fragilis* (A. Adams 1855) were collected in large numbers (Fig. 5). These species were still alive in May 1997 in similar numbers as before isolation, but most of them had died off by August 1997 (Sato S et al. 2001). Many studies have suggested that the distribution patterns of marine benthos are usually limited by salinity or dissolved oxygen (DO), and individual densities of marine benthic animals decrease rapidly when the salinity is $<$5 psu or DO is $<$2–3 $mg\,L^{-1}$ (Reish 1971, Rosenberg 1977, Imabayashi 1989, Furota 1991, Nakamura 1998). In the adjustment pond of Isahaya Bay, salinity of the bottom water layer decreased from 5–20 psu (May 1997) to $<$5 psu (August 1997) in most stations, but DO was still high ($>$8 $mg\,L^{-1}$) in most stations where *Theora fragilis* and the other species lived (Sato & Kanazawa 2004). Thus, it seems that marine bivalves and gastropods in the adjustment pond of Isahaya Bay died off because of low salinity.

However, only a brackish species of a corbulid bivalve, *Potamocorbula* sp., increased rapidly after isolation in the adjustment pond of Isahaya Bay. In *Potamocorbula* sp., although no individuals were found before isolation, small numbers of juveniles appeared near the estuary in May, and finally enormous subadults (ca. 1 cm in shell length) were distributed at most stations of the adjustment pond in August 1997 (Fig. 6, Sato & Azuma 2002). In April 1998, an enormous number of small specimens appeared again, and grew and survived until October 1999. The maximum density of this species was 832 indiv. 0.1 m^{-2} at St. 5 in April 1998 (Sato & Azuma 2002). However, this species decreased suddenly from all the stations from July 2000, and it disappeared in March 2002 (Fig. 6).

Living individuals of *Potamocorbula* sp. were not found in Japan before the 1990's. This species first appeared in September 1992 at the Okinohata Port in Yanagawa City and rapidly increased and spread to many localities in 1993

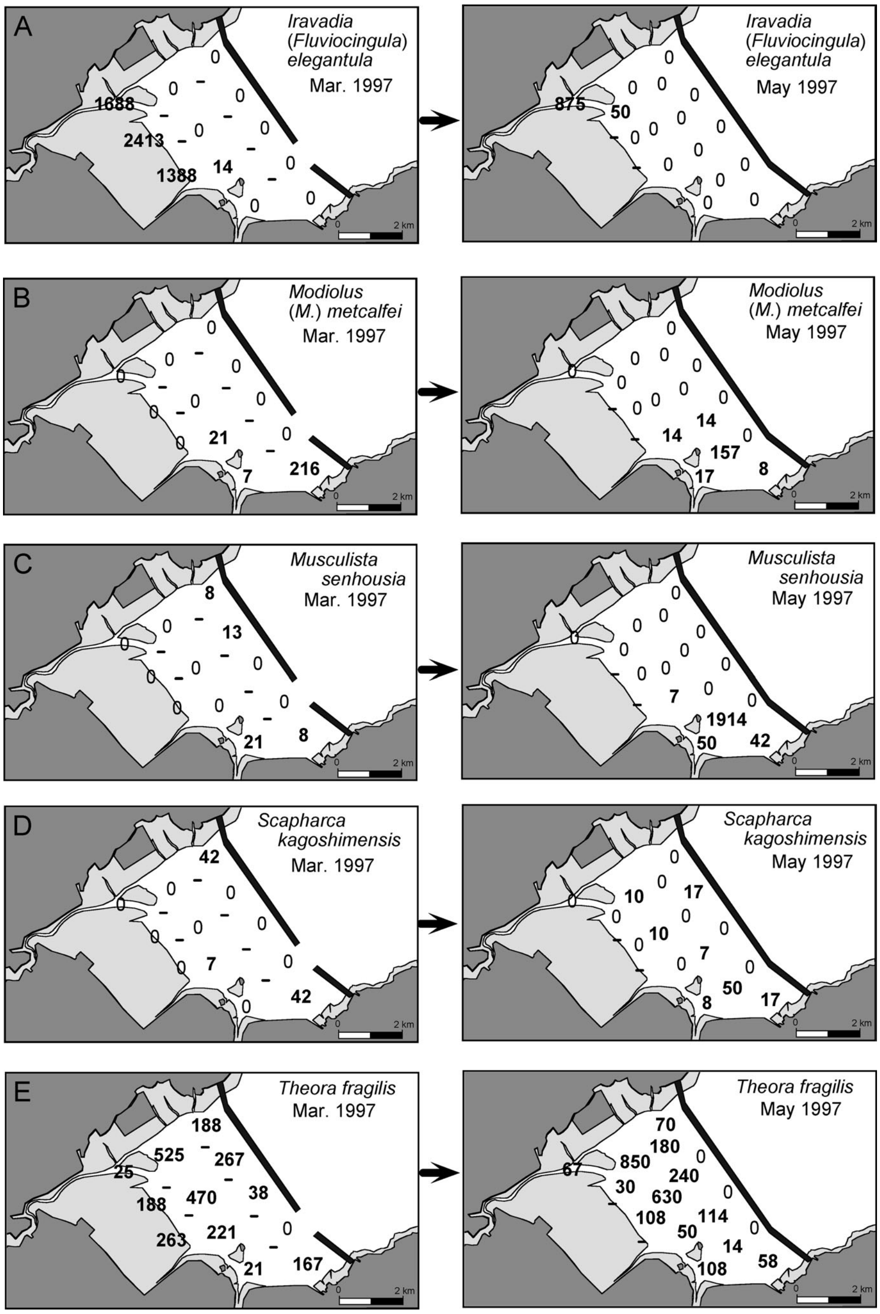

Fig. 5. Temporal change of distribution patterns (indiv. m^{-2}) in (A) *Iravadia* (*Fluviocingula*) *elegantula*, (B) *Modiolus* (*Modiolus*) *metcalfei*, (C) *Musculista senhousia*, (D) *Scapharca kagoshimensis* and (E) *Theora fragilis* in the adjustment pond of Isahaya Bay (from Sato S et al. 2001).

(Horikoshi & Okamoto 1994, Sato & Tomari 1994). In 1996 and 1997, this species became the most dominant species among all the gastropods and bivalves in the inner part of Ariake Bay (Kikuchi in Furota et al. 1999). In Isahaya Bay, a large number of small specimens were found in both May 1997 and April 1998, so Sato & Azuma (2002) hypothesized that most larvae of this species settle before early spring. However, small individuals have not been found since July 1999 (Sato & Azuma 2002). In August 1998 and July 1999, most adults of this species were sexually mature, and anoxic water was not distributed in this area after August 1997 (Sato & Azuma 2002). Therefore, it is assumed that although adults of this species can survive and perhaps can release their germ cells, larvae of this species could not settle in this area after 1998 because of low salinity. Salinity of the bottom water layer at most stations was >1 psu in April 1998, and it decreased to <1 psu in July 1999 (Sato & Azuma 2002). The lower limit of salinity tolerance for larvae of this species is, therefore, at least >1 psu.

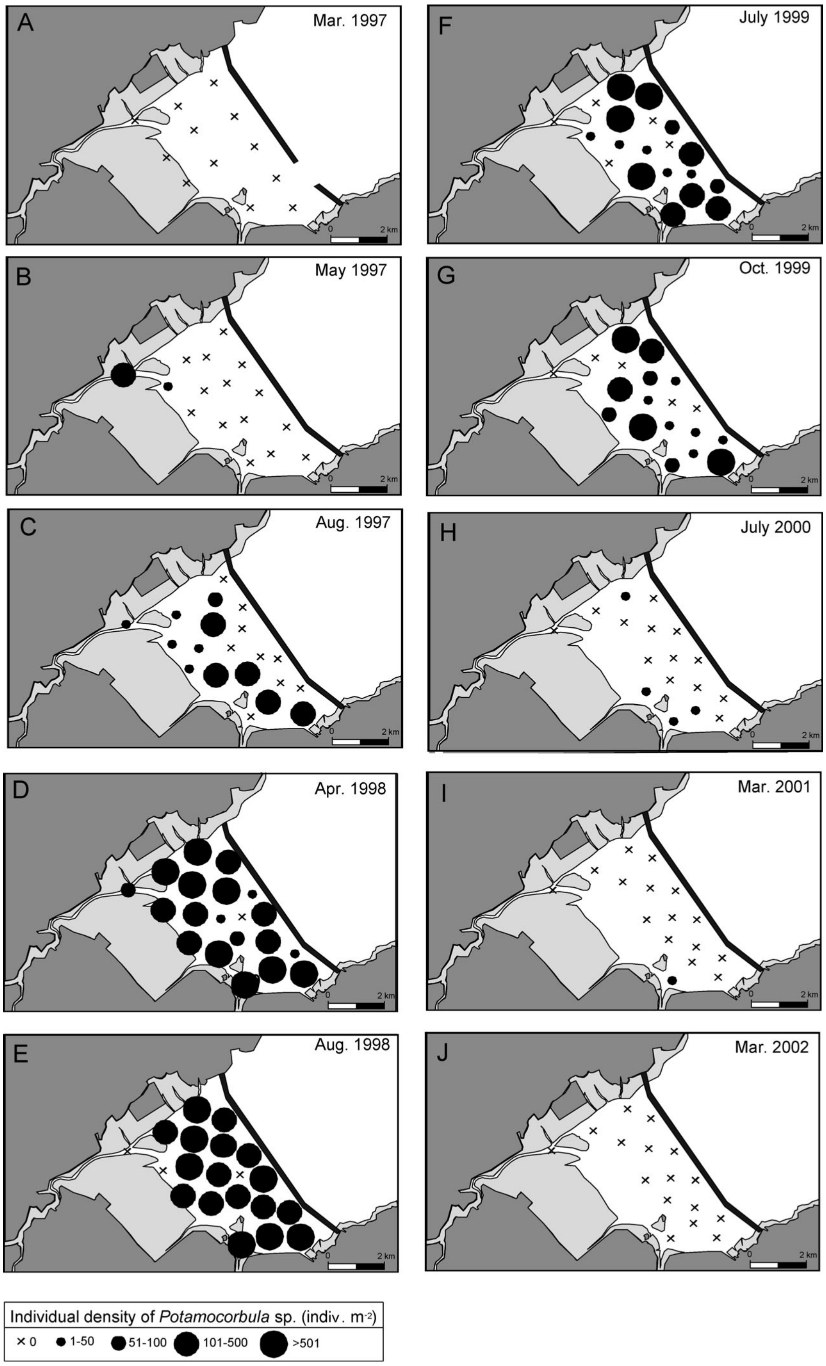

Fig. 6. Temporal change of distribution patterns in *Potamocorbula* sp. in the adjustment pond of Isahaya Bay from March 1997 to March 2002 (modified from Sato 2002).

Temporal changes of bivalves and environmental conditions in the outer part of Isahaya Bay

In the outer part of Isahaya Bay, several changes in environmental conditions, such as a drastic increase in red tides and hypoxic water, have been observed since 1997 (Tsutsumi 2006). In June 1997, hypoxic water (DO $<2.8\,\mathrm{mg\,L^{-1}}$; Diaz & Rosenberg 1995) occurred at the outside of the reclamation dike (Fig. 7). In and around the mouth of Isahaya Bay, large amounts of the bottom sediments were dug in order to construct the reclamation dike, and it seemed that hypoxic water occurred from these depressions (Azuma 2000, Sato M et al. 2001). Hypoxic water was also found in June 1999 and June 2001 (Fig. 7). Especially, in June 2001, hypoxia was observed in a wide area (Fig. 7), and low values of DO ($<4\,\mathrm{mg\,L^{-1}}$) were also found in early August of this year (Tsutsumi et al. 2003). However, DO values were $>4\,\mathrm{mg\,L^{-1}}$ in June 2000 and June 2002 (Fig. 7), and they were always $>6\,\mathrm{mg\,L^{-1}}$ in November during 1998 and 2003 (Kanazawa et al. 2005).

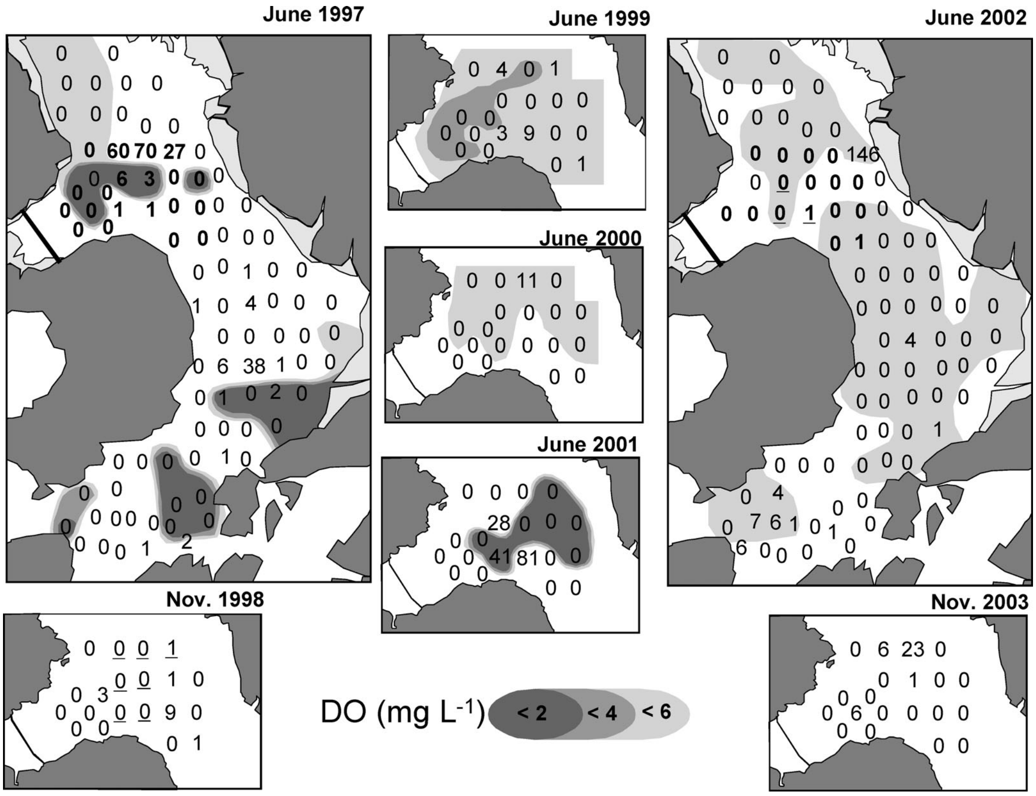

Fig. 7. Temporal changes in dissolved oxygen (DO: $mg\,L^{-1}$) of bottom water layer and in the density of *Musculista japonica* (indiv. $0.05\,m^{-2}$) collected from 20 fixed stations in and around the mouth of Isahaya Bay and 92 fixed stations in Ariake Bay from June 1997 to November 2003 (from Kanazawa et al. 2005). In June 1997 and June 2002, bold-faced numbers pertain to the 20 fixed stations in and around the mouth of Isahaya Bay. Also, underlined numbers in November 1998 and June 2002 mean the fixed stations where *M. japonica* decreased after hypoxia occurred in June 1997 and June 2001, respectively.

Kanazawa et al. (2005) periodically monitored the number of species and mean densities of bivalves in the 20 fixed stations using the Smith-McIntyre grab (sampling area: $0.05\,m^2$) around the mouth of Isahaya Bay from June 1997 to November 2003 (Fig. 2B). Also, in June 1997 and June 2002, sediment samples were collected from the 92 and 88 fixed stations from the whole Ariake Bay, respectively (Fig. 2A). The bivalve fauna drastically changed after the dike's completion in the outer part of Isahaya Bay. In and around the mouth of Isahaya Bay, many bivalve species such as *Musculista japonica* (Dunker 1856), *Musculista senhousia*, *Modiolus* (*Modiolusia*) *elongata* Swainson (1821), *Raetella pulchella* (Adams & Reeve 1850) and *Theora fragilis* distributed in the muddy and fine sand sediments in June 1997, but these species decreased rapidly until June 1999 (Figs. 7, 8, Kanazawa et al. 2005). However, a bivalve species, *Modiolus* (*Modiolus*) *comptus* Sowerby III (1915), distributed in the medium sand sediments, was abundant from June 1997 to June 1999 (Fig. 9, Kanazawa et al. 2005). Also, in June 1997, hypoxic water occurred near the region where the former 5 species lived rather than the region where *M.* (*M.*) *comptus* lived (Figs. 7, 8, 9).

Hypoxic water can usually be moved around a wide area by the tide and wind. For example, observation of DO at a fixed station in Mikawa Bay, central Japan, revealed that during the 49 days of the observation period, hypoxic water (DO $<20\%$) was occasionally observed more than 10 times, but each hypoxia was always disappeared within 24 hours (Suzuki et al. 1998). By contrast, some examinations on tolerance of bivalves to hypoxic water revealed that *Theora fragilis* died off within 2 days in anoxic water (DO $<0.05\,mg\,L^{-1}$) at 25°C, and *Musculista senhousia* also died for 3 days in anoxic water (Tamai 1993, Nakamura 1998).

Therefore, although not all bivalves necessarily die in hypoxic water within 24 hours, hypoxic water strongly influenced the benthos fauna over a wide area (Imabayashi 1989, Furota 1991, Wu 2002). These facts suggest that hypoxic water occurring near the mouth of Isahaya Bay in June 1997 caused a decrease in *Theora fragilis*, *Musculista senhousia* and the other bivalve species. From June 2001 to August 2001, hypoxic water also occurred in a wide area around the mouth of Isahaya Bay, and it caused a decrease in *Musculista japonica* and *Raetella pulchella* in November 2001 (Figs. 7, 8, Kanazawa et al. 2005).

In contrast, because the distribution area of *Modiolus* (*M.*) *comptus* was far from the hypoxic water occurring in June 1997, this species has not been influenced by the hypoxic water and is still distributed around the mouth of Isa-

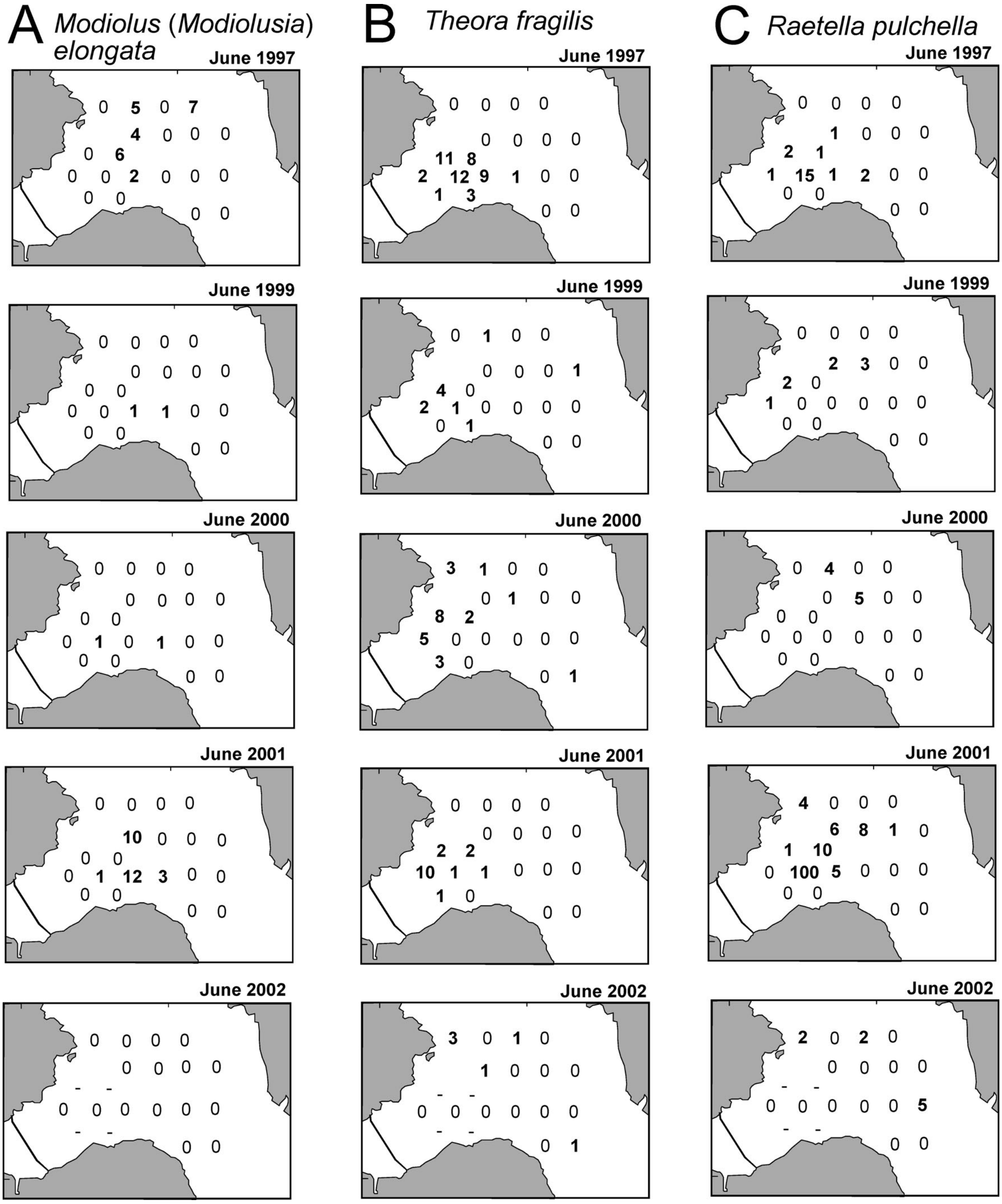

Fig. 8. Temporal changes in the density (indiv. $0.05\,m^{-2}$) of (A) *Modiolus* (*Modiolusia*) *elongata*, (B) *Theora fragilis* and (C) *Raetella pulchella* in and around the mouth of Isahaya Bay from June 1997 to June 2002 (A–B: unpublished data, C: from Sato & Kanazawa 2004).

haya Bay till June 1999. However, *Modiolus* (*M.*) *comptus* suddenly disappeared from this area in June 2000 and then rapidly increased in June 2002 (Fig. 9). In June 1997, *Modiolus* (*M.*) *comptus* was generally distributed at the area of sediment with medium particle diameter (Md) of 1.5–2.0ϕ (Fig. 9, Kanazawa et al. 2005). From June 1999 to June 2000, the distribution area of sediment with Mdϕ 1.5–2.0 reduced in and around the mouth of Isahaya Bay, and *Modiolus* (*M.*) *comptus* temporarily disappeared from this area (Fig. 9). In June 2002, the distribution area of sediment with Mdϕ 1.5–2.0 spread rapidly toward the east side of this area, and *Modiolus* (*M.*) *comptus* proliferated again around the mouth of Isahaya Bay (Fig. 9).

These facts suggest that the distribution pattern of *Modiolus* (*M.*) *comptus* is influenced by the temporal change of sediment distribution. It has been pointed out that the de-

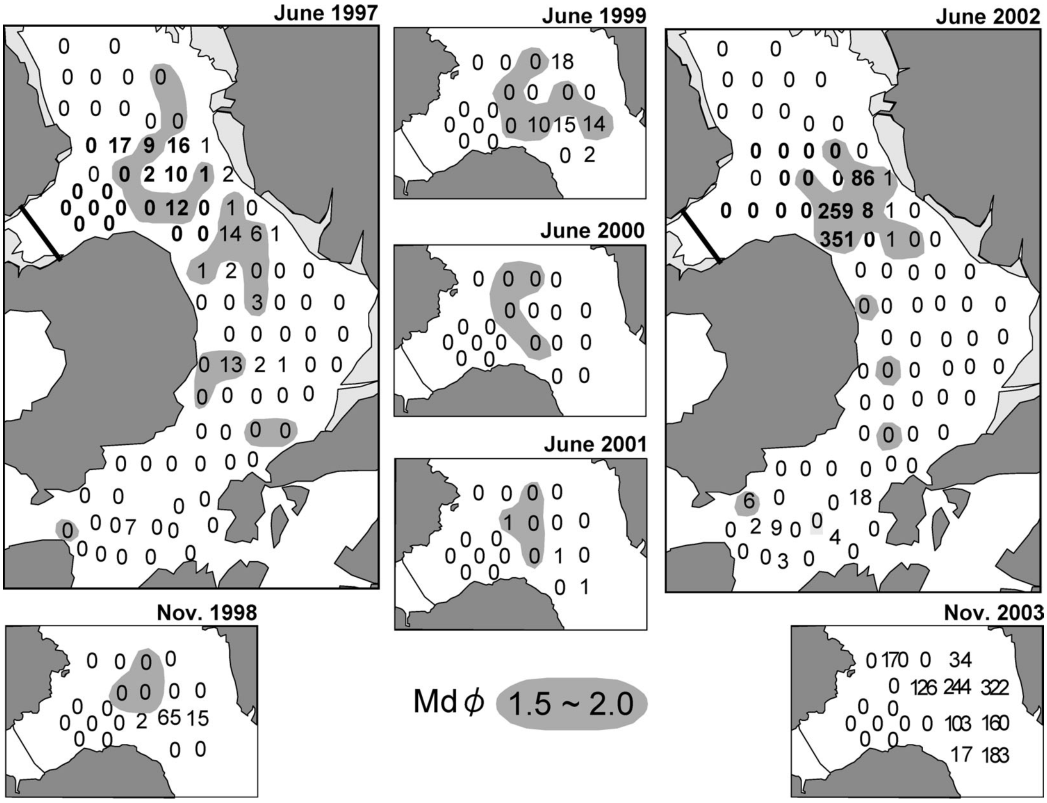

Fig. 9. Temporal changes in the density of *Modiolus* (*M.*) *comptus* (indiv. 0.05 m^{-2}) from June 1997 to November 2003, and in distribution area of sediment with a median particle diameter (Md) of 1.5–2.0ϕ from June 1997 to June 2002 in and around the mouth of Isahaya Bay and in Ariake Bay (from Kanazawa et al. 2005). In June 1997 and June 2002, bold-faced numbers pertain to the 20 fixed stations in and around the mouth of Isahaya Bay.

crease in the tidal current speed after isolation of Isahaya Bay caused a decrease in grain size of bottom sediments in June 2002 (Azuma 2005). In conclusion, temporal changes of bivalve fauna were strongly influenced by the environmental changes, such as occurrence of hypoxic water and change of grain size of bottom sediments, and those are caused by isolation of Isahaya Bay.

Faunal change of bivalves and gastropods in the Saemangeum area

The Saemangeum area is located in the middle of the western coast of South Korea (Fig. 1). The length of the dike is 33 km (the largest in the world), and the reclamation area is 401 km^2 (Fig. 10). The construction of the dike was started in November 1991, and the project is scheduled to be completed in 2011. The northern part of this dike has been isolated since June 2003. The southern part of the dike was also completed on April 21, 2006, but the water gates have not yet been closed.

The Japan/Korea Tidal-flats Joint Survey Group began studies on waterfowls, benthos and "tidal-flat culture" in the Saemangeum area in May 2000 (Japan/Korea Tidal-flats Joint Survey Group 2001, 2003, 2006). In this survey, we examined macrobenthos fauna at 18 fixed stations on the tidal flat of the northern and middle sites in the Saemangeum area 10 times from May 2000 to March 2006 (Fig. 10A, B). At each fixed station, one or two quadrat samples (25 cm×25 cm) were dug with a shovel to a depth of 20 cm and were passed through a sieve or sack of ca. 2 mm mesh size. The remnants were preserved in ethanol, and living benthic animals were removed from the debris and identified in the laboratory. The samples collected from the Saemangeum area will be stored at the National Biological Resources Center in South Korea.

In May 2000, a brachiopod *Lingula anatina* Lamarck (1801), gastropods such as *Umbonium* (*U.*) *thomasi* (Crosse 1863), *Reticunassa festiva* (Powys 1833) and *Bullacta exarata* (Philippi 1849), and bivalves such as *Mactra veneriformis* Reeve (1854), *Solen* (*Solen*) *strictus* Gould (1861), *Tellina* (*Moerella*) *rutila* Dunker (1860), *Nuttallia japonica* (Reeve 1857), *Meretrix petechialis* (Lamarck 1818), *Glauconome chinensis* and *Laternula* (*Exolaternula*) *marilina* (Reeve 1860) were collected from the tidal flats (Table 1). Moreover, a possibly undescribed bivalve species, Montacutidae gen. et sp. attached to the shell of *Lingula anatina* were found from the quadrat samples (identified as Galeommatidae gen. et sp. in Sato 2002, Sato & Yamashita 2006, Yamashita et al. 2006). The existence of bivalve species attached to the shell of *Lingula anatina* is also re-

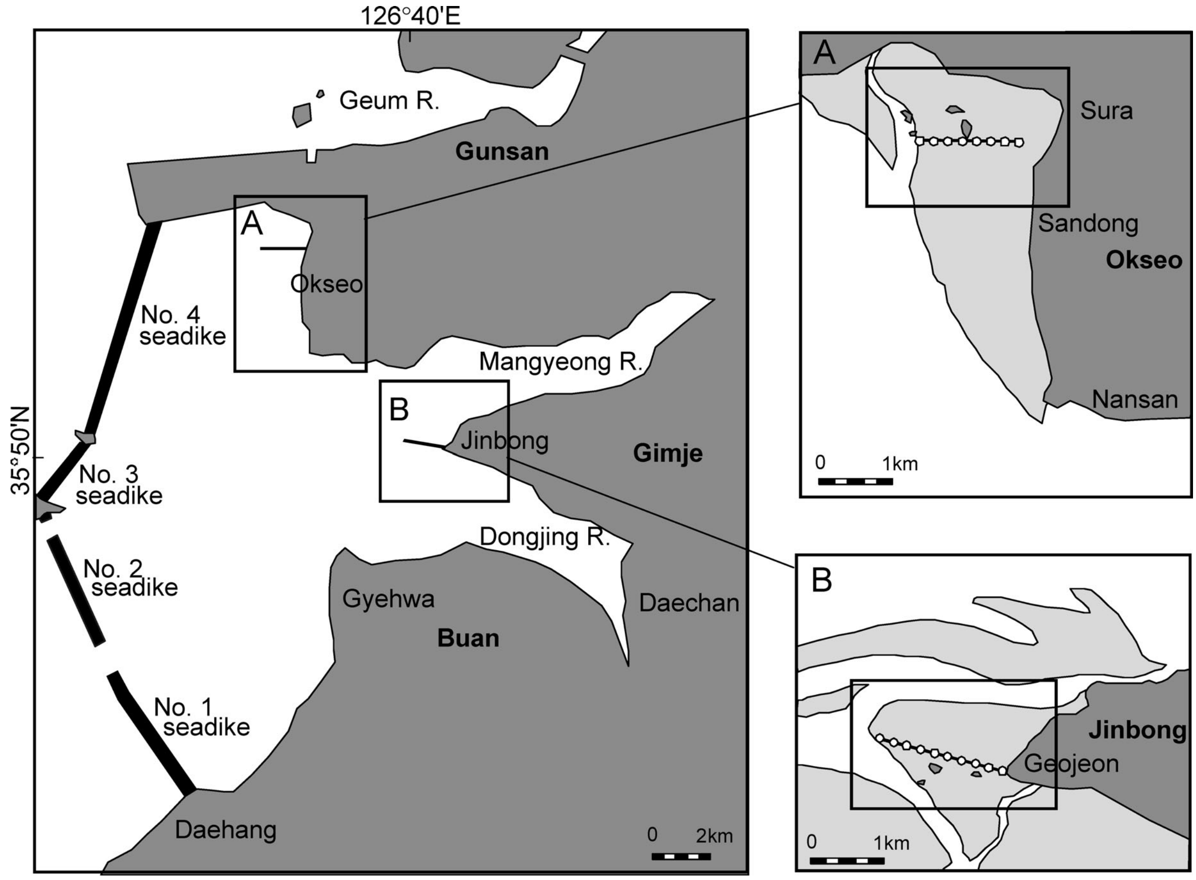

Fig. 10. Locality map showing the Saemangeum area. (A) 8 stations of the northern sites and (B) 10 stations of the middle sites in this area (modified from Sato & Yamashita 2006).

ported from the Philippines (as *Mysella* sp. in Savazzi 2001). Besides, a similar bivalve species attached to the shell of *Lingula adamsi* Dall (1873) has been already found on the southwestern coast of South Korea (as Galeommatidae gen. et sp. in Sato et al. 2004). Therefore, taxonomic examinations of these bivalve species and analysis of the symbiotic relationship between these bivalves and *Lingula* are urgently needed.

However, since the completion of the northern part of the reclamation dike in June 2003, rapid changes of bivalves and gastropods have been found in the tidal flat of the Saemangeum area. In the northern site of this area, *Umbonium* (*U.*) *thomasi*, *Bullacta exarata* and *Tellina* (*Moerella*) *rutila* have decreased rapidly since 2003 (Fig. 11A, C, Table 1). In their place, *Felaniella sowerbyi* Kuroda & Habe (1951) and *Laternula* (*Exolaternula*) *marilina* increased and subsequently decreased in the northern site of Saemangeum area (Fig. 11D, E). In the fixed stations where *Umbonium* (*U.*) *thomasi* was found in abundance in May 2000, *Batillaria cumingii* (Crosse 1862) has been crowded since 2003 (Fig. 11A, B). On the other hand, in the middle site of Saemangeum area, many gastropods and bivalves including Montacutidae gen. et sp. have decreased rapidly since 2003, and *Potamocorbula* sp. and *Laternula* (*Exolaternula*) *marilina* increased and subsequently decreased (Fig. 12, Table 1). Especially, *Potamocorbula* sp. that increased after isolation of Isahaya Bay has also been found in high density since 2002 (Fig. 12). When the data before the construction of the dike in 1988 are compared with the results after the dike construction in 2000 (Choi & Koh 1994, Je 2000, Sato 2002), the distribution range and individual density of this species increased in the subtidal zone of the inner part of the reclamation dike (Je 2000, Sato 2002, 2005). In the intertidal zone, only few individuals of *Potamocorbula* sp. were found from the 65 stations in the Saemangeum area in 1988 (An & Koh 1992), so it is clear that this species suddenly increased during 2000 and 2001 (Table 1). These drastic changes of bivalves and gastropods in the Saemangeum area are very similar to those occurring in Isahaya Bay after isolation. This result shows that the ecosystem of the Saemangeum area has already shifted to an unstable state like Isahaya Bay.

Conclusion

In the inner part of Isahaya Bay, most of the marine bivalves and gastropods had died off by 4 months after the dike's completion. Thereafter, only *Potamocorbula* sp. increased temporarily in the adjustment pond from August 1997, and then disappeared. In the outer part of Isahaya

Table 1. Mean individual number (indiv. m^{-2}) for each species of a brachiopod, gastropods, and bivalves collected from the northern and middle sites of Saemangeum area (modified from Sato & Yamashita 2006).

Locality	northern site (Sura, Okbong-ri, Okseo-myeon, Gunsan City)								middle site (Geojeon, Simpo-ri, Jinbong-myeon, Gimje City)							
Date Year	May 3 2000	Aug. 31 2001	Aug. 15 2002	May 4 2003	July 19 2003	Sep. 26 2003	Oct. 1 2004	May 7 2005	May 4 2000	Sep. 1 2001	Aug. 16 2002	May 5 2003	July 20 2003	Sep. 25 2003	Oct. 2 2004	May 8 2005
number of sampling stations	12	2	8	8	8	8	8	8	12	4	8	10	9	10	10	10
BRACHIOPODA																
INARTICULATA																
Lingula anatina	17	16	32	50	26	38	18	14	44	32	36	46	64	107	29	16
MOLLUSCA																
GASTROPODA																
Umbonium (*U.*) *thomasi*	457	8	776	40	52	92	2	0	109	8	260	19	4	37	69	40
Batillaria cumingii	0	320	154	438	496	180	92	158	0	0	0	0	0	0	0	0
Assimineidae gen. et sp.	1	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0
Pseudomphala latericea	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
Glossaulax didyma	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
Lunatia fortunei	0	0	4	0	0	0	0	2	0	0	0	0	0	0	0	3
Reticunassa festiva	16	0	120	0	14	0	0	6	9	0	12	0	0	6	10	3
Terebra spp.	12	0	8	0	0	2	0	2	0	0	0	0	0	0	0	2
Odostomia spp.	20	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bullacta exarata	1	80	12	0	0	2	6	0	4	36	3	10	9	10	2	3
BIVALVIA																
Mactra veneriformis	8	0	34	6	4	2	0	0	3	12	95	5	0	2	5	14
Solen (*S.*) *strictus*	5	0	0	2	4	0	0	0	0	0	4	0	0	0	0	2
Tellina (*Semelangulus*) *tokubeii*	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
Tellina (*Moerella*) *iridenscens*	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
Tellina (*Moerella*) *rutila*	192	360	170	144	176	210	12	18	7	16	22	5	5	2	22	42
Nuttallia japonica	4	0	2	0	0	0	0	0	4	8	0	2	0	0	2	0
Felaniella sowerbyi	0	0	0	78	52	118	4	6	0	0	0	0	0	0	0	0
Montacutidae gen. et sp.	0	0	0	0	0	0	0	0	1	12	2	3	4	6	0	0
Dosinia (*Phacosoma*) *japonicum*	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Meretrix petechialis	3	8	2	4	0	0	0	0	3	0	4	0	0	2	5	6
Tapes (*Ruditapes*) *philippinarum*	1	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0
Cyclina sinensis	0	0	6	4	8	2	4	0	0	0	0	0	0	2	0	0
Glauconome chinensis	4	0	0	0	0	22	2	0	0	0	0	0	0	0	0	0
Potamocorbula sp.	0	0	2	0	0	0	0	0	0	216	494	2	329	829	205	94
Laternula (*Exolaternula*) *marilina*	3	0	7	106	24	0	314	6	9	148	26	6	256	141	3	14

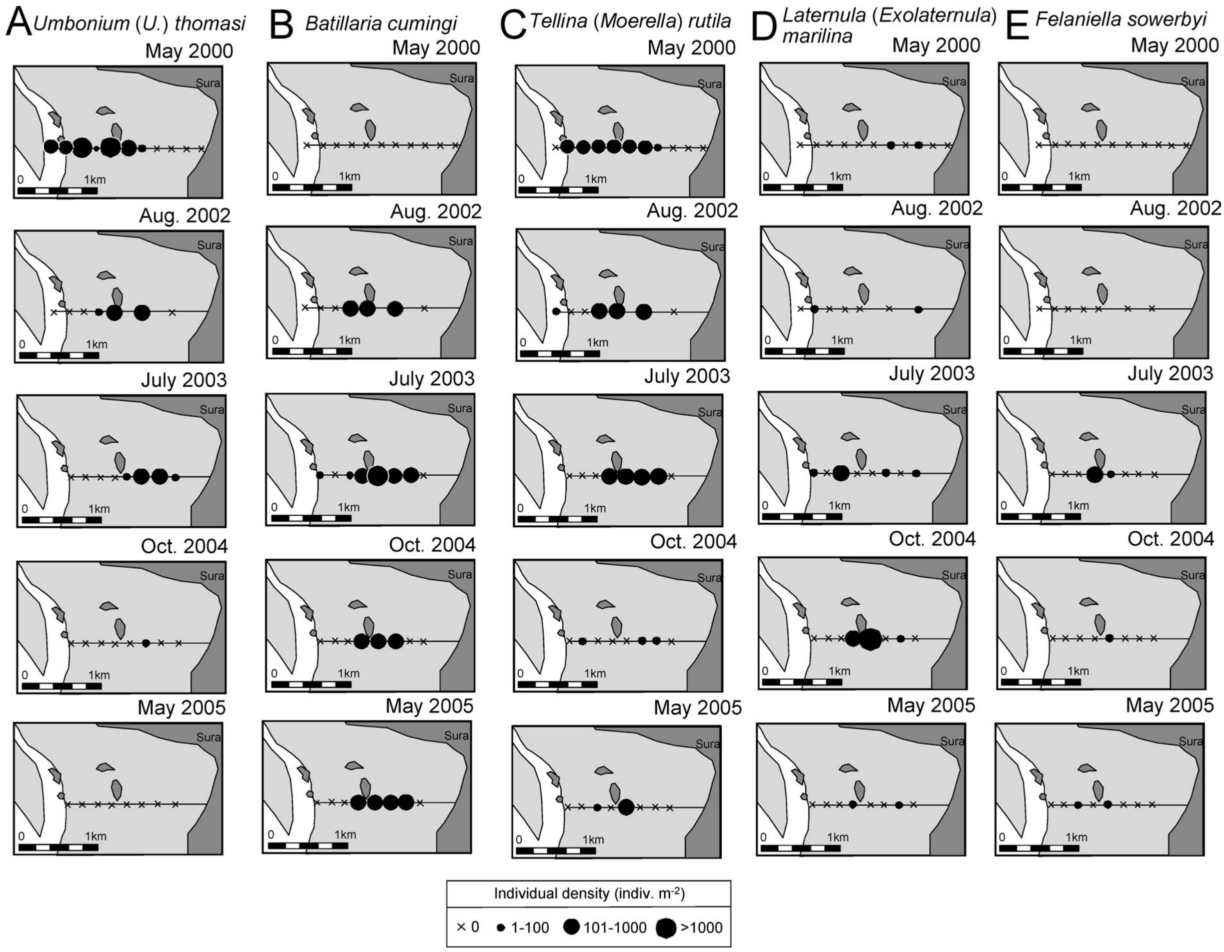

Fig. 11. Temporal change of distribution patterns in (A) *Umbonium* (*U.*) *thomasi*, (B) *Batillaria cumingii*, (C) *Tellina* (*Moerella*) *rutila*, (D) *Laternula* (*Exolaternula*) *marilina* and (E) *Felaniella sowerbyi* in the northern site of the Saemangeum area from May 2000 to May 2005 (from Sato & Yamashita 2006).

Bay, most of the bivalve species decreased rapidly from 1997 to 1999. However, only a few bivalve species such as *Modiolus* (*M.*) *comptus* increased rapidly in abundance from June 2002. In the Saemangeum area, many bivalves and gastropods also decreased rapidly from 2003, when the northern part of the reclamation dike was completed. In addition, a few species of bivalves and gastropods increased temporarily and subsequently decreased. Especially, *Potamocorbula* sp., that increased after isolation of Isahaya Bay, was also found in high density after the dike construction. These results suggest that faunal response of bivalves and gastropods to large environmental disturbances such as isolation is very similar in the Saemangeum area and Isahaya Bay. If there is no improvement in environmental conditions in these areas, it is supposed that a few species of bivalve and gastropod will increase and subsequently decrease while most species will disappear completely from the Yellow Sea and Ariake Bay.

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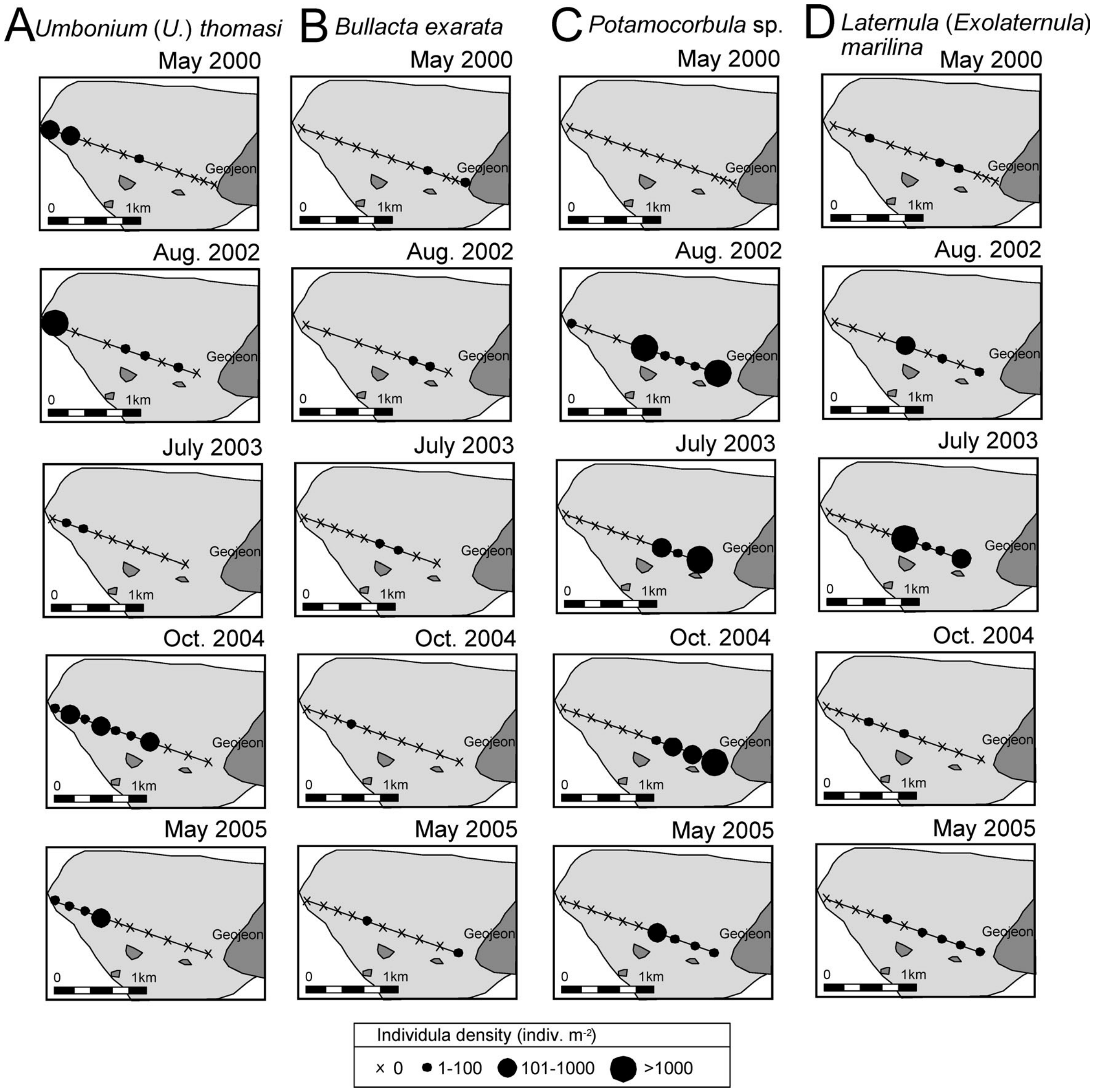

Fig. 12. Temporal change of distribution patterns in (A) *Umbonium* (*U.*) *thomasi*, (B) *Bullacta exarata*, (C) *Potamocorbula* sp. and (D) *Laternula* (*Exolaternula*) *marilina* in the middle site of the Saemangeum area from May 2000 to May 2005 (from Sato & Yamashita 2006).

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