ISSN 2432-4965
有明海漁民・市民ネットワーク
2017年11月7日発行　第4号
4

有明海の環境と漁業

Environment and fisheries in the Ariake Sea

● Featured Articles in English

Isahaya Bay Reclamation Problem

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表紙写真

シチメンソウ群落とガネ捕りの女性（諫早湾小野島地先）

写真・文　中尾勘悟（有明海写真家）

諫早湾奥部のシチメンソウ群落が注目され始めたのは、南総計画が浮上して有明海全域の漁民が抗議を始めた1970年代だったような気がする。最初、長崎大学の伊藤秀三教授が、ハママツナの群落があると新聞に発表したが、何年か経って実はミルマツナ（シチメンソウ）だったと訂正されたことがあった。

そのころまでは、シチメンソウは小野島の堤防の外に少し生えていたのだが、諫早湾干拓事業が本格的に地元漁協と漁業権放棄の交渉に入った1980年代になると、県も国も旧堤防の補強には全く手を付けなくなって、旧堤防の外側も放置された状態が続き、潟泥の堆積が進み、ヨシは干陸化した干潟に進出しはじめ、シチメンソウも生育面積を広げていった。そのため閉め切る数年前には、小野島、黒崎の堤防の外側には、シチメンソウの大群落ができていた。

堤防のすぐ近くの干潟とシチメンソウの群落の周辺には、カニ類やトビハゼなどがたくさん生息していて、初夏から晩秋にかけて“ガン漬け”（シオマネキやアリアケガニを香辛料と塩を入れてすりつぶした塩辛）の材料にするカニを捕りに、地元からも佐賀県芦刈や久保田、福富、白石、有明、鹿島からも軽トラックなどで来ていた。他にもアゲマキやウミタケ、ワラスボ、ムツゴロウ、ウナギ、アキアミなどを狙って、時期になれば必ず何人かやってきていた。実は諫早湾の干潟は佐賀県の干潟よりも豊かだったわけだ。いろいろな経緯があって、年間数万円の入漁料を納めて、鹿島市浜町の7名のムツ掛け漁師が諫早湾に通うようになった。

Isahaya Bay Reclamation Problem

Introduction

Under the Isahaya Bay Reclamation Project, Isahaya Bay was closed off from the rest of the Ariake Sea by a dike in 1997, destroying the vast tidal flats in the bay and living organisms that inhabited there. This incident made the headlines both at home and abroad. Ever since, fisheries in the Ariake Sea has been on the decline. The third-party committee made a proposal to the government to open the floodgates of the dike and carry out medium- and long-term surveys. And the court ordered the government to open the floodgates and conduct the surveys, but the government refused to follow the order and this spring (2017) Minister of Agriculture, Forestry and Fishery announced the government's policy not to open the floodgates.

Asian Wetland Symposium 2017 will be held this November in Saga City that faces the Ariake Sea. The symposium, which is related to the Ramsar Convention, will attract many individuals who are committed to wetland conservation from around Asia and other parts of the world. And problems arising from the reclamation project in Isahaya Bay will catch the attention of the participants as an example of wetland destruction.

However, very few materials that explained the problems caused by the reclamation project in a comprehensive manner have been prepared in English until now. For this reason, we planned to publish an English version of featured articles so that people of different nationalities can refer to it.

Articles carried in this journal are mainly summaries and excerpts of papers from our booklet titled "Open the Floodgates in Isahaya Bay to Revive the Ariake Sea" that was issued in 2016 by the Association of Researchers Calling for the Opening the Floodgates in Isahaya Bay.

Dams and estuary weirs have caused problems of wetland destruction all around the world. We hope you will read these articles and further deepen your understanding of the problems in order to avoid a tragedy similar to the one we have suffered in Isahaya Bay. Furthermore, we will be very happy if we could have your generous support and advice for our activities to call for the open-gate surveys to revive the ecosystem and fisheries of the Ariake Sea.

Association of Researchers Calling for the Opening
the Floodgates in Isahaya Bay

Ariake Sea Network of Fishermen and Citizens

1 Isahaya Bay Reclamation Project —the most devastating wetland destruction in Japan—

Takayuki Jinnai
The Ariake Sea Network of Fishermen and Citizens

1. A desperate cry of the Ariake Sea, "the Sea of Treasures"

The Japanese archipelago has large and small inner bays, and inner bay fisheries were thriving in various areas including Tokyo Bay, Osaka Bay, Ise Bay, Seto Inland Sea and so on. Among them, the Ariake Sea was a representative area for inner bay fisheries in Japan. Fishery in the Ariake Sea was vibrant until the 1990s when fisheries in other inner bays around major cities declined due to post-war development in Japan. It was home to many endemic species such as the blue-spotted mudskipper and eel goby. Sustainable fishing was practiced by local fishermen using more than 60 traditional fishing methods and fishery was one of the key industries that supported the regional economy. The Ariake Sea was called "the sea of treasures". A pen shell fisherman could earn as much as 20 million yen in one season and build a "palace". Related industries such as shipbuilding and tourism were also prosperous. Eel fishing using unique fishing methods was also flourishing and eel was one of the local specialties. In the coastal tidal flats, local residents gathered shellfish and other edible organisms as their ingredients for supper. The tidal flats were a bustling playground for children.

However, as the period of high economic growth began, human activities affecting the ecosystem in the fishing ground increased. Amounts of gravel mined from the bottom of the Chikugo River and other rivers draining into the tidal flats rapidly increased, and the area of the tidal flats rapidly decreased due to the reclamation of the inner part of the Ariake Sea. It was the Isahaya Bay Reclamation Project that dealt the final blow to the Ariake Sea.

The project plan has survived through many years by changing its name from "Nagasaki Grand Reclamation Plan (for rice cultivation)" to "Comprehensive Regional Development Plan for Southern Nagasaki (for securing freshwater resources)", and then to "Isahaya Bay Comprehensive Flood Prevention Reclamation Plan (for disaster prevention)". In an effort to dodge the fishermen's fierce opposition, the state government put a disguise of "disaster prevention for the local residents" on the project and explained that "the impact would be limited to the vicinity of the project site (environmental assessment)". In the end, the fishermen were compelled to agree to the project.

However, when the construction work of the flood-control dike began, the pen shell fishery in Nagasaki prefecture was forced to be suspended

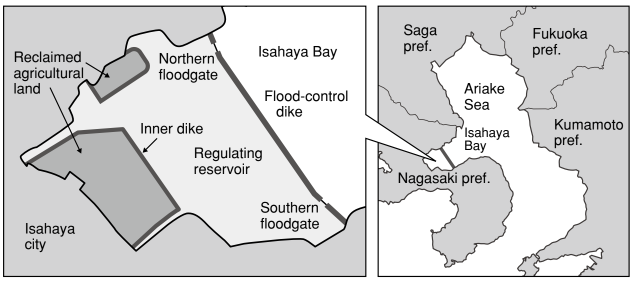

Fig. 1 Isahaya Bay Reclamation Project
The inner part of Isahaya Bay (approx. 3,550 ha) was shut off from the rest of the Ariake Sea by the flood-control dike which stretches about 7 km across the bay. A double dike system of land reclamation where a regulating reservoir (2,600 ha) was constructed inside the flood-control dike and 942 ha of farmland was developed on the landward side of the regulating reservoir. Total project cost is ¥253.3 billion. The reclamation works commenced in 1989. The flood-control dike was closed in 1997 and the project completed in 2008.

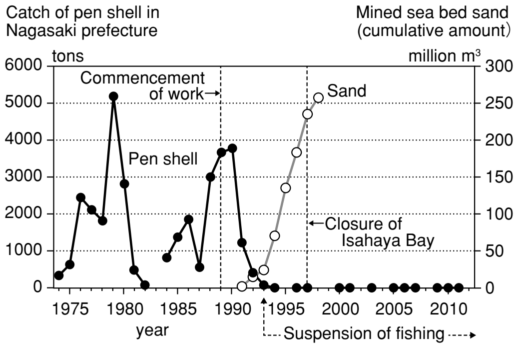

Fig. 2. Catch of pen shell in Nagasaki Prefecture and cumulative amounts of sea bed sand mined from the bay mouth of Isahaya by the reclamation work

from 1993 due to a massive sand mining operation at the mouth of the bay and increased turbidity of water due to suspended mud particles stirred up from the bottom by the operation of work ships.

And on April 14, 1997, when 293 steel panels were dropped one after another into the open part of the 1.2 km flood-control dike, the inner recess of Isahaya Bay was closed. The tidal flats in Isahaya Bay completely dried up and transformed into a vast expanse of carcasses of blood cockles, oysters and many other organisms. The lost vast tidal flats were a major breeding ground for endemic species in Japan such as the blue-spotted mudskipper and fiddler crab, and were also globally important as a stopover for migratory birds. The 2,900 ha of lost tidal flats represents the largest wetland destruction in Japan. The loss of vast tidal flats, which used to be a nursery ground for fish and have excellent purification function, greatly impacted the inner bay fishery in the subsequent years.

In addition, three years after the dike was closed, in December 2000, a massive red tide involving *Rhizosolenia* occurred, and aquaculture of nori or seaweed laver was hit hard in the entire Ariake Sea. The fishermen's opposition was intense, and it became a big social problem known as the "environmental disturbance in the Ariake Sea". For 17 years since then, the Ariake Sea has not been restored, and the damage to the local fishery has become serious year by year.

2. The battle to restore the Ariake Sea

The extremely poor harvest of nori ignited the anger of the fishermen. They forced the reclamation work to stop and demanded the removal of the dike. On the other hand, the state government formed a third-party committee to control the situation, but the committee recommended that an open-gate investigation be conducted by gradually opening the floodgates in December 2001. The government feared that the project will have to be canceled if the result of the open-gate investigation proves the impact of the reclamation project. They decided to resume the construction early in the following year, and conducted a short-term open-gate investigation in April on condition that they will be excused from conducting a mid-to long-term investigation as the project has to be completed without delay. The government enacted the Act on Special Measures concerning Rejuvenation of Ariake Sea and Yatsushiro Sea and established the Ariake Sea and Yatsushiro Sea Comprehensive Investigation and Evaluation Committee. In May 2004, Minister of Agriculture, Forestry and Fisheries issued a statement that the government will carry out a rehabilitation project instead of a mid-to long-term open-gate investigation.

In response to this, in October 2002, the fishermen filed a lawsuit in Saga District Court seeking an injunction to put a halt to the project and to remove the flood-control dike. The long struggle in a judicial court which continues even now has started. After the plaintiffs' victory in the provisional decision of the district court (August 2004) and the reversal of the decision by the upper court (May 2005), farming on the newly reclaimed land started in April 2008. The fishermen's movement had to adjust its course towards seeking the opening of the floodgates on the premise that farming had already begun on the reclaimed land. Then, following the fact that the Saga District Court ordered the state government to open the floodgates in June 2008, Fukuoka High Court also passed a judgment in favor of the plaintiffs in December 2010. As the then Prime Minister Naoto Kan's cabinet did not appeal to a higher court, Fukuoka High Court's ruling to order the state government to open the floodgates was finalized.

However, the state government continues to fail to fulfill their obligation ordered by the final court ruling even after seven years. They conspire

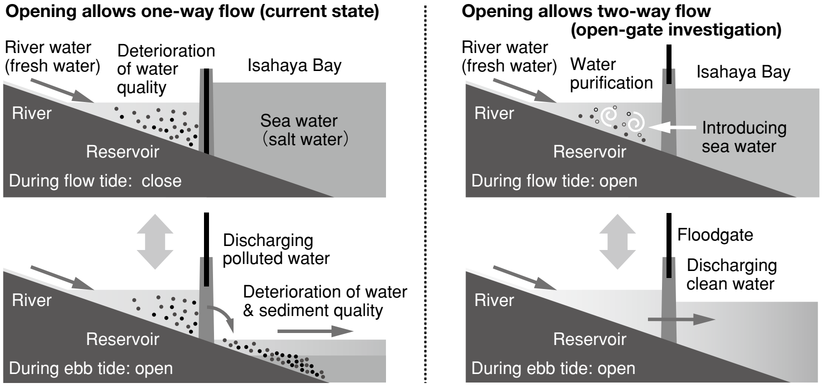

Fig. 3. Different way of opening the floodgates — floodgates that are currently opened and the way they should be opened for the open-gate investigation

with those who oppose to the final court ruling such as Nagasaki Prefectural government to work behind the scenes, taking a stance to deliberately lose a lawsuit filed against them by farmers and residents seeking an injunction barring the government from opening the floodgates. In April 2017, when Nagasaki District Court passed a judgment ordering the cancellation of opening the floodgate, the state government did not appeal and declared that they will not honor the final ruling by Fukuoka High Court that ordered the opening of the floodgates.

3. Obey the laws of nature and realize a sustainable society!

Besides the Ariake Sea, inner bay and brackish water areas are rich in biodiversity and are regarded as internationally important areas supporting the ecosystem. It is important not only internationally as a habitat to nurture young migratory birds but also an important place to support the coastal fishery and eventually the community. Three tidal flats (Arao-higata, Hizen Kashima-higata and Higashiyoka-higata) are registered as Ramsar Sites, but the bounty of the tidal flats in Isahaya Bay is far greater than those of the three sites. Speaking from the viewpoint of the restoration of the Ariake Sea, the Ariake Sea as a whole deserves to be registered as Ramsar Wetland. When restoration of Isahaya Bay tidal flats and revitalization of the Ariake Sea are realized, it will attract attention globally as a precious experience.

The state government has spent about 100 billion yen for a revitalization plan for Ariake Sea for 13 years since 2004. However, the ecosystem of the fishing ground has not improved even slightly. It is because all measures are symptomatic and ignore the laws of nature. Specifically, as Isahaya Bay was shut off from the rest of the Ariake Sea, (1) Isahaya Bay tidal flats, which used to function as a natural septic tank, was modified to a pollution control site called regulating reservoir, and polluted drainage from the reservoir has exacerbated the fishing ground environment. (2) The state government has not taken fundamental measures against the fact that the tidal current characteristics of the Ariake Sea have changed, and the occurrence of red tide and hypoxic water mass has become more frequent. In other words, if we look seriously at the cause of such incidents and respond to them according to the laws of nature, nature will surely be restored. Open-gate investigation of Isahaya Bay is essential to determine the cause, but it is merely the first step toward restoration. Ariake Sea will not be restored forever, if the state government continues to refuse an open-gate investigation.

The necessary measures (such as securing water for agriculture and measures against salt damage) can be taken sufficiently in conducting an open-gate investigation. As Isahaya Bay Reclamation Project has almost no disaster prevention effect besides storm surge control, it is important to carry out disaster prevention measures which are originally required for protecting the reclaimed land. In order to fulfill the social mission of revitalizing the Ariake Sea, and to build a society where agriculture and fishery are mutually prosperous, the open-gate investigation, which is the first step, must be carried out. It is the first step toward realizing the sustainable society that the Ramsar Convention calls for and it is also an international request.

2 The values of very soft mudflats in the Isahaya Bay in the Ariake Sea, Kyushu, Japan

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Introduction

The estuarine environment is characterized by having a constantly changing mixture of salt and fresh water, and by being dominated by fine sediment carried into the estuary from the sea and rivers, which accumulates in the estuary to form mudflats, fringing the interface between the sea and land (McLusky & Elliott, 2004). The estuarine mudflats have the highest levels of primary production of microalgae and salt-marsh vegetation, which support large numbers of invertebrates, fish and shore birds. This is because estuarine waters are typically rich in nutrients which have been carried there mainly from the land through rivers and underground water currents, and the wide area of intertidal mudflats can receive direct sunlight at low tide. Though the number of species within estuaries is less than that either in the sea or in fresh water, the small number of species that are well adapted to the changeable estuarine environments can markedly increase in biomass and productivity (Levinton, 2009).

Japan is favored geographically by semi-enclosed embayments with various scales of estuarine mudflats (Sato, 2010). Therefore the mudflats have traditionally been a rich source of food, such as bivalves and bottom-dwelling fish, as evidenced by ancient shell mounds. However, estuarine mudflats have been severely damaged by recent anthropogenic coastal developments such as land reclamation and sea-wall construction. About 40% of the total area of intertidal flats on the Japanese coasts were lost between 1945 and 2005 (Hanawa, 2006). Consequently, the peculiar fauna and flora of estuarine mudflats appear to have been extirpated in many embayments in Japan, and many traditional fishery products have diminished, as various traditional fishery methods have disappeared. At present, many mudflat-specific species are designated as endangered species, including the major food species which typically make up part of the traditional Japanese diet, such as the bivalves *Tegillarca granosa* (vulnerable species, VU) and *Sinonovacula lamarcki* (critically endangered and endangered species, CR+EN) (Ministry of the Environment, 2017).

The Ariake Sea in western Kyushu (**Fig. 1**), which constitutes the largest area of mudflats remaining in Japan, has the greatest variety of mudflat-specific species (Sato & Takita, 2000). Lots of the mudflat-specific species are completely or almost completely restricted to the Ariake Sea in Japan (Ariake Sea indigenous species), although populations of the same or closely related species are distributed along Asian continental coasts, suggesting that they are continental relicts. The Ariake Sea is special in that the original mudflat ecosystem and the traditional fishery have been well preserved, compared with other areas in Japan. With no social attention to this aspect, however, vast mudflats in the inner part of Isahaya Bay, covering up to 29 km^2 at spring tides (Kyushu Agricultural Administration Office, 1991), in the inner part of Ariake Bay, were lost due to the enclosure of the inner bay area (36 km^2) by the construction of a 7-km dike in April 1997 (**Fig. 2**) (Sato & Takita, 2000; Sato & Koh, 2004; Sato, 2010, 2017).

In the present article, the characteristics of the mudflat ecosystem in the Ariake Sea are summarized, with reference to the significance of restoration of the estuarine habitats in Isahaya Bay to conserve the last remaining habitat for

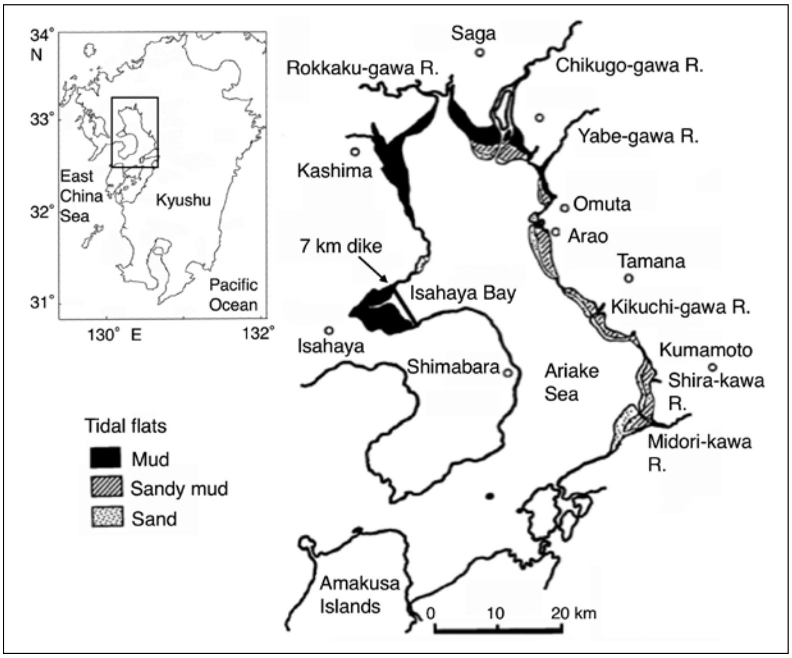

Fig.1. A map showing the distribution of tidal flats in the Ariake Sea in western Kyushu in Japan. After Shimoyama & Nishida (1999). The range of tidal flats in Isahaya Bay was modified based on the measurement at the low-tide mark of spring tides at 1983 by the Kyushu Agricultural Administration Office (1991).

many endangered species, together with the traditional fisheries of the Ariake Sea.

Characteristics of the mudflats in the Ariake Sea

The Ariake Sea (1,700 km^2 in total area, 20 m in average depth) (**Fig. 1**) is a unique macro-tidal embayment with a maximum tidal range of about 6 m in the innermost area, whereas Japanese coasts are generally micro-tidal with ranges of less than 2 m (Sakakura, 2004). The whole area of the semi-enclosed Ariake Sea with a large amount of freshwater inflow could be regarded as a single estuary (Kikuchi, 2000). In this embayment, vast tidal flats are formed on the northern (innermost) and eastern coasts, where the largest river in Kyushu (Chikugo-gawa) and several other large rivers flow, also supplying large amounts of sand and mud particles (Sato & Takita, 2000). Yokoyama (2007) estimated that 76% of the total particles supplied to the Ariake Sea come from Chikugo-gawa River, mainly originating from the volcanic sediment of Mt. Aso and Mt. Kuju.

Mud particles deposited on the sea floor of the bay are easily separated from sand particles and re-suspended into the water column by strong tidal currents as floating mud particles. The floating mud particles are transported to the upper littoral zones in a vertical direction, and to the upper reaches of the estuary in a horizontal direction by “flood-ebb current asymmetry” (Sakakura, 2004), and are also displaced counterclockwise by the Coriolis effect (Shimoyama & Nishida, 1999). Consequently, extensive mudflats composed of silt or clay particles are formed in an area from the innermost of the Ariake Sea to Isahaya Bay, fringing the north and northwest coasts of the embayment. Of the whole sediment particles originated from the Chikugo-gawa River, the finest mud particles (clay) are transported farthest, into Isahaya Bay, producing typical soft mudflats there before the reclamation (Fujimagari & Makino, 2001). On the other hand, sand particles, which are not re-suspended by tidal currents, collect around the mouths of rivers, forming wide sandflats on the eastern coast of the Ariake Sea (**Fig. 1**).

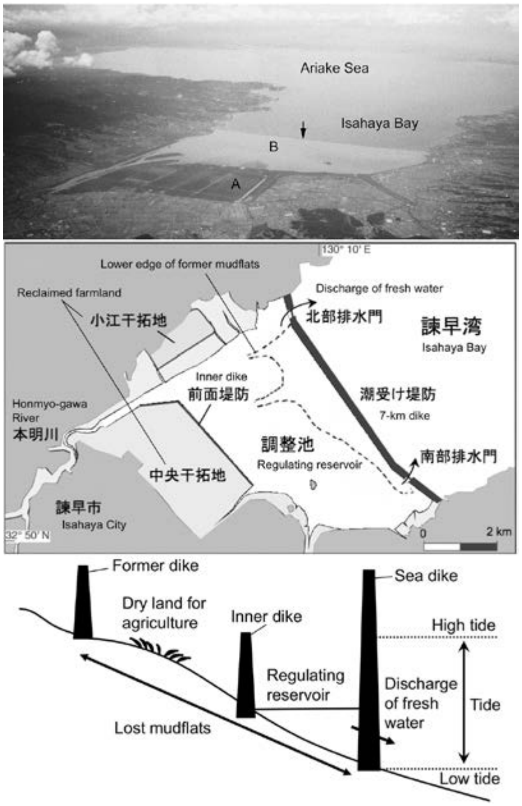

Fig. 2. Reclamation project in Isahaya Bay. (Top) The land-reclamation project in progress in Isahaya Bay in the Ariake Sea in Kyushu, photographed in July 2000. The inner part of Isahaya Bay was completely closed by a 7-km dike (arrow) in 1997. The original tidal flats were changed to dry land in the upper part (A) and to a regulating reservoir in the lower part (B). After Sato (2010). (Middle) Map showing the inner part of present Isahaya Bay, with the lower edge of former mudflats of 2900 ha (dotted lines). Modified from an original figure by Shinichi Sato. Fresh water has been constantly discharged from the regulating reservoir to the sea through the two gates to keep the elevation of the regulating reservoir as -1 m. (Bottom) Schematic diagram of the sectional view of the land reclamation. Average tidal range in spring tides is 5.4 m here.

Endangered species remaining in mudflats in the Ariake Sea

Many endangered species inhabit the Ariake Sea, some of which are no longer found elsewhere in Japan. For example, the following seven Ariake Sea-indigenous fish mostly inhabit the inner part of the Ariake Sea, and depend on mudflats or related environments for at least some period in their life cycles (Nature Conservation Committee of Ichthyological

Fig. 3. Mass deaths of the bivalve *Tegillarca granosa* inhabiting mudflats in the inner part of Isahaya Bay in the Ariake Sea in August 1997 (4 months after enclosure of the sea by the dike construction). Photographed by Kenji Tominaga. After Sato & Takita (2000).

Society of Japan, 2009): *Boleophthalmus pectinirostris* (endangered species (EN)), *Odontamblyopus lacepedii* (VU), *Acanthogobius hasta* (VU), *Trachidermus fasciatus* (EN), *Coilia nasus* (EN), *Neosalanx reganius* (critically endangered species (CR)), and *Salanx ariakensis* (CR). Some of them have benefited local people as fishery resources.

At least some of the species now restricted to the Ariake Sea previously had a wide distribution in Japan. This has been well documented in some bivalves. For example, *Tegillarca granosa* (VU) was once distributed widely, ranging from Kyushu to Hakodate, in Hokkaido, about 6,000 years ago according to fossil records, and living specimens were recorded in several embayments in central and western Japan as recently as 100 years ago (Sato, 2000). However, at present, its distribution is limited to the innermost part of Ariake Sea and additional small habitats in the Shiranui Sea and Imari Bay in western Kyushu (Japanese Association of Benthology, 2012). The dense population of this species, inhabiting mudflats of Isahaya Bay, was recently extirpated by the reclamation project mentioned above (**Fig. 3**) (Sato, 2000; Sato & Koh, 2004).

Our recent examinations of old polychaete specimens deposited in Japanese and European museums revealed that the distribution of *Hediste japonica* (EN) formerly extended to central Japan, including the Seto Inland Sea, Ise Bay, and Mikawa Bay at least until 1969 (**Fig. 4**)

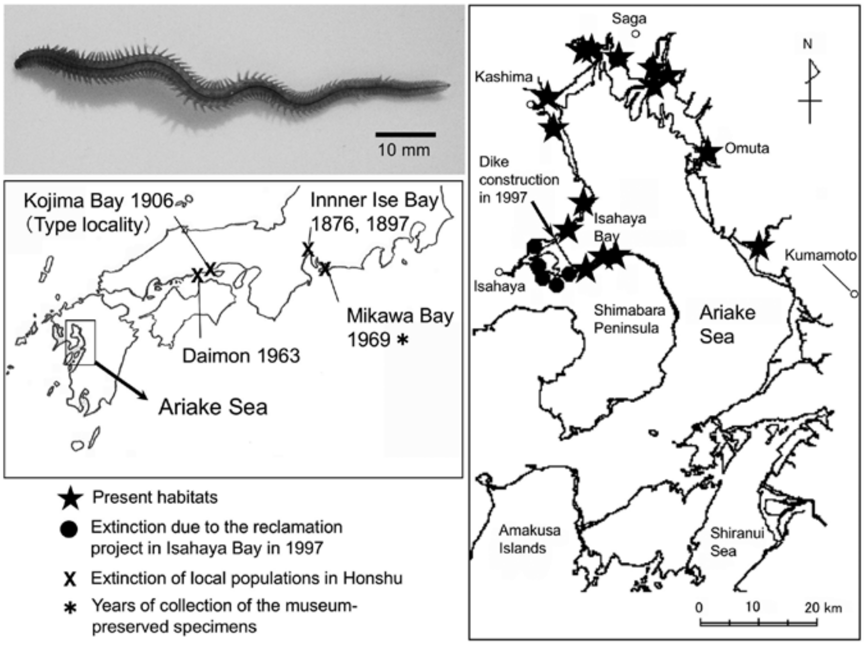

Fig. 4. Distribution of *Hediste japonica* in Japan. Modified from Sato (2017).

(Sato & Sattmann, 2009; Sato M, unpublished data). However, all populations of *H. japonica* seem to have been extirpated throughout Japan, except for in the inner part of the Ariake Sea.

Similar reduction of the distribution has also been suggested for the brachiopod known as a "living fossile", *Lingula adamsi* (CR) (Ministry of the Environment, 2017), and a salt marsh plant, *Suaeda japonica* (VU) (Jinno, 2000), both surviving only in the inner part of Ariake Sea in Japan at present.

The reclamation project in Isahaya Bay caused the loss of the most important habitat for many endangered mudflats-specific species (Sato, 2010).

High productivity of the mudflat ecosystem

Intertidal mudflats have the highest levels of primary production by benthic microalgae (mainly diatoms), because they are rich in both nutrients and light; fine mud particles can adhere to large numbers of nutrient substances, and the wide surface of mudflats exposed to air around low tides can receive the energy of sunlight efficiently, acting like huge solar panels, so that the blooming of benthic diatoms is promoted on the surface of the mudflats (**Fig. 5**) (Sato, 2017).

The benthic diatoms and detritus deposited on the mudflats are fed on by various macrobenthis invertebrates, fish, and even shore birds. The macrobenthos are fed on by carnivores coming from outside of mudflats. Mudflat-specific endangered species often attain extremely high densities and biomasses in the Ariake Sea. For example, the maximum density of a population of the bivalve *Tegillarca granosa* (3−5 cm in shell length) reached 73 ind. m^{-2} on mudflats in Isahaya Bay at the time of its mass deaths due to the enclosure of the Bay in 1997 (Sato, 2001, see **Fig. 3**). The maximum biomass of a population of the polychaete *Hediste japonica* was recorded at as much as 1kg m^{-2} in wet weight in an estuary of the Omuta-gawa River (Hanafiah et al., 2006).

Such large biomass of macrobenthic invertebrates on mudflats can support the lives of large numbers of carnivores such as shore birds and bottom-dwelling fish. The highest number of migratory shorebirds in Japan (13,500 individuals) was recorded on the mudflats in Isahaya Bay in spring 1988, before the enclosure of the mudflats (Hanawa & Takeishi, 2000).

Traditional local fisheries are also supported by high productivity in the mudflat ecosystem. For example, the estuarine mudflats play a key

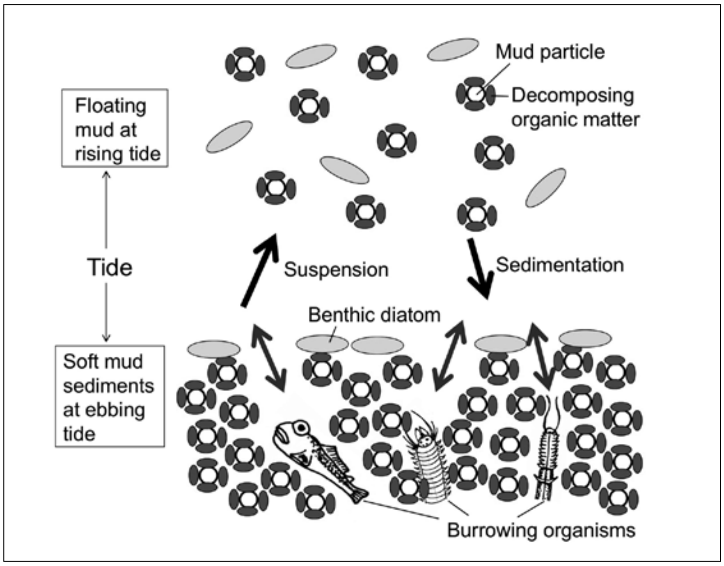

Fig. 5. Schematic diagram of the typical mudflats composed of fine mud particles at rising (top) and ebbing (bottom) tides. Modified from Sato (2017).

role for the larval settlement and the following growth of the Japanese eel, *Anguilla japonica* (EN, one of the most important fishery resources in Japan), greatly contributing to maintainance of the natural populations of the eel (Kaifu, 2016). The eel feeds on various macrobenthos on the mudflats (Kan et al., 2016). Traditional eel fishing on the mudflats using various methods (e.g., using a Japanese eel fork "Unagi-kaki") continues to this day in the inner part of the Ariake Sea.

Function of mudflat ecosystem

Through the food chain in the mudflat ecosystem, most nutrients (nitrogen and phosphate) carried from the land to the sea are efficiently used for production of biota in the ecosystem, and are consequently moved out of the mudflats by migrating carnivores such as shore birds (Sato, 2017). Local traditional fishery activity also plays a role similar to that of the shore birds. Some of the nitrogen is transported from the mudflats to the atmosphere as a gas through bacterial denitrification, which is highly active in the mudflat ecosystem (Sayama, 2007).

Consequently, the mudflat ecosystem acts as a natural filter that absorbs and removes most of the large quantities of nutrients flowing from the land into the sea, reducing the nutrient input in coastal waters in embayments. This activity (water-purifying function) is important to reduce the deteriorative effects of eutrophication, such as occurrences of red tides and low-oxygen bottoms. The water-purifying function of the ecosystem is not only limited to the removal of nutrients, but also includes the simultaneous production of various biota including fishery resources by use of the nutrients (Sato, 2017).

Moreover, estuarine mudflats play another important role as a nursery ground for many fish and macrobenthic invertebrates such as prawns, whose lifecycle includes migrations between the mudflats for the larval or juvenile stages and off shore, freshwater, or land for the adult stages (Sasaki, 1999). Therefore, the loss of mudflats negatively impacts on a wide area of neighboring habitats including coastal waters, rivers, and the land.

Conclusion

From a long-term viewpoint for the next generations, conservation and restoration of Japanese mudflats are desirable in terms of the conservation of many endangered species inhabiting mudflats and the traditional fisheries supported by them. In particular, the restoration of the estuarine mudflats in Isahaya Bay in the inner part of the Ariake Sea is highly desirable, because the inner part of the Ariake Sea is the last remaining habitat in Japan for many endangered species, which the traditional fisheries depend on. If the tidal currents can be recovered within the regulating reservoir, which was converted from lower estuarine mudflats to a freshwater pond due to the enclosure of Isahaya Bay, the estuarine habitats for many endangered species have the propensity to be restored rapidly, leading to the recovery of the function of the mudflat ecosystem as a water-purifier and nursery ground in Isahaya Bay. Large-scale restoration is expected to improve the recent poor environmental conditions for the traditional fisheries in the inner part of the Ariake Sea.

Acknowledgments
I thank Bo Causer (Kagoshima University) for help in English review.

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3

Changes in Water Quality of the Regulating Reservoir and Impacts of Isahaya Bay Reclamation Project on Isahaya Bay and the Ariake Sea

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1. Water quality of the regulating reservoir of Isahaya Bay has deteriorated since the the flood-control dike were closed

The tidal flat area of Isahaya Bay was cut off from the waters of the Ariake Sea by a dike in April 1997. Ever since, water quality of the regulating reservoir in the bay has deteriorated dramatically with no sign of improvement for 20 years to this day in 2017. Nagasaki Prefecture has taken water purification measures since the reservoir was constructed, but has seen little effect. Its "Second Stage Action Plan for the Conservation and Creation of Shore Environment in the Regulating Reservoir of Isahaya Bay" that specifies actions to be taken after 2008 describes what the prefecture intends to do but does not analyze why their measures have not produced any result.

Fig. 1 shows changes in the concentrations of suspended solids (SS) and chemical oxygen demand (COD) and **Fig. 2** shows those of total nitrogen (TN) and total phosphorus (TP) in the regulating reservoir. All values show that its water quality has deteriorated since 1997 when the dike was closed. Compared with the concentrations before the closure, SS, COD, TN and TP values increased 3.8-fold, 2.2-fold, 3.1-fold and 3.9-fold respectively.

According to the data that Hitomi Horie, a member of the Nagasaki prefectural assembly, obtained in November 2014, Nagasaki Prefecture spent about ¥14.7 billion for measures to improve the water quality from 2004 to 2013. However, as **Fig. 1** and **Fig. 2** indicate the water quality has not improved.

There are three possible causes for the sharp increase in the concentration values: (1) effects of seawater dilution was lost because the dike prevented the freshwater in the reservoir from mixing with sea water whose SS, COD, TN and TP concentrations are low, (2) decrease in benthic population slowed down the decomposition of organic matters (secondary treatment), and (3) SS increased because lower salinity prevented its aggregation and sedimentation (any rise in the SS value can lead to higher COD, TN and TP values because SS adsorbs nitrogen, phosphorus and organic matters). Opening the floodgates

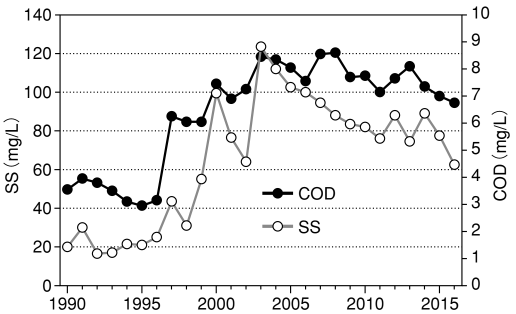

Fig. 1. Changes in the concentrations of SS and COD in the regulating reservoir.

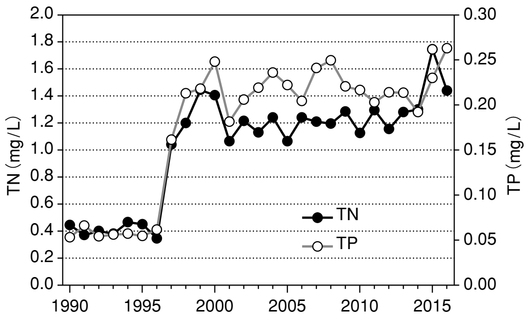

Fig. 2. Change in the concentrations of TN and TP in the regulating reservoir.

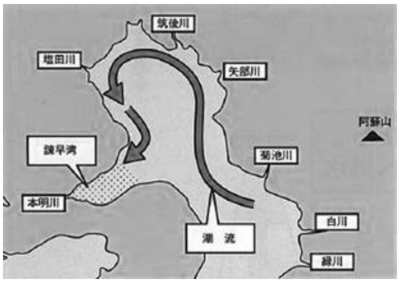

Fig. 3. Formation mechanism of Isahaya tidal flats. (Source: Website of Isahaya bay reclamation division of Nagasaki Prefectural Government)

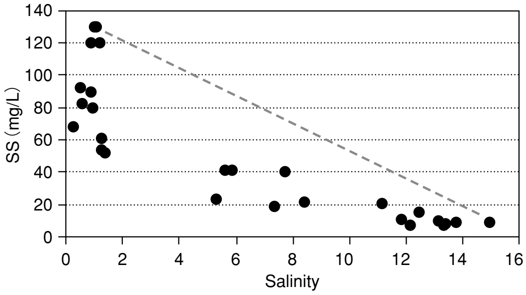

Fig. 4. Relation between salinity and SS during the short-term open-gate survey.

will have three effects. (1) It will lower their concentrations through dilution by seawater. (2) It will increase benthic population and thus reduces organic loads in Isahaya Bay to certain levels even though it will not reduce nitrogen and phosphorus loads significantly. (3) The gate opening is related to a tidal flat formation mechanism and this paper focuses on the third effect.

2. Relation between the formation mechanism of Isahaya Tidal Flat and the deterioration of water quality in the regulating reservoir

On the website of Isahaya Bay Reclamation Division of Nagasaki Prefectural Government, one can find the following explanation of how Isahaya Tidal Flat was formed along with **Fig. 3**:

> Major rivers including the Chikugo River that flow through Fukuoka Prefecture carry volcanic ash from Mt. Aso as well as sand and mud into the Ariake Sea. A counterclockwise current in the central and inner parts of the sea slowly carries fine sand and mud particles and volcanic ash, which are deposited in the areas such as Isahaya Bay where the flow slows down. Sediment or gata-soil deposits at a rate of 5–6 cm per year and the tidal flat expands by about 10 cm toward the sea every year.

River water flowing into the Ariake Sea contains fine and invisible clay particles whose diameter is less than 5 μ (1 μ = 1/1000 mm). They are too small to see, and therefore water is not turbid. Since the surface of clay particles is usually negatively charged, they repel each other and never stick together. However, near the estuary where water contains more salt ($Na^{+}CL^{-}$), clay particles lose their negative charge due the positive ion of salt, stick together and form larger particles. As a result, water becomes turbid. When the particles become larger, they are deposited and form a tidal flat. Shirota (1998) calls the process in which clay particles encounter salt, grow and form lumps “flocculation”. He stated that flocculation occurs in an instant and the particles adsorb phosphoric acid and organic matters in the process. When flocs become large, they accumulate on the sea floor and form a tidal flat. In the regulating reservoir, clay particles flocculate to a certain extent, but do not become large enough to be deposited onto the bottom because of low salinity (around 1). The particles are suspended in water, and water becomes turbid. This is why SS values jumped from 20 mg/L to approximately 100 mg/L as shown in **Fig. 1**. As Shirota describes (1998), SS adsorbs organic matters, nitrogen and phosphorus. This means as the amount of SS increases, the values of COD, TN and TP rise. Because of the regulating reservoir, clay particles flow into Isahaya Bay without being deposited onto the sea floor. Consequently, substances that used to be removed through deposition stay in water without being, and the reservoir loses its water purification capacity and becomes polluted.

The result of a survey conducted in 2002, when the floodgates were opened for a short period of time, proved that Shirota’s theory is correct. **Fig. 4** shows the relation between salinity and SS during the survey. The dotted line in the figure represents the relation between the SS concentration and salinity when the water is diluted by seawater. Actually, the SS concentration increased as salinity rose, peaked at the salinity level of around 1.0, and then plunged. Based on Shirota’s theory, SS lost its surface charge as salinity increased. This triggered the flocculation of SS, and the concentration reached to its peak at the salinity level of around 1.0, and then as flocculation accelerated the growth of SS particles and started to fall onto the sea floor. As a result, the SS concentration dropped substantially. The gap between the lines representing the SS flocculation when the water in the regulating reservoir was diluted by seawater and the actual SS flocculation in the figure indicates the amount of SS that was flocculated and fell to the sea floor. It appears that a certain percentage of the amount was deposited on the sea floor. Probably because they do not want to admit flocculation, sedimentation and deposition of SS, the Kyushu Regional Agricultural Administration Office argued that the drop in the SS value was resulted from the dilution effect by sea water, which is obviously incorrect.

3. Estimates of purification capacity of Isahaya Tidal Flat and pollution load from the regulating reservoir after the dike was closed

Based on the data of the Kyushu Regional Agricultural Administration Office (1991), the layer of sediments deposited on the Isahaya Tidal Flat during 14–15 years is about 20–80 cm thick. Suppose that the sedimentation rate is 5 cm/year and the area of the regulating reservoir is 2,900 ha, one can estimate that 58 tons of sediment is deposited on the tidal flat every year (For details, please refer to “Estimated purification capacity of Isahaya Tidal Flat by deposition before the closure of the dike”, Chapter 2-1, Section 5 of “Opening the Floodgates in the Isahaya Bay to Revive the Ariake Sea” published by the Association of Researchers Calling for the Opening the Floodgates in Isahaya Bay). A calculation by multiplying the estimated value by the average value of sediment concentrations including COD in 1989 and 1990, indicates that the annual deposition volumes of COD, TN and TP are 7,772 tons, 1,098 tons, and 398 tons respectively. According to a report on the Ariake Sea and Yatsushiro Sea by Comprehensive Investigation and Evaluation Committee (2017), a graph of annual pollution load from the Chikugo River in recent years shows that the COD, TN and TP loads are about 12,000 tons, about 7,000 tons, and about 500 tons respectively. Comparing these values against the pollution loads from rivers, one can estimate that about 65 % of COD, about 15 % of TN and about 77% of TP were removed from the bay through deposition in the tidal flat, and COD and TP removal rates were high.

COD, TN and TP loads discharged from the regulating reservoir are estimated to be 4,125, 599 and 139 tons/year respectively. Comparing the values before and after the closure of the dike, one can see the COD load increased about 12,000 tons/year from –7772 to +4125, the TN load about 1,700 tons/year from –1096 to +599, and the TP load about 530 tons/year from –398 to 139.

4. Conclusion

In the Ariake Sea, like other inland seas and particularly in summer when stratification occurs, water in the upper layer flows from the inner part to the outer part of the bay, while conversely water in the lower layer flows from the outer part to the inner part. This type of flow is called estuarine circulation. This circulation suggests that part of a hypoxic water mass that is formed in the lower water layer in the bay during summer can flow out from the mouth of Isahaya Bay into the Ariake Sea. In such a case, the hypoxic water can be advected to the area off the coast of Saga by estuarine circulation. The commission argues that in the Ariake Sea, hypoxic water masses can be formed in Isahaya Bay and the inner western part of the Ariake Sea separately and simultaneously. It was found that hypoxia occurs in the tidal flat at the inner part of the sea area off the coast of Saga because of mass putrefaction of Chattonella washed ashore on the tidal flat. However, causes of hypoxia in deep water off the coast of Saga is yet to be clarified. There is a possibility that hypoxic water mass occurred in Isahaya Bay is advected to the area. Also impacts of a large quantity of pollution loads caused by the construction of the regulating reservoir on Isahaya Bay must be further examined.

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4 The Causality between the Isahaya Bay Reclamation Project and Declining Fisheries in the Ariake Sea

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As for fishery catches in the Ariake Sea, the shellfish catch has been in consistent decline since 1980 and the fish catch since 1990 (**Fig. 1**). In 1989 when the Isahaya Bay Reclamation Project was launched, the total catch was 58,477 tons and the fish catch was 12,294 tons. In 1996 before the dike was closed, the total catch was 40,607 tons and the fish catch was 7,997 tons. And the total catch was 15,612 tons and the fish catch was 2,498 tons in 2015. Compared with the catches in 1989, the total catch decreased to 69% in 1996 and 27% in 2015, and the fish catch decreased to 65% in 1996 and 20% in 2015. **Fig. 1** shows that the catches have decreased since 1989 when the reclamation works started. The question is whether the decline was caused by the reclamation works or not. The Ministry of Agriculture, Forestry and Fisheries insists that the causal relation between the reclamation works and the decline in catches is unknown, while local fishermen feel that catches have decreased due to the impact of the reclamation works. This paper examines the causality between the decline and the reclamation works based on fishery catches by prefecture and fish species.

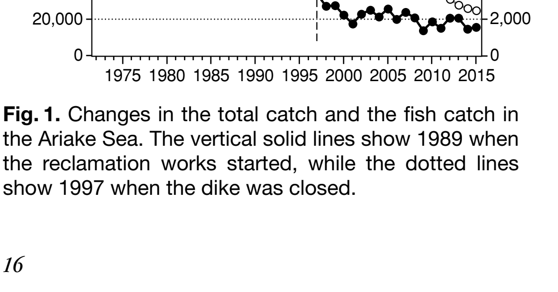

Fig. 1. Changes in the total catch and the fish catch in the Ariake Sea. The vertical solid lines show 1989 when the reclamation works started, while the dotted lines show 1997 when the dike was closed.

1. Bottom fish catches in steep decline

Fig. 2 shows changes in catches of epipelagic fish and bottom fish in the Ariake Sea. It is obvious that the bottom fish catch dropped sharply. Compared with the catches in 1989, the epipelagic fish catch decreased to 37% and the bottom fish catch to 18% in 2012. The significant drop in the bottom fish catch indicates that hypoxic water is the most likely cause of the decline. The decline in the epipelagic fish catch also requires attention.

2. Saga and Nagasaki prefectures experienced significant drops in catches

Let's look at the ratios of the fish catch in 2015 to the catch in 1989 in four prefectures along the Ariake Sea (Fukuoka, Saga, Kumamoto and Nagasaki). The ratios are 0.31 in Fukuoka, 0.15

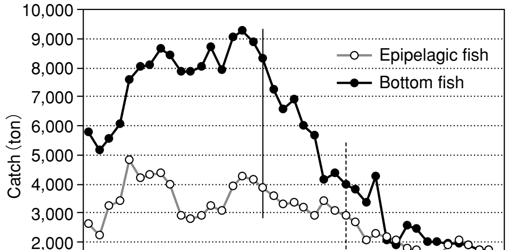

Fig. 2. Changes in catches of epipelagic fish and bottom fish in the Ariake Sea. Epipelagic fish: threadfin shad, Japanese sardine, anchovy, Japanese jack mackerel, yellowtail, lizardfish, flatfish, ribbonfish (50%) and others (35%). Bottom fish: flounder, mullet, sea eel, drumfish, ribbonfish (50%), ray, red seabream, black sea bream, sea bass, and others (65%).

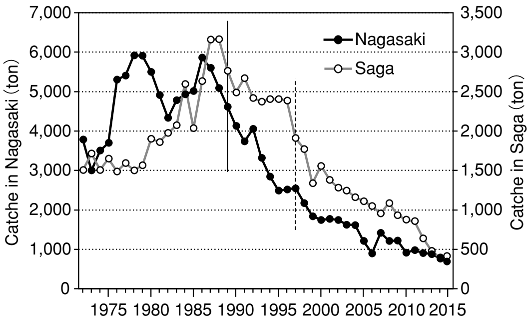

Fig. 3. Changes in fish catches in Nagasaki and Saga prefectures.

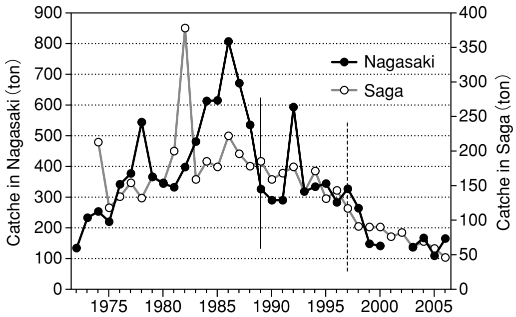

Fig. 4. Changes in drumfish catches in Nagasaki and Saga prefectures.

in Saga, 0.28 in Kumamoto and 0.15 in Nagasaki. This shows that Saga and Nagasaki prefectures experienced serious drops. **Fig. 3** shows changes in fish catches in these two prefectures. The catch in Nagasaki has been on the constant decline since 1989, while that in Saga started declining in 1997. No figure is attached, but the catch in Kumamoto started declining in 1989 and has decreased at an accelerated rate since 1999, which exhibits a pattern that combines the features of Nagasaki and Saga prefectures shown in **Fig. 3**. The fish catch in Kumamoto prefecture also shows similar trends. The fish catch in Fukuoka prefecture also has decreased since around 1989, but it does not show any accelerated decline since around 1997.

3. Changes in catches by fish species

Fig. 4 shows changes in catches of drumfish in Nagasaki and Saga prefectures. (No data on drumfish catches is available after 2006.) In the Ariake Sea, the drumfish catch is the largest in Nagasaki, followed by Saga, Kumamoto, and then Fukuoka prefectures. **Fig. 4** shows that the catches of drumfish started plummeting since around 1997 in Nagasaki and Saga prefectures. The catch in Kumamoto shows a similar trend, while the catch in Fukuoka, whose catch is the lowest, has not decreased since around 1997.

The average catches of Japanese tiger prawn in the Ariake Sea from 1972 to 2011 stand at 90 tons in Kumamoto, 27 tons in Nagasaki, 23 tons in Saga, and 17 tons in Fukuoka. **Fig. 5** shows changes in the catches of Japanese tiger prawn in Nagasaki and Saga prefectures. As dotted lines indicate, the catches have plunged since 1997. Even through it is not so large, the catch in Fukuoka, which is not included in the figure, also dropped sharply after 1997 just like those of Saga and Kumamoto. The catch in Nagasaki prefecture plunged after 1992 from 60–70 tons to 20–30 tons.

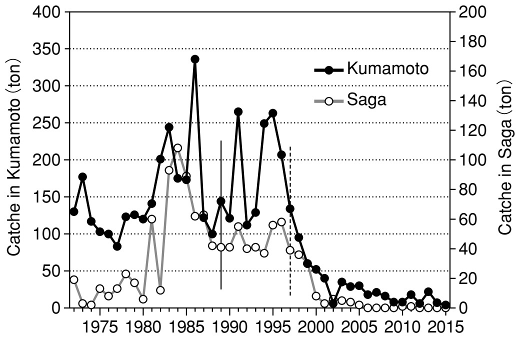

Fig. 5. Changes in Japanese tiger prawn catches in Kumamoto and Saga prefectures.

4. Consideration about the decrease in fish catches caused by the Isahaya Bay Reclamation Project

1) Changes in the fish catches clearly indicate that the catches have consistently decreased since around 1989 when the Isahaya Bay Reclamation Project was launched (**Fig. 1**). A sharp drop in the bottom fish catch is illustrated in Section 1 (**Fig. 2**). These facts suggest the possibility that the reclamation project influenced the fish catches in the Ariake Sea and in particular caused the deterioration of its sea floor environment.

2) Let's take the perspective of material circulation. After the reclamation works started, a large quantity of gata-soil or soil of the tidal flat flowed into Isahaya Bay from the construction site in the inner part of the bay. The first process

of the reclamation works that began in 1989 was ground improvement. Casing piles were driven into the tidal flat to install compaction sand piles in the ground. The sand piles are 1.6 m in diameter and 10–25 m in depth. In 1989, 1,296 sand piles were installed, removing the equivalent volume of gata-soil from the tidal flat. And the removed soil overflowed into the bay. Local fishermen surmise that the gata-soil, characterized by its high viscosity, moved slowly into the mouth of the bay without dispersing immediately, part of which was deposited on the pen shell fishing ground in the bay. Actually, fishermen in Konagai located along the bay caught 1,760 tons of pen shell in 1990, but have had no catch since 1993. It is possible that the fish catch in Nagasaki prefecture has been on a steady decline ever since 1987 due to the impact of the reclamation works. On the other hand, it appears that the catch in Saga prefecture has decreased since 1997 by the influence of a large hypoxic water mass that was formed in the bay after the dike was closed. Even though no figure is attached, the catch in Kumamoto prefecture started declining in 1989, and has plunged since 1999. This indicates possible impacts of the reclamation works and hypoxic water mass formed after the closure of the dike.

3) Changes in fish catches in the Ariake Sea are shown on page 389–397 of the Report on Comprehensive Investigation and Evaluation of the Ariake Sea and the Yatsushiro Sea which was compiled in March 2017. The following is excerpt from the report “Most of the major fish species caught in the Ariake Sea are bottom fish, whose catches have decreased. In particular, catches of tonguefish, flatfish and drumfish plummeted, and also the catch of Japanese tiger prawn shows a similar trend”. The ecology of white croaker is described on page 392: “Croaker spawns from June to August. Its spawning ground is the sea floor off Shimabara Peninsula. It is known that the larvae are passively transferred to the eastern part of the Ariake Sea. And its juveniles grow in tidal flats in the inner part and estuarine areas of the Ariake Sea.” Also page 393 carries a figure entitled “Spawning ground of Japanese tiger prawn and areas where its juveniles appear” even though no explanation is added. This figure shows that the floating larvae settle in tidal flats in Kumamoto and Fukuoka prefectures after floating from the area around the mouth of the gulf of Ariake off the southernmost tip of Shimabara Peninsula to the east part of the Ariake Sea, grow into juvenile prawns, move further away from the shore in the western part of the sea while spawning in the areas off Shimabara Peninsula and Amakusa.

Juvenile drumfish and Japanese tiger prawn grown from larvae in the tidal flats in the inner part of the Ariake Sea grow further while moving from the area off the coast of Saga to the mouth of Isahaya Bay and then to the sea off Shimabara Peninsula. Therefore bottom hypoxia in these areas causes great damage to them. Indeed, the catches of these species dropped since the dike were closed in 1997, possibly due to the influence of hypoxia.

4) In Isahaya Bay, red tides occur in summer almost every year after the dike closed in 1997. When a red tide occurs, harmful algae eventually die, sink to the sea floor and consume oxygen during the decomposition process, creating hypoxia at the bottom. Actually, in the Isahaya Bay, a hypoxic water mass is formed in summer almost every year. And it is highly possible that bottom water containing hypoxic water in the bay is transferred to the sea area off the coast of Saga by estuarine circulation. On the other hand, it is reported that seawater in the bay flows out along to Shimabara Peninsula. Therefore one can expect that hypoxic water is transferred to the sea area off the peninsula along with the flow. Indeed, hypoxia is confirmed at the bottom of this area. Therefore, it is highly possible that the closure in the Isahaya Bay resulted in the decline in bottom fish catches in the Ariake Sea.

5 Blooming of toxic cyanobacteria in the Isahaya Bay reclaimed land reservoir, South Japan:
Present conditions and prospects to resolve the problem

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Nominal function of the reservoir

The Isahaya Bay reclaimed land reservoir was created in April 1997, enclosing the innermost tidal flats of Isahaya Bay with 7 km of dike. The original tidal flats had an area of 29 km^2, and provided a habitat for a large number of species, as well as breeding and nursery areas for fish, crustaceans, and molluscs. After enclosure, many tidal flats creatures (mudskippers, fiddler crabs, etc.) were unable to survive in the drying and cracking mud. The reservoir was later filled with fresh water. The reclamation project was designed as a "reclamation by double dike", with an outer dike preventing seawater ingress and the inner dyke containing fresh water. The fresh water stored in the reservoir between the outer and inner dike was proposed for use in farming on the reclaimed land. Disaster prevention was another stated purpose of the reclamation project. Large-scale public works projects often include disaster prevention as a purpose, which is suspicious but beyond the scope of this report and will not be considered here. The primary purpose of the reservoir was securing water for agriculture; however, a detailed inspection of this purpose is necessary. A certain amount of water is necessary for agriculture, however, even if the reservoir is denoted "a pond" in Japanese, the area of this reservoir is 2600 ha with a capacity of 3000 m^3. The displacement from the reservoir is approximately 400 million m^3/year and reaches more than 500 million m^3 in some years. If a reservoir of such scale is necessary for 670 ha of reclaimed farmland, other local farms should be surrounded by reservoirs. One of us (Takahashi) lives in the hills of the rural district of Kumamoto Prefecture, and the surrounding land is extensively used for carrot, Chinese cabbage, and Japanese radish cultivation, however, there are no rivers or ponds. The land is watered by rainfall only and cultivation of these plants occurs in large quantities. The amount of supplied water in the Isahaya reclamation farmland was approximately 420,000 m^3 in 2008, only 0.1 % of the total output. Only limited irrigation is required in the Isahaya district, as the average rainfall is more than 20 % higher than the national average. In addition, the water used in the reclamation farmland is supplied from the mouth of the Honmyo River rather than from the main body of the reservoir. The government of Nagasaki Prefecture is concerned about "the loss of agricultural water from gate opening", however this problem can be solved by establishing a small gate and water intake, a feature commonly seen in the lower basin around the Ariake Sea. Paddy-rice cultivation is carried out on the old reclaimed land created before 1997, and water from the main body of the reservoir is used for this, however, there are a number of problems. The water quality in the reservoir is significantly below that of the agricultural water standard established by the Ministry of Agriculture, Forestry and Fisheries (MAFF), for a number of parameters including COD[1] and hydrogen-ion concentration (pH). In addition, microcystins (MCs) have been detected

1) COD: Chemical Oxygen Demand. A measurement of the oxygen required to oxidize soluble and particulate organic matter in water.

in rice harvested from the reclaimed land despite the fact that they are present in very small quantities. Contaminated water is discharged to the sea in large quantities at ebb tides. The government of Nagasaki Prefecture has stated that if an investigation into gate opening is conducted, large quantities of contaminated water will be discharged into the sea, leading to damage to the fishing ground, and concerns from the local population. However, mass discharge of contaminated water is routinely carried out, and damage to the fishing ground is an almost daily occurrence. The gate opening was settled by a judgment from the Fukuoka High Court, which indicated that the drainage gate should be opened for 5 years, and that seawater should be introduced to the reservoir, eliminating the adverse effects discussed. It is otherwise incomprehensible what the very large reservoir, a main component of this reclamation, is useful for.

Blooming of toxic cyanobacteria

In the reservoir, cyanobacteria blooms occur in the presence of abundant nutrients in the warm season. Unlike phytoplankton such as diatoms, cyanobacteria have significant adverse effects. Research has been conducted in the reservoir since 2006, and blooming of cyanobacteria has become an annual event in early summer–mid autumn, although the dominant species change year by year. However, in most years, *Microcysis aeruginosa*, the most prominent MC (hepatotoxic cyanotoxin) producer, was the dominant species (Umenara et al., 2012).

Cyanobacteria

Cyanobacteria are oxygenic photosynthetic prokaryotic bacteria that appeared on earth around 2,700 million years ago at the latest. The carbon dioxide concentration of the earth's atmosphere at that time was extremely high, and it is thought that no isolated oxygen existed in the atmosphere. Cyanobacteria supplied a large quantity of free oxygen molecules to the earth's atmosphere, which was then exposed to cosmic rays and formed the ozone layer. It is also thought that some parts of the cyanobacteria developed a symbiotic relationship with eukaryotic cells and became plant chloroplasts. In other words, the earth's ecosystem would not have been established without cyanobacteria.

However, chemical substances produced by cyanobacteria are sometimes toxic to vertebrates, which appeared 2 billion years later. Why they produce toxins is not clear, as some species are toxic while others are not. Cyanotoxins can be roughly categorized into two categories: neurotoxins and hepatotoxins. A wide diversity of cyanobacteria producing both types of toxins has been observed in the Isahaya reclaimed land reservoir, however, *Microcystiss aeruginosa*, which produces MCs, is usually dominant. Although there is some year-to-year difference, the blooming cycle of cyanobacteria is usually as follows: during the low temperature season, eukaryotic phytoplankton (cryptophytes, diatoms) dominate; in May when the water temperature reaches approximatley 20°C, various cyanobacteria, including neurotoxin producers, can be seen under a microscope (Umehara et al., 2012, 2015). They are drained with the discharge and disappear when a large quantity of water flows in the rainy season. However, nutrients, such as inorganic nitrogen and phosphorus, flowing in large quantities then become the source of the next large-scale blooms. After the rainy season, as the strong summer sunshine continues, cyanobacteria spread and cover the surface of the water. The cyanobacteria may disappear sporadically through disturbance or heavy rain, but are revived when winds drop. The cyanobacteria disappear in late autumn when the water temperature drops below 15°C.

Cause of large-scale blooms

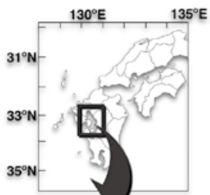
Microcystis aeruginosa prefer high water temperatures, as do some phytoplankton. However, phytoplankton such as diatoms decline when cyanobacteria blooming occurs. Why do cyanobacteria dominate? There may not be one single factor, however unstable nutrient supply and extremely low transparency may play some part. Although the reservoir stagnates, the turnover ratio is high and the full water capacity is drained more than 12 times per year; the reservoir water is hence replaced more than once a month on average. The water flowing into the reservoir from the basin via farmland is rich in nutrients (inorganic nitrogen and phosphate). However, during cyanobacteria blooms, nitrogen is used in great quantities by cyanobacteria and often becomes depleted. Then, neither cyanobacteria nor phytoplankton can grow, though cyanobacteria revive quickly with a new nitrogen supply in the next rainfall.

Another factor is the extremely low transparencies of approximately 15–20 cm. Before 1997, the Isahaya reservoir was tidal flats with small-particle Ariake clay deposits. Ariake clay dispersed with intense ebb currents plays a role in the purification capacity of the Ariake Sea, by surface adsorption. As the mean depth of the reservoir is only 1.4 m, bottom mud is lifted and dispersed even by low winds. Ariake clay particles have a surface positive charge, and the electrostatic repulsion means that these particles float without precipitating, leading to transparencies of only 15–20 cm throughout the year. Transparency is measured by allowing a white disk with a diameter of 30 cm to sink and measuring the depth at which the disk can no longer be seen. Such simple observation data provides useful information. In the zone deeper than roughly 2–3 times the transparency (approximately 40 cm in this case), oxygen consumed by phytoplankton exceeds that produced by photosynthesis. In contrast, strong light intensities at the surface are not conducive to phytoplankton photosynthesis; photoinhibition occurs, whereby strong ultraviolet rays damage proteins and genes, and single cell phytoplankton are therefore rarely found at the water surface. The area that is most suitable for eukaryotic phytoplankton is therefore limited to a narrow depth zone, and cyanobacteria spreading on the surface can monopolize sunlight. The ozone layer provides protection from strong ultraviolet rays, and was formed by cyanobacteria; cyanobacteria survived the harsh environment before the ozone layer was formed using a pigment called mycosporine-like amino acid that absorbs the energy of strong ultraviolet rays, allowing them to dominate at the water surface.

Cyanotoxins in the Isahaya Reservoir

Various cyanobacteria including producers of the neurotoxin anatoxin occur in the Isahaya reservoir, however, the most dominant species is *Microcystis aeruginosa*, which produces MCs. With a molecular weight of around 1000, MCs are cyclic peptides with more than 100 homologs. They are highly toxic to both plants and animals at sufficient doses. For acute toxicity, the LD_{50} of MC-LR is 43 μg/kg (mouse, intraperitoneal administration; Gupta et al., 2003). At lower doses, MCs inhibit protein phosphatase 1 and 2A, and promote the development of liver cancer [reviewed by Campos and Vasconcelos (2010)]. However, liver dysfunction is a disease in which symptoms are slow to appear, and can be caused by a number of factors, making the contribution of MCs difficult to ascertain.

MCs are broken down by specific resolution bacteria (Park et al., 2001), but are otherwise stable and relatively heat resistant. The MC contents of water and bottom sediments were measured at four locations, and the results are shown in **Fig. 1**. **Figure 2** shows the MC concentrations of the surface water and bottom sediment measured using ELISA (enzyme-linked immunosorbent assay). A sharp change in epipelagic MC concentrations was



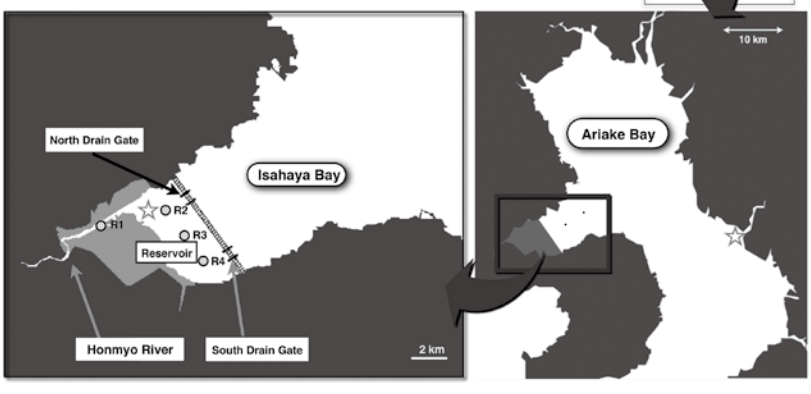


Fig. 1. R1-4 indicates the fixed research points. R1 in the Honmyo River estuary is close to an agricultural water intake.
☆: Mullet capture locations.

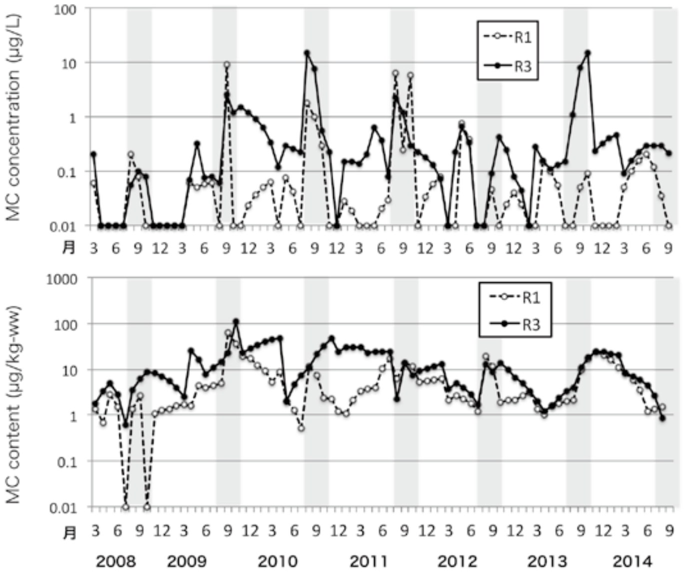


Fig. 2. Changes in microcystin (MC) content at R1 (mouth of Honmyo River) and R3 (central reservoir). The shaded area indicates the cyanobacteria blooming season.

observed, and values were lower than the detection limit during the period of low water temperature. However, the MC content of the bottom sediment was high; there was some decline during the non-blooming season, but the next bloom occurs before the MCs are entirely eradicated, so some MCs remain in the sediment throughout the year (Umehara et al., 2012; Takahashi et al., 2014).

Diffusion and remaining MCs

Contaminated water containing MCs and dispersed mud is routinely discharged to the sea. The gross weight of MCs discharged to the sea can be estimated by multiplying the displacement of each gate by the concentration of the nearest observation site (**Fig. 3**). This is only a rough estimation because the MC concentration fluctuates daily, and the MC concentration in dispersed mud is not included. It can still be concluded that MCs are discharged in quantities of dozens to several hundred kilograms. This is a significant quantity given the toxicity of MCs (Takahshi et al., 2014), and indicates that the reservoir is virtually an automatic toxin manufacturing facility.

Drainage from the reservoir scatters without immediately mixing with seawater because it has lighter specific gravity than seawater. The

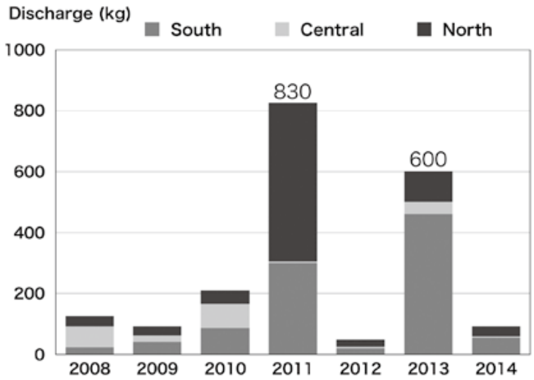


Fig. 3. Estimated total MC amount discharged to the sea area each year (kg).

diffusion range extends throughout the Ariake Sea across Isahaya Bay, and MCs from the bottom sediment have been detected throughout the Ariake Sea.

MAFF has stated that the influence of drainage from the Isahaya reservoir is limited to Isahaya Bay. This is not consistent with the testimonies of fishermen working at the fisheries. MCs could provide a tracer for the drainage. It is possible that not all MCs on the seabed originate from the Isahaya reservoir because there are small colonies or blooms of cyanobacteria everywhere, however, no location where a cyanobacteria bloom sufficient to pollute the seabed over a wide area is known in the basin around the Ariake Sea. We conducted 24 h measurements at nine sampling stations in Isahaya Bay on September 18, 2012 when approximately 2,300,000 tons of water were drained from the northern drainage gate, and confirmed that approximately 240 g of MCs were deposited in 24 h (**Fig. 4**; Komorita et al., 2014; Umehara et al., 2015). This is only approximately 1 % of the estimated gross weight of discharged MCs; the remainder were either broken down, or flowed outside of Isahaya Bay. However, it is likely that MCs gradually accumulate on the seabed, because the gross discharged weight is large even if this ratio is small. In addition, MCs were measured in the top 1 cm of the Ariake seabed, however, contents tend to be higher at depths of 1 – 3 cm, likely because this layer is less disturbed, has lower exposure to oxygen, and a slower bacterial rate. While MCs are broken down by ultraviolet rays, these do not reach the seabed. MAFF explained during a discussion meeting with fishermen that there are no problems with MCs during discharge, because they are broken down by resolution bacteria, however, no data has been provided. The question remains whether they are immediately broken down by bacterial activity. According to the results of our laboratory experiment, the degradation process did not progress at temperatures less than 20°C (Umehara and Takahashi, unpublished data). The existence of resolution bacteria at low temperatures, leading to removal of MCs, is unlikely, and even if these bacteria exist, enzyme activity will be low at these temperatures. Further investigations are being conducted.

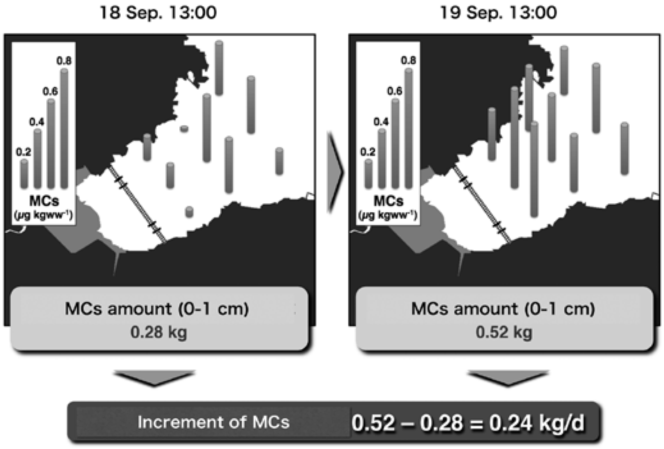


Fig. 4. MC contents in the surface sediment (0–1 cm) at nine stations (Stns 1–9) in Isahaya Bay at 13:00 on 18 September and 13:00 on 19 September 2012.

Bioaccumulation

Rachel Carson published "Silent Spring" more than half a century ago, and discussed the threat of bio-accumulation of toxins such as pesticides through food chains. Chemical substances such as organic mercury (as found in Minamata disease), PCBs (polychlorinated biphenyl), or dioxins also bio-accumulate in carnivores at the top of the food chain. Are MCs bio-accumulated? We have investigated the concentrations of MCs in aquatic organisms found around the reservoir. Preprocessing is required to measure the MC content of organisms; a numerical value cannot be obtained directly, and hence mass investigations over a wide area are labor-intensive and difficult. However, small numbers of measurements over many years have indicated that MCs accumulate in the bodies of many organisms (Takahashi et al., 2014). An MC concentration of 0.41 μg/g-ww[2)] was obtained for natural oysters collected near the southern drainage gate in December 2007 (**Table 1**). This value exceeds the TDI[3)] for a 60 kg person eating 6 g of oysters. Although oysters may not be consumed daily by urban residents, judgment by city standards may be dangerous, as evidenced by the lesson learnt from Minamata disease. The MC contents of oysters cultivated off the coast in the bay were very low, and usually below detection limits, likely because these oysters had a lower direct exposure to the drainage, which tends to drift along the coast. MCs were also detected in fishery creatures such as mullet (liver, muscle) and swimming crab (hepatopancreas, muscle) (**Table 2**). In particular, very high concentrations of MCs accumulated

2) g-ww: gram-wet weight. Dry weight is used for more accurate expression in the scientific article, but we used wet weight for the actual situation in this text.

3) TDI: tolerable daily intake, 0.04 μg/kg/day (microcystine-LR equivalent). For a person weighing 50 kg, TDI = 50 × 0.04 = 2.0 μg/day.

Table 1. MC content of natural oysters (*Crassostrea gigas*) collected near the south drainage gate and the intake upper limit to exceed the TDI for the adult weighing 60 kg in weight

year	date	n	MC content (mean ± SD)		Mean body weight (g)	TDI limit for a person of 60 kg	
			(μg/g-ww)	(μg/g-dw)		Wet wight (g)	number
2007	10 Dec.	2	0.41 ± 0.057	2.21 ± 0.24	12	5.9	0.49
2009	20 Nov.	1	0.31	1.7	8.4	7.7	0.92
2011	26 Sep.	4	0.030 ± 0.001	0.20 ± 0.053	3.6	80	22
2012	10 Feb.	4	0.010 ± 0.003	0.061 ± 0.027	4.4	240	55
2013	27 Sep.	4	0.033 ± 0.015	0.18 ± 0.079	5.6	73	13
	25 May	5	0.024 ± 0.016	0.18 ± 0.12	5.2	100	19

Table 2. MC content of fisheries creatures collected in the reservoir and surrounding fields

Name	Collection place	Orgen	Collection date	MC content		Intake over the TDI* (g-ww)
				(μg/g ww)	(μg/g dw)	
Mullet (*Mugil cephalus*)	Reservoir	Liver Gonad	22 Jul. 2007	2.4 0.17	4.9 0.93	1 14
	Reservoir	Liver Gonad	11 Jul. 2009	2.4 0.046	5.1 0.24	1.0 52
	Midorikawa river mouth	Liver Muscle	20 Jul. 2010	0.0087 0.0017	0.017 0.006	270 1400
	Midorikawa river mouth	Liver Muscle	20 Jul. 2010	ND 0.0013	ND 0.0058	– 1800
Flounder (*Paralichthys olivaceus*)	Five km offing from the northern drainage gate	Liver Muscle	28 Apr. 2013	0.0096 0.0056	0.13 0.013	250 430
Shiba shorimp (*Metapenaeus joyneri*)	The purchase (indicated as a product in Isahaya Bay)	Gonad Muscle	3 Aug. 2013	0.0015 0.0051	0.0099 0.011	1600 470
Blue crab (*Portunus trituberculatus*)	The purchase (indicated as a product in Isahaya Bay)	Hepatopancreas Muscle	13 Aug. 2011	0.035 0.0026	0.037 0.0034	69 920
		Hepatopancreas Muscle	10 Sep. 2011	0.032 0.003	0.12 0.0035	75 800

* Intake that over the TDI 2.4μg for an adult person weighing 60 kg.

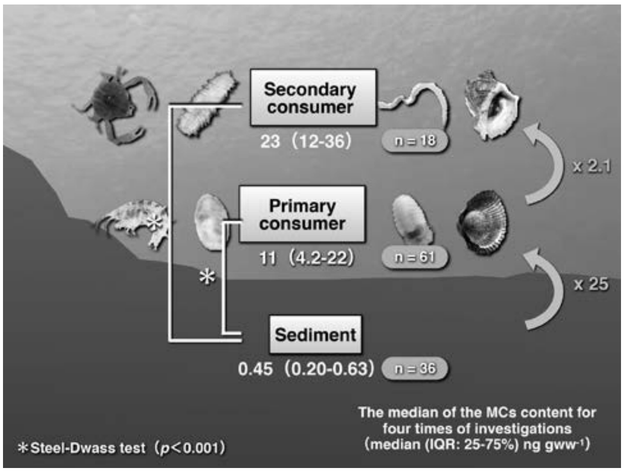


Fig. 5. Accumulation of MCs in the sediments of Isahaya Bay, the Ariake Sea, and benthos. The values show the median MC contents from four investigations.

in the livers of mullets captured in the reservoir, compared to those captured in the mouth of the Midorikawa River in the south of the Ariake Sea (**Fig. 1**). High MC concentrations also accumulated in benthos, while the MC contents of the associated sediments were lower. **Figure 5** shows the MC contents accumulated in various benthos from Isahaya Bay (Umehara et al., 2017). The median value is presented as these values varied over a wide range. The MC content of the top 1 cm of the bottom sediment had a median value of 0.45 μg/kg-ww, and the MC content of benthos, including small organisms thought to be primary consumers (bivalves, crustaceans, and

Table 3. MC content of midges and its predators

Name	Collection date	MCs content		Concentration rate [wet (dry)]
		(μg/g-ww)	(μg/g dw)	
Midges (*Microchironomus tabarui*)	13 Aug. 2011	0.00050	0.0025	
Long-jawed spider (*Tetragnatha praedonia*)	9 Sep. 2011	0.0043	0.013	8.6 (5.2)
Dragonfly (*Pantala flavescens*)	10 Sep. 2011	0.0061	0.019	12.2 (7.6)

polychaeta) had a median value of 11 μg/kg-ww, approximately 25 times higher than that of the bottom sediment. Furthermore, the median value for carnivorous polychaeta and snails was 23 μg/kg-ww, approximately 2.1 times of that of primary consumers (**Fig. 5**).

Although such small creatures are not eaten directly by humans, some fishery organisms may have accumulated MCs by eating these benthos. A larger scale investigation is required, one which would exceed the capacity of a single laboratory in a local university. We appealed in February 2013 to Mr. Yoshimasa Hayashi, the Minister of Agriculture, Forestry, and Fisheries who visited Saga Prefecture, that such a large-scale official investigation is needed, and the minister promised that this would be conducted. However, there has been no further news on this investigation. A file was uploaded to the website of the Kyushu Agricultural Administration Station titled "Summary of the investigation into the quality of the bottom of Isahaya Bay and peripheral sea areas". This document indicated that measurements were conducted on four occasions at nine locations in Isahaya Bay and the Ariake Sea, but "all MC contents were confirmed to be under the fixed quantitative lower limit (2.0 μg/kg)". The MC contents of bottom sediments reported in the original document provided to the minister were less than 1.9 μg/kg-ww, and in addition, there was no mention of research on organisms in the government document, although such research was included in our original document. We also found that there were some parameters that lead to "not detected" results in the method used by MAFF. For example, 80 % methanol was used for extraction; we have confirmed that only a small portion of the total MC concentration can be extracted with methanol at a concentration higher than 70 %, and advised the person in charge of the Kyushu Agricultural Administration Station of this several times, but received the answer "we carried it out appropriately". Because there are a number of problems with the removal of impurities in solid-phase extraction, we processed the same sample using both treatment methods (our water extraction method and the MAFF method) as a trial. No MCs were detected using the MAFF method whereas an MC concentration of 2 μg/kg was measured using our method. MAFF has explained this result to the Nagasaki Prefecture Fishery Unions, but there remains significant doubt about the scientific reliability of these results.

Large crowds of midges occur regularly around the reservoir. When the bottom mud of the reservoir was sieved with a 1 mm mesh, only a few types of organisms were found, including two types of midge larva, tubifex, and a small amphipod crustacean, which appeared in limited locations. The midge outbreaks might occur because of a low density of fishes (a predator of the larvae), allowing the emergence of large numbers of midges. As midge larvae eat sludge derived from cyanobacteria in the lake sediment, they naturally contain MCs. In August 2011, we captured two midge predators: a long-jawed spider (*Tetragnatha praedonia*) and a dragonfly (*Pantala flavescens*), and measured their MC contents. A 10-fold accumulation of MCs was observed in these predators (**Table 3**). Swallows are another predator of midges that may show bio-accumulation of MCs; this could lead to transfer of MCs from the aquatic to the land ecosystem.

The only solution

MAFF and the government of Nagasaki Prefecture have repeatedly asserted that no problem exists because cyanobacteria exist everywhere and human health impacts have never been reported in Japan. We cannot help but feel that this “excuse” is strange. Surely cyanobacteria exist even in small ponds; however, there is no relationship between safety and universality. It is very imprudent to state that, after a dangerous traffic accident, “this happens everywhere”. What we have identified is a large-scale outbreak that has polluted the bottom of the sea over a wide area, rather than a small bloom in a pond. Should we conclude that there is no problem because of the omission of the domestic report? It is regrettable that the preventive principle, a lesson learned from Minamata disease, has not been made use of in the message given from the administration of this country.

MAFF and the government of Nagasaki Prefecture have placed many types of algal handling machines near the northern drainage gate. The lease charges and personnel expenses for these machines are considerable, but they are wholly ineffective. The processing capacity is less than several tons per hour and it is likely to process the water of the 50 m pool with an earpick in comparison with the capacity of the reservoir of 30 million tons and displacements more than 400 million tons a year. These machines are designed for small reservoirs and work only under specific conditions. In contrast, since the creation of the reservoir in 1997, a total of 35,200 million yen (1,850 million yen per year) has been spent on water quality improvements up to the spring of 2016. The effect of these measures may be a decrease in dissolved inorganic nitrogen and phosphate in the Honmyo River; however, the total flow of this river is less than 20% of the total displacement of the reservoir. In fact, the Honmyo River is not the only river flowing into the reservoir, and a much greater quantity of water will flow through large-scale farms, leading to inflow of nutrients.

The only possible conclusion from these trials is that any measure other than the introduction of seawater will be ineffective. Nutrients, such as nitrogen and phosphorus, may be sometimes be regarded as contaminants, as causative agents for cyanobacteria blooming or red tides, but are also necessary for protein formation, phosphatide cell membranes, and most biopolymers, including DNA and ATP. Before the reclamation, nutrient-rich water flowed over the tidal flats.

It is said that the net primary productivity of a temperate tidal flats are almost equal to that of a tropical rain forest. Net primary productivity indicates the amount of respiration from the amount of organic matter photosynthesized in one year. It is easy to understand that productivity is high in a tropical rain forest with rapid tree growth; however, there is no obvious source of this productivity in tidal flats, at first glance. However, the single cells of benthic microalgae divide on tidal flats surfaces in abundance. Light, water, and nutrients are plentiful on tidal flats, and conditions are similar to that of a laboratory dish for cell division. However, it is not possible to see a large quantity of cells on a tidal flats, because they are carried to the offing with the next tide. Microalgae carried to the offing are eaten by water fleas, and water fleas are eaten by small fishes, and hence the original cells are incorporated into the offshore food chain and contribute to offshore marine resources. In contrast, cyanobacteria in the reservoir will not contribute to marine resources even though they also thrive on nitrogen and phosphorous. This lost tidal flats ecosystem will not be recovered easily, and this can only be achieved by introducing seawater by opening the gates. *Microcystis* cannot multiply in seawater, and cyanobacteria outbreaks will be suppressed promptly with the introduction of seawater. This situation differs from that found with a nuclear power plant that continues to emit radiation even after closure. The government of Nagasaki Prefecture states that opening the gates will lead to the spread of contaminated water and ecological damage to the sea, however, as discussed above, contaminated water is routinely drained away at present. Because the cyanobacteria continuously bloom and die, organic matter within the reservoir is always exhausted. There is no reason why the introduction of seawater will suddenly increase contamination by wastewater. Organic matter precipitates by agglutination when fresh water mixes with seawater, and water quality within the reservoir will approach that of the healthy sea area.

Therefore, opening the gates and introducing seawater is the first step towards bringing the

Table 4. Economic value of the tidal flats ecosystem service (Ministry of the Environment, 2014)

Ecosystem service		Appraised value (yen/yr)	Primary unit (/ha/yr)
Suapply service	Food	90,700 million	1,850,000
Adjustment service	Water purification	296,300 million	6,030,000
Habitat service	Offer of the habitat	218,800 million	4,450,000
Cultural service	Recreation and environmental education	4,500 million	91,000
Total		610,300 million	12,421,000

present negative spiral close to the original state. Of course, the decreased tidal current will not fully recover and the tidal flats will not regenerate immediately by opening only 250 m of gates over 7 km of dike, however, the introduction of seawater should stop the cyanobacteria blooms. Some MCs will remain in the sediment, but most will be degraded by bacteria over summer. A gate opening investigation was carried out in 2002 over a short period of less than one month. A dramatic change in sea area benthos was observed (Chapter 6, pp.10–15), however, strangely, MAFF ceased the investigation immediately. MAFF has continued to state that damage to fisheries from the reclamation construction is restricted. However, this deviates from the experience of fishermen and researchers. MAFF should demonstrate the correctness of their claim if they are convinced that it is right by carrying out a medium-and-long term gate opening investigation.

Value of the tidal flats and significance of a gate opening investigation

The tidal flats have various functions. Before reclamation, there was a tidal flats of 2,900 ha in Isahaya Bay, but most of this has been lost. The first loss with the loss of the tidal flats are the net primary production discussed above. Furthermore, in contrast to photosynthesis, organic matter is degraded by extensive microbial activity and nitrogen is released to the atmosphere. This capability is often compared to the large-scale purification facilities found in cities, however, neither personnel expenses nor electricity are needed in tidal flats. In addition, the whole shallow water area of Isahaya Bay, including the tidal flats, provides an egg laying and nursery ground for many fishes. The reduction in tidal current also leads to the loss of the gently sloping shallow water area.

In May 2014, the Ministry of the Environment reported the economic value of wetlands including tidal flats. We feel some resistance to the idea of quantifying the blessings of nature with a monetary value expressed as an “ecosystem service”, understood through the filter of market mechanisms. For example, oxygen supports life and may be recognized as the ecosystem service provided by tropical rain forests and ocean phytoplankton, however, we cannot choose to breath depending on a market price. Also, the value of the tidal flats cannot be exchanged for others of an equal price. However, we believe that the test calculation is effective as a policy for capturing the value of lost nature from a multidirectional viewpoint. Table 4 shows an extract of the sections on tidal flats from the Ministry of the Environment documents. This is the mean of the estimated value of all Japanese tidal flats. The large tidal difference and suspended Ariake clay, and the high activity of the Ariake Sea may mean that this numerical value is an underestimate. Even so, a value of 12.4 million yen per ha per year is reported. Considering a tideland area of 2,900 ha was lost from the reclamation, the monetary loss is 36 billion yen per year, or approximately 100 million yen per day. This may be an underestimate because the contribution to the current is not calculated, and the value of the biodiversity cannot be converted into an amount of money. This is not a loss borne only by fishermen.

Introduction of seawater by a gate opening investigation will prevent the production of toxins by the reservoir immediately. Also, it is clear from the short-term gate opening in 2002 that sea benthos exhibited an epoch-making change. On the other hand, there is some concern that tide recovery across the whole Ariake Sea cannot be achieved by only opening 250 m of gates along 7 km of dikes. We cannot expect to see a visible effect simply by opening the gates, however, because no conclusion was provided, even with the full use of computer simulation, the Fukuoaka High Court judgment stated that an investigation was required into gate opening. The established judgment did not give an order for "environmental remediation by gate opening" but ordered a check on the effect of reclamation construction on the Ariake Sea by opening the gate continuously for 5 years. To compare the Ariake Sea, where red tides and hypoxia are frequent occurrences, to a critically ill person, the judgment ordered examination rather than treatment. Needless to say, when we are ill and request medical consultation, examination is the first step.

In modern medical care, no doctor would consider carrying out a treatment without first conducting an examination. With the Isahaya problem, the investigation that corresponds to the common-sense act (examination) in the healthcare setting has never been carried out, even though 4 years have passed since the investigation start time limit mandated by that final and conclusive judgment. More than 40 billion yen has been spent on constructions based on Ariake Sea revival, however, these correspond to treatment without examination. A gate opening investigation is immediately necessary, according to the final and conclusive judgment of the Fukuoka High Court; we are not yet even at the starting line. From the news, only an argument over 10 billion yen that MAFF newly suggested plays a key role of the topic, but political power relations and the revival of Ariake Sea are stories of the different dimension . The dynamics of marine ecosystems follow the laws of nature but the circumstances of human society. To understand the laws of nature, a 5-year gate opening investigation as ordered by the Fukuoka High Court in 2010 is an absolute requirement. The professional societies of oceanography and biology have repeatedly provided statements and demands highlighting the importance of a gate opening investigation (Oceanographical Soc. Jap., Ichthyological Soc. Jap., Jap. Ass. Benthol., The Ornitholog. Soc. Jap.).

In Kumamoto Prefecture, the removal of the Arase dam has just been completed, and various environmental changes have been reported. It is still possible to regain the value and beauty of nature in Isahaya Bay. Industries have declined in Isahaya, and largely attract negative press; instead there is the opportunity to attract the world's attention as a valuable example of restoration of a damaged ecosystem. However, there is a limit to the ability to restore the deterioration of an ecosystem. We do not have enough time.

Acknowledgement

We would like to express our gratitude to the fishermen of Mr. Hiromitsu Doi for piloting the boat; students of the Laboratory of Marine Ecology, Faculty of Environmental and Symbiotic Science, Prefectural University of Kumamoto for their assistance in the field survey. This work was supported by the Takagi Fund for Citizen Science, a Grant-in-Aid for Scientific Research (C) from the Japan Society for the Promotion of Science (No. 17K00639), and a Kumamoto Health Science University Special Fellowship Grant.

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6 Shut-off of Isahaya Bay is causing decrease of benthic animals in the entire Ariake Sea

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In Isahaya Bay, a reclamation dike was completed on April 14, 1997. Our survey has started from March 23, 1997, three weeks before the shut-off of the dike, and continued to the present. We collected benthic animals from the 92 fixed stations in the entire Ariake Sea in June of 1997, 2002, 2007 and 2015, and also collected them from 32–50 fixed stations in the inner part of Ariake Sea every year for over two decades.

Benthic animals living in the sea bottom, having low mobility and slow movement, serve not only as good indicators of environmental changes, but are also an important food source for fish and shellfish which are caught by fishing vessels. Benthic animals occupy an important position in the marine ecosystem as a primary and secondary consumer linking the primary producers (such as phytoplankton and marine algae) and detritus (non-living organisms: remains, debris and excrements of organisms, and products from their decomposition) with fish and shellfish through the food chain (Azuma & Sato, 2016). Therefore, information on trends and changes of benthic animals is very important in order to grasp the current situation of fishery.

This paper aims to report on the changes of benthic animals based on the results of our long-term sediment sampling from the fixed stations in the inner part and the entire area of the Ariake Sea from the shut-off of the floodgates of the Isahaya Bay dike in 1997 to the present, and thereby clarify the fact that the shut-off of Isahaya Bay is causing the decrease of benthic animals in the entire Ariake Sea.

1. Materials and method

The sediment sampling from the entire Ariake Sea (**Fig. 1A**) has been conducted 4 times (June 1997; 92 stations, June 2002; 88 stations, June 2007; 107 stations, June 2015; 100 stations). Further, annual sediment sampling from the 32–50 fixed stations in the inner part of the Ariake Sea (**Fig. 1B**) has been held continually 1 or 2 times (25 times in total) a year from June 1997

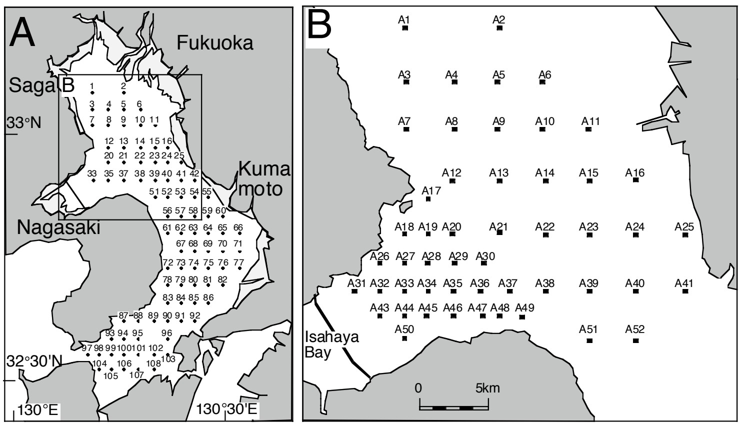

Fig. 1. Maps of the Ariake Sea, western Kyushu, Japan, showing sampling stations for this study. A: 88 fixed stations for sediment sampling conducted in June of 1997, 2002, 2007 and 2015. B: enlargement showing 50 fixed stations around Isahaya Bay for annual sediment sampling from June 1997 to June 2016. Figures were partly modified from Uesugi et al. (2012).

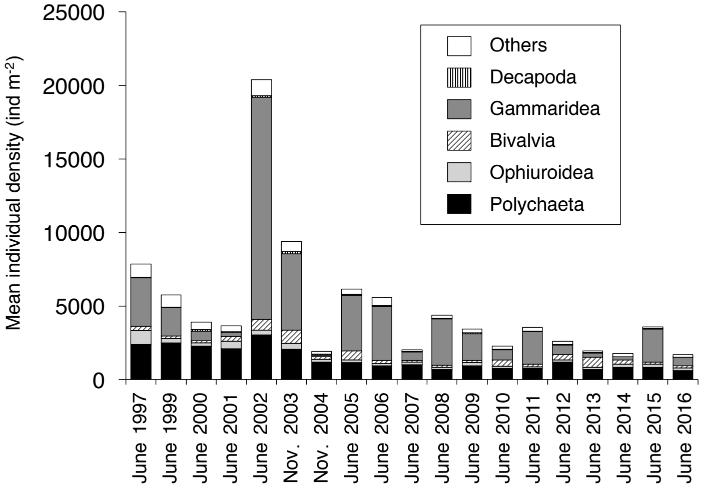

Fig. 2. Annual changes in mean individual density (m^{-2}) of benthic animals collected from the 32–50 fixed stations around Isahaya Bay between June 1997 and June 2016. Figure was partly modified from Azuma and Sato (2016).

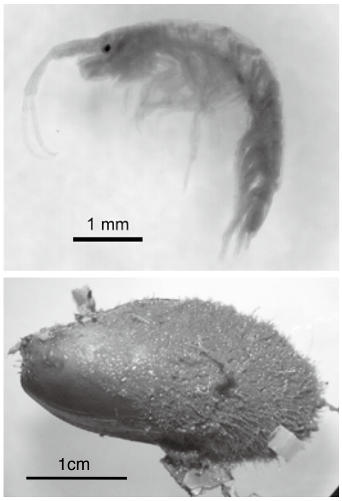

Fig. 3. Photographs of *Corophium* sp. (upper) and *Modiolus* (*Modiolus*) *comptus* (bottom).

to June 2017.

The sites of the fixed stations in the entire Ariake Sea and the inner part were determined using GPS (Global Positioning System), and a sediment sample was taken once from each fixed station using a Smith-McIntyre grab (sampling area : 0.05 m^2). A portion of the obtained sediment sample was removed for grain size analysis. After the mud temperature was measured, the sediment sample was washed using a 1 mm-mesh sieve. Then, all the macrobenthic animals that remained on the sieve were fixed with 10% neutral-buffered formalin and seawater. In addition, water temperature, salinity, dissolved oxygen concentration, pH and conductivity of surface and bottom water layers were measured using a multi-parameter water quality meter at each fixed station.

Samples brought to the laboratory were sorted at the higher taxonomic level. All bivalves were identified at the species level. Among the gammaridean amphipods and polychaetes collected in the entire area survey, the former was identified at the species level, the latter at the family level. Organisms, which could not be identified at the family or lower taxonomic levels, were classified into the lowest known level such as class or suborder before counting the number of individuals.

2. Annual change of benthic animals in the Ariake Sea

Fig. 2 shows the mean individual density (m^{-2}) of each taxa collected from the sediment samples among 32 to 50 fixed stations (**Fig. 1B**) in the inner part of the Ariake Sea between 1997 and 2016.

In June 1997, two months after the shut-off of Isahaya Bay, the mean individual density of all macrobenthic animals including polychaetes, ophiuroids, bivalves and gammaridean amphipods was 7,858 individuals m^{-2} in the inner part of the Ariake Sea. After that, mean individual density (m^{-2}) of benthic animals was 5,737 in June 1999, 3,914 in June 2000 and 3,646 in June 2001. These figures indicate that benthic animals have gradually decreased in the four years after the closure of the bay (**Fig. 2**).

However, in June 2002, two months after the short-term opening of the floodgates, there was a sudden increase in benthic animals (**Fig. 2**). The mean individual density of benthic animals in the inner part of the Ariake Sea reached 20,387 individuals m^{-2}, which is a tremendous increase of 5 – 6 times compared with June 2001. Most of the increased taxa was gammaridean amphipods *Corophium* spp. and a bivalve species *Modiolus comptus* (**Fig. 3**, Kanazawa et al., 2005; Matsuo et al., 2007).

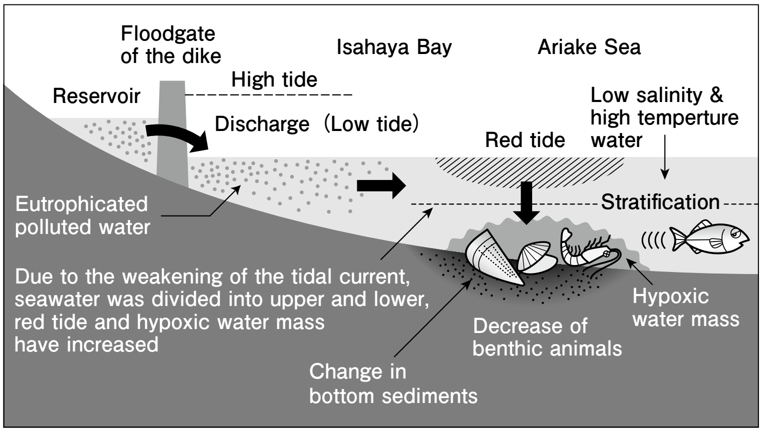

Fig. 4. Isahaya Bay and Ariake Sea after the closing of the dike on April 14, 1997.

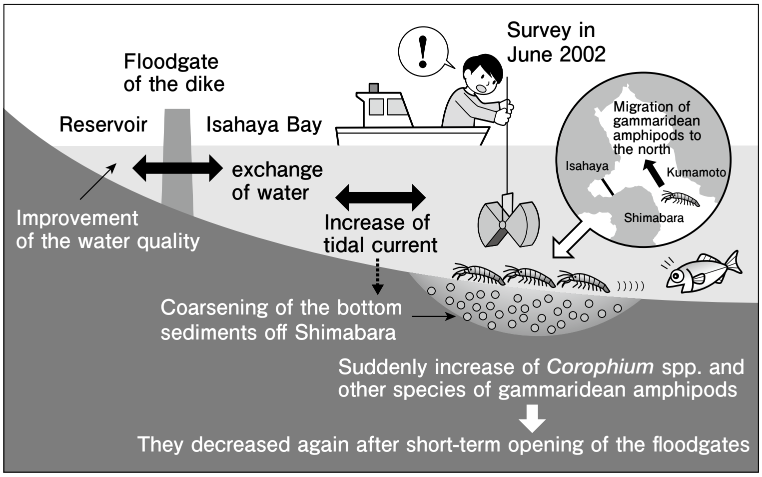

Fig. 5. The short-term open-gate from April to May 2002 and the situation at the time of the survey in June.

The floodgates were opened for 27 days from April 24 to May 20, 2002, for the first time since the dike was shut off in 1997. Although the tide level difference was within 0.2 m, it was intended to restore the environment of the Ariake Sea by introducing sea water into the regulating reservoir through the floodgates. Kyusyu Regional Agricultural Administration Office stated in its report that there was hardly any change in living organisms after the floodgates were kept open for that period (Kyusyu Regional Agricultural Administration Office, 2003). However, our survey captured a significant change in benthic animals.

Why did benthic animals suddenly increase in this area? As a result of large scale hypoxic water mass which occurred in the inner part of the Ariake Sea in June 2001, many species of gammaridean amphipods and bivalves which had hitherto existed temporarily decreased (**Fig. 4**). In addition, in June 2001, we have captured the change in bottom sediments. Very coarse sand was confirmed for the first time around the stations where there was medium to coarse sand (Kanazawa et al., 2005). After that, the floodgates were opened for a short term of 27 days from April to May 2002. As a result, it was observed that the tidal current increased temporarily in the waters off the coast of Shimabara and off the coast of Nagasu, and the

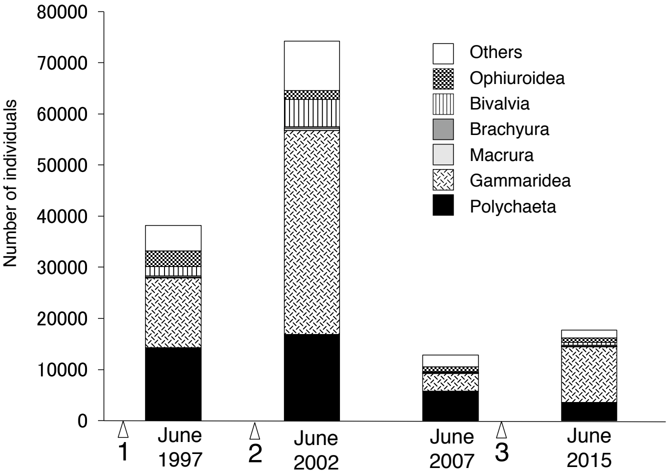

Fig. 6. Changes over 18 years in numbers of individuals of benthic animals collected from the 82 fixed stations in the Ariake Sea, shown at 5-year or 8-year intervals. White triangles denote major events in Isahaya Bay: 1. isolation of the inner part of the bay by the reclamation dike on April 14, 1997; 2. short-term opening of the water gates of the reclamation dike from April to May, 2002; 3. completion of construction of the reclamation dike on November 20, 2007. Figure was partly modified from Uesugi et al. (2012).

bottom sediments in those areas became coarse. Then, it seems that *Corophium* spp. and other species of gammaridean amphipods which had inhabited the south-central part of the Ariake Sea migrated northward to the inner part of the Sea and were distributed there at high density (**Fig. 5**).

Many species of gammaridean amphipods which increased in June 2002 were called “opportunistic species” capable of instantly responding to temporary environmental changes and rapidly increasing the number of individuals. Base on these results, it is considered that the significant change in benthic animals was occurred by the temporary environmental change in the waters of the inner part of the Ariake Sea due to the short-term opening of the floodgates. In the subsequent 14 years from 2003 to 2016, no sudden changes in benthic animals like those in June 2002 have been found and the mean individual density of benthic animals has continued to decline (**Fig. 2**). It can also be asserted that the influence of the short-term opening of the floodgates on the environment of the inner part of the Sea was significant.

Furthermore, the rapid increase in benthic animals two months after the short-term opening of the floodgates in 2002 was confined not only in the inner part of the Ariake Sea, but also similar changes were observed in the entire Ariake Sea (**Fig. 6**, Uesugi et al., 2012). We compared the total population of macrobenthic animals in the 82 fixed stations collected commonly the four previous surveys of the entire Ariake Sea. While the macrobenthic animals was about 40,000 individuals in June 1997, it rapidly increased to about 75,000 in June 2002 two months after the short-term opening of the floodgates, then fell to about 13,000 in June 2007 (**Fig. 6**). In the latest survey in June 2015, it increased slightly from June 2007 due to the increase in gammaridean amphipods, but still the number of individuals is overwhelmingly smaller than those in June 1997 and June 2002. The results of the survey also showed the same downward trend of benthic animals in the entire Ariake Sea since the short-term opening of the floodgates in 2002.

Kyusyu Regional Agricultural Administration Office could not found the increase of benthic animals in the inner part and the entire Ariake Sea after the short-term opening of the floodgates (Kyusyu Regional Agricultural Administration Office, 2003), using only the results of benthic surveys at nine fixed points in Isahaya Bay as its grounds. However, our surveys in the 32 to 50 fixed stations in the inner part and the 82 fixed stations in the entire Ariake Sea definitely captures the sudden change in benthic animals after the short-term opening of the floodgates. These observations clearly show that the shut-off of Isahaya Bay in 1997 caused benthic animals to decrease in the entire Ariake Sea and that opening the floodgates to draw sea water into Isahaya Bay is the most effective solution.

However, after opening the floodgates for a short period, the Ministry of Agriculture, Forestry and Fisheries has refused to carry out medium-to long-term opening of floodgates and then continued to stray by seeking a way to "revitalize the Ariake Sea without opening the floodgates" for the past 15 years. Meanwhile, they have taken countermeasures by conventional symptomatic methods such as cultivation of sea bottom and sand capping, spending tens of billions of yen of public funds. On the other hand, our findings also reveal that all measures taken after the short-term opening of the floodgates in 2002 did not stably increase the average population density of benthic animals. This means that there remains no means of regenerating the Ariake Sea except by keeping the floodgates open at all times to draw sea water into the regulating reservoir of Isahaya Bay.

3. What will happen to the Ariake Sea if the floodgates of Isahaya Bay are kept open at all times?

Our survey results predict what will happen to the Ariake Sea if the floodgates of Isahaya Bay are kept open at all times in the future (Sato & Azuma, 2016). The first effect to be observed soon after the floodgates are opened will be a sudden increase in opportunistic species such as *Corophium* spp. These small benthic animals eat phytoplankton and organic matters in the sea water, and they also play a role as an important food resource for fish and shellfish, which will be subject to commercial fishery. Activities of these benthic animals promote the oxidation of sediments and enable the inhabitation of larger benthic animals. As a result, the benthic animals of the Ariake Sea may gradually recover their diversity.

These changes are predicted to begin immediately after the floodgates are opened. Since the short-term open-gate survey of 2002 was stopped in only 27 days, the benthic animals quickly decreased in one to two years. But if the floodgates are opened stepwise, faunal changes of benthic animals stated above will also be seen, and that is expected to lead to an increase of fish and shellfish which are subject to commercial fishery. In order to confirm it, research and observation of water quality change and benthic animals not only in Isahaya Bay but also in the inner part and the entire Ariake Sea, as have been done by our survey, should be continued. Stepwise opening of the floodgates under adaptive management which takes into account the findings from the research and observation is expected to restore even larger number of organisms. In order to recover the Ariake Sea, it is desirable to proceed with the removal plan of the flood-control dike after taking disaster prevention measures and securing a freshwater source for the reclaimed farmland.

Acknowledgements

We are grateful to members of the Research Group for Conservation Ecology on the Ariake Bay for their help in collecting samples. This work was partly supported by the Pro Natura Foundation Japan (for M.A.) and JSPS KAKENHI Grant Numbers JP25440229 (for S.S.)

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7 Ecosystem crisis of Ariake Bay caused by the construction of a dike in Isahaya Bay

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The authors contributed the original research paper in Japanese to the booklet "Open the Floodgates in Isahaya Bay to Revive the Ariake Sea" (by the Association of Researchers Calling for the Opening the Floodgates in Isahaya Bay) published in 2016.
The latter half of the original research paper was edited and translated into English by **the Secretariat of the Ariake Sea Network of Fishermen and Citizens.**

1. Relations between the current and water quality in the inner waters of the Ariake Bay

An analysis of bottom sediment distribution in the inner waters of the Ariake Bay found that there was a characteristic pattern of tidal flow from the 1950s to the late 1990s. From the fact that the bottom sediment is largely muddy in the eastern part and sandy in the western part, it is estimated that the tidal flow was almost stagnant for a sustained period of time in the western part, while it was at a level that allowed sandy sediments to settle and expand in the eastern part Also, a study of tidal current of the Ariake Bay by Inoue in 1980 (**Fig. 1**) found that while there is no significant difference in the tidal current velocity between the eastern part and western part during the flow tide, the current velocity in the western part is approximately half that of the eastern part (**Table 1**) during the ebb tide. This difference in the current velocity is considered to be a cause of constant counterclockwise flow (**Fig. 2**) in the inner waters of the Ariake Bay.

Because of these conditions of tidal current velocity, the nutrient-rich water from the Chikugo river is mixed with less nutrient-rich sea water as it enters the Ariake Bay. This keeps the nutrient concentration in sea water below a level where a red tide is likely to occur. However, an inexplicable phenomenon has begun to take place. While the nutrient transport from the

(a) The highest velocity during the ebb tide（July 30, 1977）

(b) The highest velocity during the flow tide（July 30, 1977）

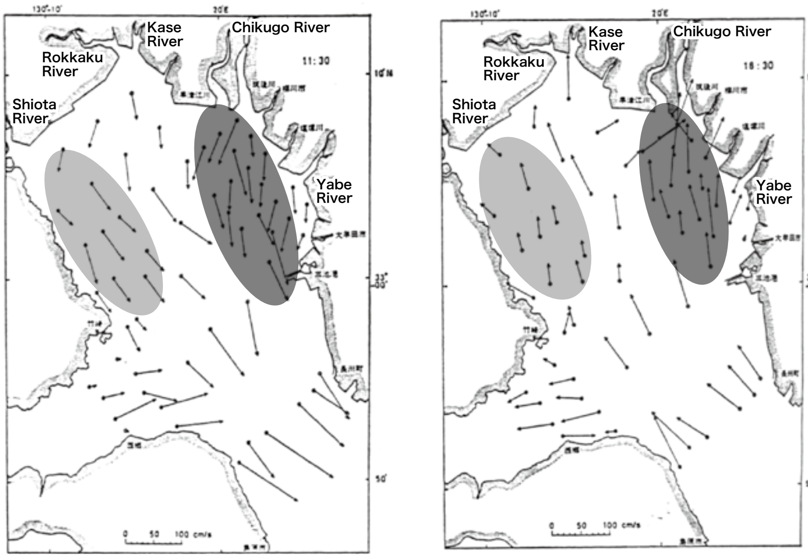

Fig. 1. Results of the tidal current survey using drift plates at 61 points in the inner waters of the Ariake Bay. (a) The highest velocity during the ebb tide. (b) The highest velocity during the flow tide. Survey conducted on July 30, 1977 (spring tide). Data from Inoue (1980) was partially modified.

Table 1: The highest velocity during the ebb and flow tides in the eastern and western parts of the inner waters of the Ariake Bay (Survey conducted on July 30, 1977). Tidal current velocity was calculated (cm/sec.) with reference to the data from Inoue (1980) shown in Figure 1.

Tidal current velocity	Western part (10 points)	Eastern part (17 points)
Highest velocity during the ebb tide	50.2±12.0*	60.0±15.8
Highest velocity during the flow tide	31.0±5.7**	66.1±19.5

* p=0.088, Mann-Whitney test, U=51.00 no significant difference
** p<0.01, Mann-Whitney test, U=9.50 significant difference

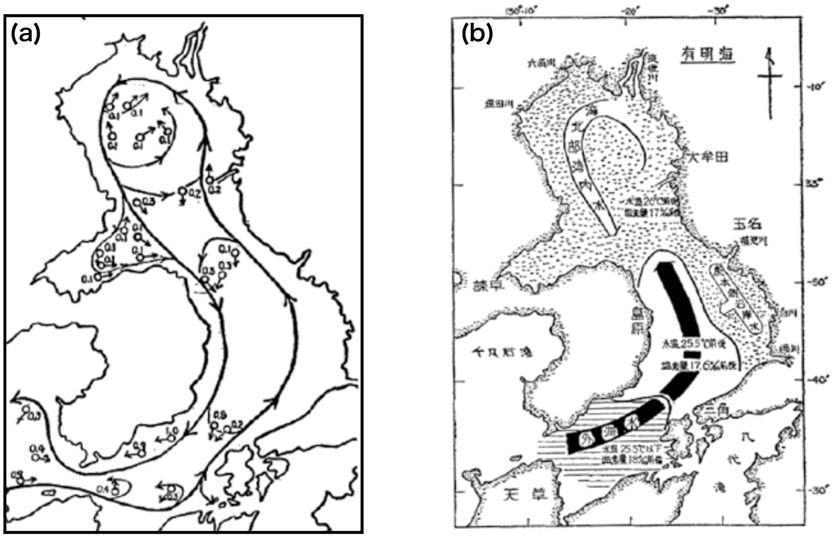

Fig. 2. Counterclockwise constant flow in the Ariake Bay (Kamata, 1967). (a) Current circulation in the Ariake Bay (steady current). Unit = knot. Original figure by Yasui et al. (1954). (b) Schematic pattern of the water system in the Ariake Bay. Original figure by Nagasaki Prefectural Institute of Fisheries (1956).

land has not changed significantly since 1965, red tide events suddenly increased in the late 1990s (**Fig. 3**). The authors have tried to elucidate the mechanism of this phenomenon through investigations into the water quality, sea floor environment and ecosystem in the inner waters of the Ariake Bay.

2. The mechanism of frequent red tides – not triggered by increased nutrient inflow from the land.

We are currently focusing on the tide mark (**Fig. 4**), which appears from the Yabe river estuary on the east coast to the area off the coast of Ohura, Saga Prefecture on the west coast in a manner that crosses the inner waters of the Ariake Bay, as something that holds the key to elucidate the mechanism of the red tides. The following is an aerial photo of the inner waters of the Ariake Bay taken from above the city of Yanagawa, Fukuoka Prefecture on Nov. 11, 2009. The waters to the right of the tide mark (the inner waters of the Ariake Bay) appears opaque with turbidity due to the large volume of fine mud particles suspended in the water. On the other hand, the waters to the left of the tide mark (the central part of the inner waters of the Ariake Bay) appears dark because of the high clarity of the sea water. This tide mark suggests that the inflow from the estuary forms a border with the sea water on the surface of the central part of the inner waters of the Ariake Bay. This pattern has been observed frequently in all seasons.

Recent investigation found that the sediment quality differs greatly in the area beyond the tide mark (**Fig. 4**). In the inner waters of the Ariake

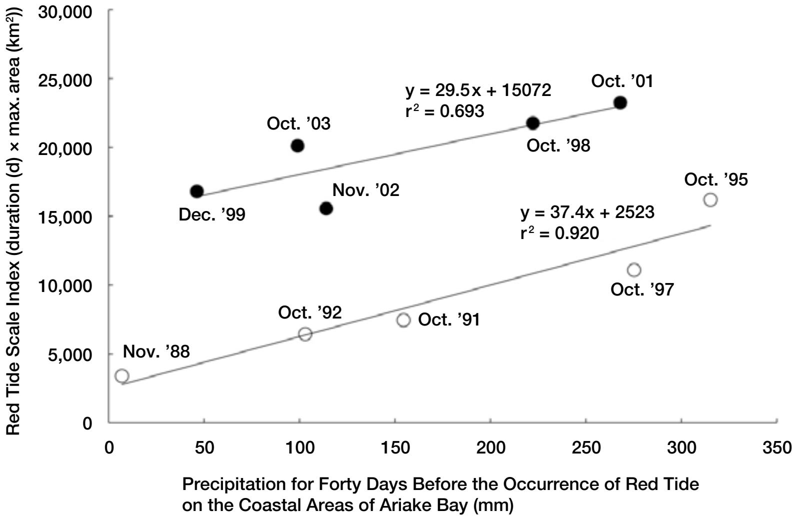

Fig. 3. Relation between the scale of red tides in the inner waters of the Ariake Bay between fall and winter (October – December) and the amount of precipitation in the coastal area in 40 days prior to the occurrence of the red tides. Data from Tsutsumi et al. (2006) was partially modified. From 1998, the scale of red tide occurred in autumn increased suddenly two to three times larger to the same amount of precipitation before the occurrence of the red tide.

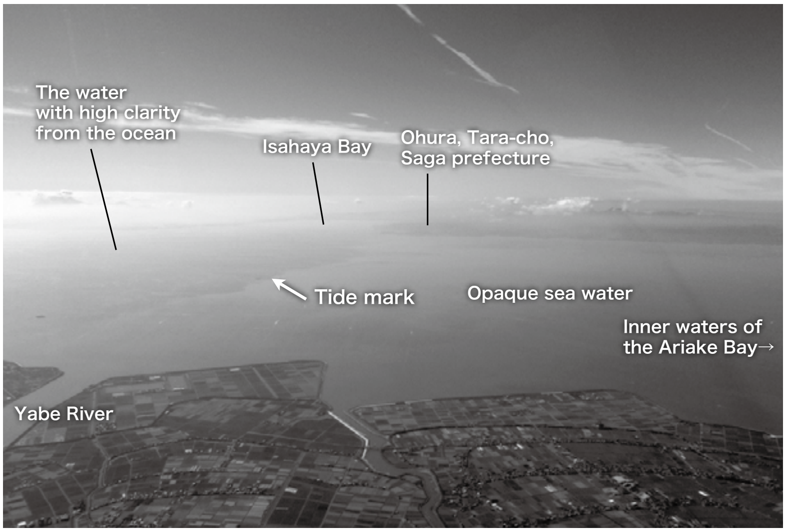

Fig. 4. Tide mark that crosses the sea area extending from the mouth of the Yabe River on the east coast to the area off the coast of Ohura, Tara-cho, Fujitsu-gun, Saga prefecture on the west coast of the Ariake Bay. Nov. 14, 2009. From above the city of Yanagawa, Fukuoka Prefecture (Courtesy of Kumamoto Kenmin TV).

Bay, muddy bottom sediments expand eastward while sandy bottom sediments are limited only to the area from the tide mark towards the central part of the inner waters of the Ariake Bay (left side in the photo) (Refer to Orita et al. 2015 for detail). This suggests that “frequently mixed sea water” and “sandy bottom sediments” which are usually brought about by strong tidal current have disappeared from the eastern part. Instead, fine mud particles in the opaque sea water shown in **Fig. 4** have begun to settle on the sea floor as the tidal current in the eastern part has weakened

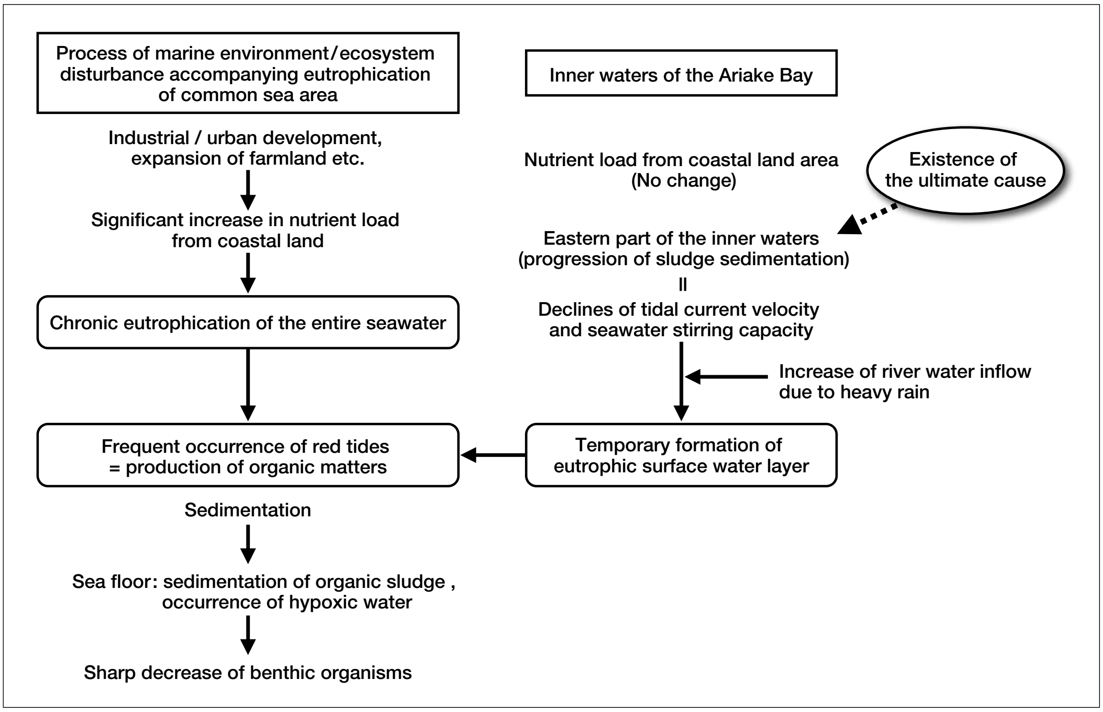

Fig. 5. Comparison of the process leading to the frequent occurrence of red tides / hypoxic waters accompanying eutrophication of common seas and the process seen in the inner waters of the Ariake Bay.

to the level of that in the western part.

Once such a condition occurs in the eastern part of the inner waters of the Ariake Bay, the innermost part of the Ariake Bay becomes especially prone to red tides. When the area is hit by a torrential rain, large volume of nutrient-rich water from the Chikugo river and other major rivers drain into the inner waters of the Ariake Bay. This leads to the temporary formation of a eutrophic surface water layer, where red tides are more likely to occur (**Fig. 5**). Once red tides become frequent events, subsequent deterioration of the sea floor environment and ecosystem will follow the same process as that of eutrophication attributable to increased nutrient inflow from the land (Tsutsumi et.al. 2006, 2007; Orita et al. 2015; Tsutsumi et al. 2015).

3. What is the ultimate cause of eutrophic surface layer water?

What, then was the “ultimate cause” (**Fig. 5**) of the eutrophic surface layer where red tides frequently occurred from the latter half of the 1990s in the inner waters of the Ariake Bay including the eastern part where red tides were unlikely, because the nutrient-rich river water was constantly mixed with sea water? Although we are still conducting investigations and research to find the answer, a certain phenomenon that would greatly change the marine environment occurred in the late 1990s and that might have impaired the original mechanism of the Ariake Bay, which used to maintain its marine ecosystem in harmony (The difference in tidal current characteristics between the eastern part and the western part of the inner waters of the Ariake Bay; **Fig. 1**, **Fig. 2**, **Table 1**). In addition, this change does not come periodically due to the influence of celestial bodies such as the moon and the sun. Based on our findings as of 2017, it is reasonable to assume that a phenomenon which greatly changed the marine environment occurred between 1997 and 1998 (Tsutsumi, 2005; Tsutsumi et al., 2003, 2006, 2007). In light of that, the closing of the flood-control dike in Isahaya Bay, which was carried out in April 1997, needs to be examined as one of the events directly affecting the tidal current of the Isahaya Bay and the inner waters of the Ariake Bay.

Based on the result of the tidal current study in Isahaya Bay and the inner waters of the Ariake Bay up until the present (Komatsu et al, 2004; Tai et al., 2012; Tai and Komatsu, 2013) we are considering the possibility of influence of the construction of the flood-control dike on the tidal current. Of particular note is the fact that because of the construction of the flood-control dike, sea water that originally flowed into the inside of the dike during the flow tide changed course. Sea water that can no longer flow into the inner recess of the Isahaya Bay flows to the western part of the inner waters of the Ariake Bay, where the current velocity becomes higher because of the increased flow.

It is estimated that in the past, some portion of the seawater in the eastern part of the inner waters of the Ariake Bay that had been advected by the flow tide also flowed into the western part where the tidal current was weaker. The characteristics of the constant counterclockwise flow in the inner waters and the schematic view of the northern part shown in Fig. 2 are considered to represent the tidal current condition in the inner waters of the Ariake Bay.

However, the construction of the Isahaya Bay Dike has changed the tidal current conditions. While the amount of seawater that flows into the western part increased and the current velocity rose accordingly, the current velocity in the eastern part declined. In other words, the difference in the current velocity between the eastern part and the western part (Fig. 1, Table 1) during the flow tide, which was one of the features of the tidal current in the inner waters of the Ariake Bay, have narrowed and the current velocity became almost uniform. This indicates the possibility that such tidal current condition acted as the “ultimate cause” shown in Fig. 5, and triggered a series of environmental and ecological disturbances.

In April 1997, when the flood-control dike was closed as part of the Isahaya Bay Reclamation Project, a line of steel shutters stretching about 1.2 km across the bay fell onto the water to cut off the Isahaya Bay from the rest of the Ariake Bay. As shown in Fig. 3, in the following year, the occurrence of red tides, which are two to three times larger in scale than those of the previous years, with the same amount of rainfall in the coastal area, suddenly increased in autumn. We point out the possibility that this is not a mere parallel phenomenon but a phenomenon linked by a causal relationship if judged comprehensively from the various research results described above. In order to verify the possibility scientifically, it is necessary to return to the point before the closure of the flood-control dike in 1997 and reexamine the tidal current, the sea floor environment, the ocean floor ecosystem etc. based on the knowledge gained so far, and thereby reconsider the influence of the closure of the flood-control dike.

There is a view that changes in tidal current can be estimated without conducting an open-gate survey as computer simulation techniques have developed in recent years. However, the area of the inner waters of the Ariake Bay that includes the Isahaya Bay has a complex topography, and in addition, has vast tidal flats to release wave energy. Unlike a simple place, like a waterway, it is considered a very difficult task to reproduce the tidal current of such a complex location with sufficient reliability. Moreover, the tidal current models created thus far have not been designed on the premise that the current velocity during the flow tide varies greatly between the eastern part and the western part of the inner waters of the Ariake Bay as shown in Fig. 1.

However, indications from researchers in this field also include points that are worth considering. Even if the floodgates of the dike were opened, only the width of 250 m (the north gate 200 m, the south gate 50 m) or about 1/5 of the opening of the dike closed in April 1997 will not be sufficient to restore the inflow of sea water. Under this restricted condition, attempting to restore the tidal flow to what it used to be before the closure of the dike should be limited.

So, what we as researchers who have studied the “Environmental Disturbance in the Ariake Bay” can do is accurately to grasp the changes in the tidal currents in the Isahaya Bay and the inner waters of the Ariake Bay when the floodgates are open even under conditions with limited prospects of restoring the tidal current, as well as to obtain scientific answer to the fundamental question as to why large scale red tides and hypoxic waters have begun to occur frequently since the late 1990s in the areas where nutrient load from the land has not increased.

Acknowledgements

The Coastal Oceanography Research Committee generously granted us permission to reprint the illustrations by Inoue (1980) in Fig. 1. This paper is a result of the research projects which were funded by the Environment Fund 2009 Research Grant (R09-B118) from Mitsui & Co. and the Basic Research Fund (B) (No. 25281031) from the Japan Society for the Promotion of Science. We would like to express our deepest gratitude to all the stakeholders involved in these research projects.

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Appendix

Proposal to Asian Wetland Symposium 2017 from Networks of Wetland NGOs in Korea, Japan and the World

Ramsar Network Japan / Korea Wetland NGO Network / World Wetland Network

We, Networks of Citizens working for the conservation of wetlands in Japan, Korea and the world, welcome that the Asian Wetland Symposium 2017 is being held in Saga City at the inner part of the Ariake Sea.

Ariake Sea has high bio-productivity nurturing a diverse variety of commercial fish species. It is also an important staging ground for migratory waterbirds. Many people earn their livelihood from goods produced by the Ariake Sea. The local community has been supported by this natural environment. In this sense, Ariake Sea is one of the representative wetlands of international importance in East Asia that has been implementing "Wise Use of Wetlands" that the Ramsar Convention promotes.

At present, however, many of its tidal flats have disappeared as a result of development projects including Isahaya Bay Reclamation Projects. There has been serious damage from the construction of estuary dams, port improvements, large scale gravel-digging and other activities carried out for development projects.

The damage to tidal flats of the Ariake Sea degraded fisheries to such an extent it was given a name: Ariake Tumult. The decrease of fishery products gave a critical impact to the livelihoods of those catching shellfish and fish species. National and local governments of Japan have been implementing various surveys, research and projects to improve the environment. However, they are all limited to local improvement of fishing spots or experiments on aquaculture methods. An effective solution has not been achieved. A court judgement requests opening the sluice gate of Isahaya Bay to introduce large tidal flows to recover Ariake Sea. But this request has not been implemented for political reasons.

This is because the Government of Japan did not understand the importance of wetlands and neglected the "Wise Use" principle of wetland management due to political concerns. The Asian Wetland Symposium 2017 held at Saga City facing the Ariake Sea may well share the sense of crisis at the present situation of the Ariake Sea.

We welcome the fact that three tidal flat sites in the Ariake Sea: Arao-higata, Hizen Kashima-higata, and Higashiyoka-higata are listed as Wetlands of Internationally Importance under the Ramsar Convention. But it is equally important to recognize that Isahaya Tidal Flat that gave us far more diverse ecosystem services has been lost by a large-scale development action. Reconfirming the original spirit of the Ramsar Convention "to conserve and wisely use all wetlands", it is indispensable to restore the tidal flat of Isahaya Bay as much as possible utilising the power of nature, and to promote conservation of the whole Ariake Sea setting bases on the three Ramsar Sites.

It is a tendency not only in the Ariake Sea, but generally in Japan that many wetlands are deteriorating. More than half of the driving force is human activities including development such as landfill, bank improvement, dam/weir, and reclamation by double dyke. These human activities have one thing in common, they are artificial structures that halt the flow of water. At Awase Tidal Flat in Okinawa, Japan, the tidal flat has been degraded heavily because a newly constructed artificial island caused stagnation of the oceanic current. In the coastal area of Henoko in Okinawa, construction of a new US military base is underway, filling the internationally important wetland. Construction of Ishiki Dam in Nagasaki Prefecture has been a tremendous threat to the sustainable life of the people that continue to live there and to its productive natural environment.

The same thing is happening in Korea. Four Rivers Project and the construction of estuary dams have caused serious degradation of water quality destroying ecosystems of the catchment area in many places. Tidal flats of the western coast that can be listed as 5 of the biggest tidal flats in the world are being destroyed by development projects including Saemangeum Reclamation Project. Hwaseong-Lake Wetland is threatened by development projects that prevent exchange of sea water. The same wetland degradation is happening in the whole Asian Region.

On the other hand, we can see cases where nature and ecosystem services have been returned to good condition by restoring the flow of water. Examples include the removal of Arase Dam in Japan, opening of the sluice gate of Sihwa Lake in Korea and others. Moreover, there are cases of local governments investigating opportunities to open estuary dams: in Japan, Aichi Prefectural Government is investigating that of Nagara River and in Korea, Busan Metropolitan City Government that of Nakdong River.

Wetland health is closely related to the flow of water. It is important that the Asian Wetland Symposium 2017 considers and discusses the way artificial construction that halts the flow of water is one of the main factors to cause destruction of wetlands.

We cordially request that our proposal will be examined sincerely, in the strong hope that the Asian Wetland Symposium 2017 will contribute sincerely to the conservation of each wetland in the Asian Region including the Ariake Sea.

24 September 2017

諫早湾干拓事業が有明海異変の根本原因であることを示す明確な事実

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1．はじめに

農水省の干拓事業によって諫早湾が長大な潮受け堤防によって閉め切られた後、宝の海とうたわれた有明海の環境は急激に悪化し、漁業は著しく衰退して、漁民は塗炭の苦しみに陥っている。そのため自らの命を絶った人も少なくない。このような有明海の環境の顕著な悪化は有明海異変として世間で大きな問題になった。干拓事業は1986年に開始、1989年に事業着工、1997年に堤防閉め切り、2006年に事業完了である。

かつて有明海が宝の海であった理由については、多くの報告がなされている。そしてこのように急激に環境が悪化し、漁業が衰退した原因については、多方面で研究がなされてきた。そして熱心な研究者たちによって、その主原因は諫早湾干拓事業であることが指摘されてきた（例えば、日本海洋学会, 2005）。だが農水省や長崎県および一部の研究者はこのことをまだ認めていない。

そして特に重大なことは、有明海異変の原因を明らかにして、環境改善の方向を指し示すべき使命を帯びた環境省の有明海評価委員会（正確には有明海・八代海等総合調査評価委員会）は成立後15年を経た現在でも、依然として有明海異変の原因はいまなお不明と結論していることである。そしてこのことが、農水省が抜本的改善対策をとらずに効果の乏しい小手先対策に終始して、悪化した環境が20数年間も継続することを助長する主要な科学的根拠になっている。さらに福岡高裁の開門判決確定後にもかかわらず、委員会の原因不可知論がその後の裁判には取り入れられて、開門調査を求める漁民の主張が退けられる原因になっている。けれども筆者は、科学的に検討すべき点が残されていても、干拓事業が有明海異変の根本原因であることを示す明確な事実は少なからず得られていると思う。3節でこの事例を述べる。

2．研究の困難性と研究者の対応

有明海の環境の悪化と漁業衰退の原因の究明、およびその解決を求める研究やシンポジウムが数多くなされてきて、諫早湾干拓事業の影響が種々指摘されている。だがこの種の環境問題では、全く疑問がないように科学的にその根拠を明確にすることは、実は大変難しいことである。そこで、決定的結論が容易には得難い理由を述べる。

それは第1に自然現象、特に生物が関与する現象では、関与する要因が単一でなく複雑多様であるからである。あるものはプラスに、あるものはマイナスに働いて、それらが複合して現象が生じる。問題を残さないように科学的に証明することは、一般的に極めて困難である。

第2に、自然現象は広範囲に、しかも時間的に変化するものである。それゆえある場所ある時間にどんなに正確に観測しても、それから理解できるものはわずかであり、広範囲に長期にわたる観測が要請される。だがこのような観測調査は資金豊富な事業者を除いては、経費、時間、人手が限られた普通の研究者には無理である。したがって部分的な観測によって推論する

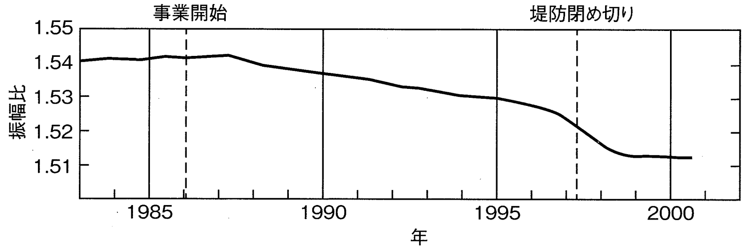

図1　大浦と口之津のM_2分潮の振幅比（増幅率）（宇野木, 2015）

わけで、問題を残さざるを得ない。

第3に、諫早湾干拓事業の場合には、農水省が実施した事前調査が、他に類がないほど杜撰（ずさん）で必要なデータが不足していることである。例えば諫早湾外の有明海における測流地点は、後出の**図2**に示すようにわずか3測点のみである。有明海のような広い海域に対する環境影響評価で、このような貧弱な事前調査の例を筆者はこれまで見たことがない。これは一例に過ぎないが、有明海の環境崩壊や漁業衰退の原因究明が難しいのは、農水省の事前調査がかくも杜撰であったために、事業前と事業後の比較が困難であることが最大の理由であるといっても過言ではない。

このように環境問題の研究は困難を伴う。そこで環境学者ノーマン・マイヤーズは環境問題の研究に関して、「60％分かれば、科学者は報告しなければならない。不確かであるとして発表しなければ、何の問題もないと思われる。」と述べている。これは環境問題における研究者の対応を明確に教えるものである。報告しなければ、事業者は問題ないと称して事業を進めて環境を悪化させる。それゆえ60％を理解しても、完璧を求めて発言を避けた研究者は、環境の悪化に手を貸したと見なされざるを得ないことを銘記すべきである。関係する委員会についても同様である。

3．諫早湾干拓事業が有明海異変を引き起こしたことを明白に示す事実

諫早湾干拓事業が有明海異変を発生させたことを指摘する研究結果は多い（例えば、日本海洋学会, 2005）。だがデータの不足や科学的に原因が十分に明確でないことを理由にして、このことを認めない意見が存在する。そこで干拓事業後に激変し、誰が見ても干拓事業の影響と認めざるを得ない3つの事例を述べる。

(1) 堤防閉め切り後における潮汐・潮流の減少

内湾の潮汐は、外海の潮汐波が内湾に進入して、流体振動系である内湾の水を揺り動かして発生するものである。それゆえ潮汐周期と内湾の固有振動周期が近いほど共鳴して、潮汐振動は大きくなる。一方、干拓事業によって面積が狭まり、平均水深が大きくなると、内湾の固有周期が小さくなって潮汐周期との差は開き、潮汐は減少する。**図1**は最も大きなM_2分潮を対象に、有明海の湾奥に近い大浦と湾口の口之津の振幅の比をとって、潮汐の増幅率を求めたものである。図では細かい変化を消すために3年間の移動平均が施してある。また干拓事業の開始と閉め切りの時期が加えてある。

図1によると、地形が安定して変化がない干拓事業開始前と堤防閉め切り後の両期間においては、それぞれ増幅率はほぼ一定の値をとっていて、事業前の値に比べて事業後の値が小さくなっている。そして工事期間中は工事の進行に伴って増幅率は一方的に減少している。この結果は、干拓事業によって有明海の潮汐が全域的に減少したことを明白に示している。ただし減少量はそれほど大きくなく、また外海の潮汐変化の影響も重なって、上記の減少が事業後の有明海の環境悪化に与えた影響はそれほど大きくないと考えられる。

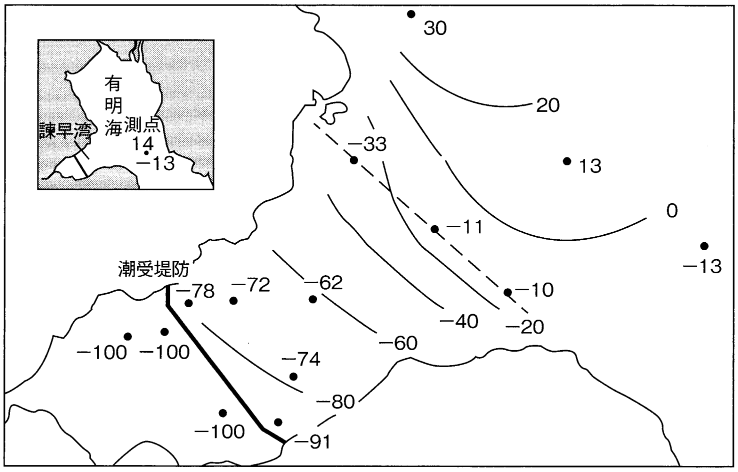

図2　潮受け堤防の閉め切り前後における大潮時の潮流の変化率（%）。マイナスは減少。農水省のデータを元に作成（宇野木, 2015）

これに対して、事業の地形変化に伴う潮流変化が、環境に及ぼす影響は著しく大きい。**図2**は農水省が潮受け堤防閉め切りの前後に実施した測流結果に基づいて、大潮最強流速の変化率を求めたものである。これによれば堤防閉め切り後は閉め切り前に比べて、当然ながら堤防前面では80～90%もの顕著な減少が認められる。堤防を離れるにつれて減少率は小さくなるが、それでも諫早湾口付近では10～30%の減少である。

一方、諫早湾外では3点で観測が行われている。一番南側の測点14では、これは有明海の中央に位置しているが、閉め切り後に流速が13%も減少している。農水省のサボタージュによって有明海全域の調査は実施されていないので、事業前後の詳細な変化は知り得ないが、西ノ首ら（2004）の部分的観測結果や数値計算によれば、閉め切りによる地形変化の影響が有明海全体に及んでいることが認められる（日本海洋学会, 2005）。国と県の水産調査研究機関が協力して実施した、広範囲にわたる簡易ひも流し法による一斉観測によれば全域平均で約12%の減少、漁師へのアンケート調査によれば、10～20数%の減少が報告されている。

以上のように干拓事業によって潮流が減少すると、海水の水平混合が弱まり、海水が停滞しやすくなる。また海水の上下混合とそれに伴う内部摩擦が減少して、成層構造が強まり、密度流が発達する。有明海の表層の密度流は湾北東部に流入する筑後川の影響が強い。この表層の流れは地球自転の影響で岸を右手に見て進むので、堤防閉め切り後に筑後川系の水が佐賀県から長崎県側寄りにより強く進むことが、西海区水産研究所の浅海定線観測データの解析（程木, 2005）や、公害等調整委員会専門委員（2004）の数値計算結果によって明らかにされている。海水の停滞が進むと、栄養塩やCODを含む海水は赤潮や貧酸素を発生しやすくなる。

また密度成層が強まるとエスチュアリー循環も強まり、調整池からの排水によって汚濁された海水や物質が、底層を伝わって有明海湾奥部に運ばれてきて、環境の悪化を強めている（公害等調整委員会専門委員, 2004; 速水ら, 2006）。

なお**図2**において、測点14より北側の沿岸寄りの2測点では、事業後に潮流は強まっているが、これは地形効果によるものである。このことは調整池から排出された汚濁水の有明海西岸への拡散を強め、海域の局所的汚濁化に寄与すると考えられる。

(2) 堤防閉め切り後の赤潮の大発生

代田・近藤（1985）によれば、有明海は瀬

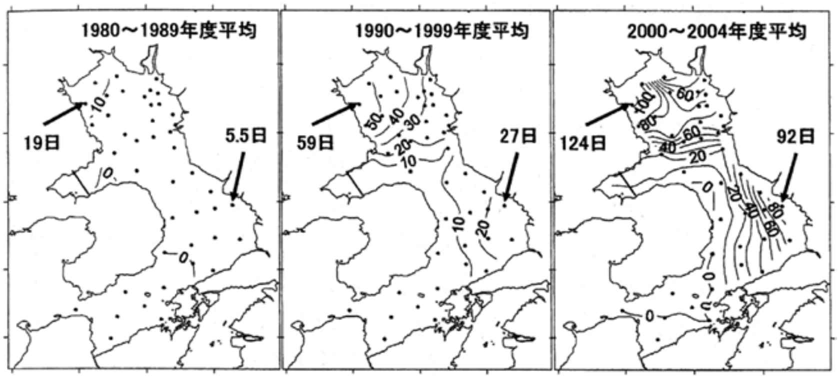

図3　有明海における年代別の10～3月の平均赤潮発生日数（日/半年）（清本ら, 2006）

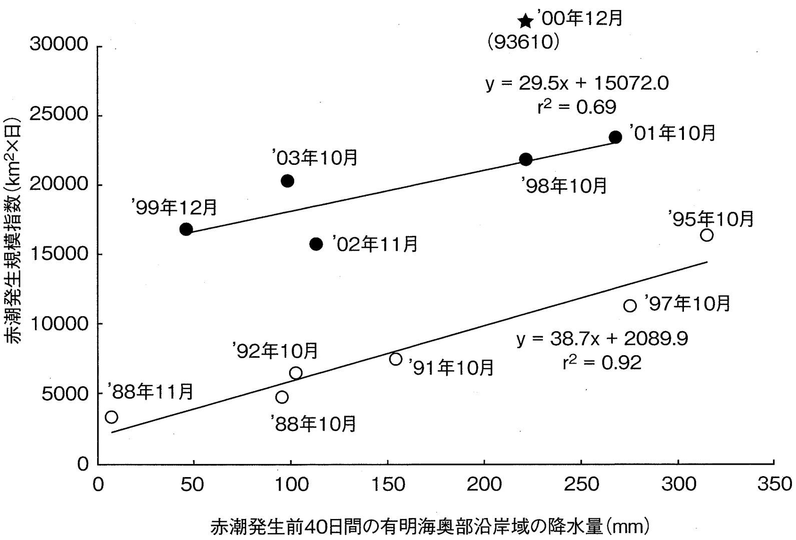

図4　有明海の10～12月における赤潮発生規模指数（赤潮の最大面積×継続日数）と赤潮発生前40日間の平均降水量との関係。飛び離れた星印（2000年12月）は特別の値（堤ら, 2006）

戸内海よりも汚染が進み、赤潮が発生する条件がそろっているにも関わらず、これまで問題にするような赤潮は発生していないと報告し、その理由を明確に述べている。

ところで清本ら（2006）は、有明海におけるノリ養殖に関係の深い10～3月における平均赤潮日数（半年間の日数）を、3つの年代に分けて比較した。結果を**図3**に示す。干拓事業の着工が1989年、堤防閉め切りが1997年であることを考慮すると、事業の始まりとともに赤潮が増え始め、堤防閉め切り後に発生回数が飛躍的に増大したことが明瞭に理解できる。この期間にこれほど急激に赤潮を発生させる要因は他に認められないので、この事実は誰が見ても明らかに干拓事業によるものと断定できるであろう。なおこの図で諫早湾における発生回数が少ないのは、年間では非常に多いものの、図に含まれない夏季に偏って発生するためである。

一方、堤らの研究グループ（2006）は、赤潮の最大面積と継続日数の積で定義された赤潮発生規模指数と、赤潮発生前の40日間の平均降水量との関係を調べて**図4**を得た。図によれば

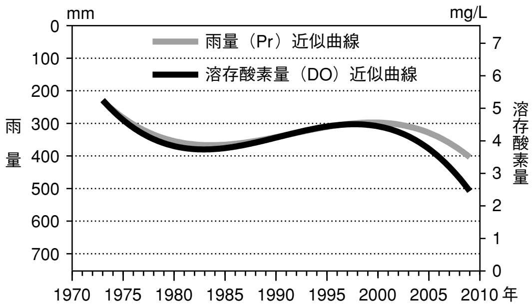

図５　佐賀県沖の測点（St.5）の底層溶存酸素と佐賀市７月雨量との関係（松川ら，2014）

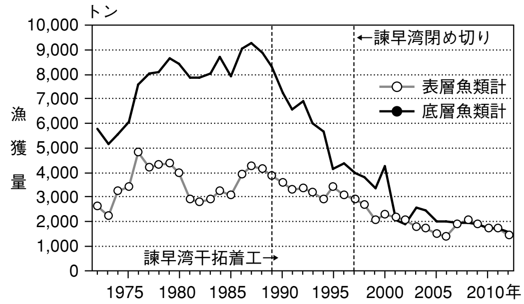

図６　有明海における表層と底層の魚類漁獲量の経年変化（佐々木，2016）

降水量が多いと、赤潮の規模が大きくなることが理解できる。ここで注目されるのは、1997年に潮受け堤防が閉め切られる以前（○）と以後（●）では、両者の関係が決定的に相違していることである。すなわち堤防閉め切り後は閉め切り前に比べて、同じ降水量であっても、発生する赤潮の規模は格段に大きくなっている。ゆえに干拓事業が赤潮の拡大に極めて大きく寄与している事実は、誰も否定できないであろう。

このような降水量と水質との関係について、松川ら（2014）は次のような結果を得た。彼らは近年の有明海における環境の変化は、およそ3期に分かれることを考慮して、この変化を極大と極小をもつ3次曲線で表して考察した。**図5**は溶存酸素量と雨量（目盛りは逆方向）の変化を比較したものであるが、これによると両者は密接な関係にあることが分かる。そして**図5**では堤防閉め切り後の2000年ごろから、従来の傾向を離れて貧酸素がひどくなり、**図3**や**図4**が示した結果と明瞭に一致している。

(3)　干拓事業後の漁獲の大激減

有明海の漁獲量は近年大幅に減少し、漁民は苦しい生活を強いられている。漁業の不振はまた関連する事業種にも甚大な影響を与えている。

図6は有明海における表層と底層の魚類漁獲量の推移を示したものである（佐々木，2016）。底層魚類が表層魚類よりも多いが、共に1988年ごろから減少した。1988 年のピーク時と比べると2012年には、表層魚類は34％、底層魚類は17％にまで低下している。

ただし、近年全国的に沿岸の漁獲量は減少傾向にあるものの、有明海の落ち込みは飛び抜けて顕著である。例えば瀬戸内海においては、表層魚類は63％、底層魚類は60％までの低下である。有明海のみのこの著しい低下には、有明海独自の原因がなければならない。諫早湾干拓事業が1989年に着工、1997年に堤防が閉め切られたことを考えると、この事業が漁獲減少の重要な要因であることが、当然考えられる。そしてこの期間に、これ程急激な漁獲の減少を引き起こすことが可能な別の要因は見いだされていない。

以上に示した3つの明白な事実から、諫早湾干拓事業が有明海異変と称される有明海の著しい環境悪化をもたらした主原因であることは、誰しも疑うことはできないであろう。

４．有明海の再生のために

福岡高裁は2010年12月6日に開門調査を命じた。その判決要旨は次のようである。「干拓事業は諫早湾内とその近場の環境変化を引き起こした可能性は高い。しかし、有明海の環境変化と事業との因果関係は科学的に明らかになったとはいえない。国が開門調査をしないのは立証妨害にあたる。因果関係を明らかにするため、3年間の間に排水門を開けて、5年間継続する。」

事実、有明海異変の適切な原因究明の方法は、開門調査である。農林水産省は2002年の4月から5月にかけて、ノリ第三者委員会の開門調査の提言を受け、約1か月間の開門調査を実施した。それは第三者委員会の要望からは大きく離れて、短期間でかつ調整池内の潮位差がわずか20 cmの微々たるものであった。それでも調整池内の水質の変化は大きく、開門が有明海の環境改善に大きく寄与する可能性が示唆された（諫早湾開門研究者会議, 2016）。そして適切な開門調査を実施すれば、有明海異変の原因は明確になると考えられた。なお農水省は、有明海異変の原因は干拓事業でないと主張しているのであるから、その主張を実証するためにも、開門調査は有効なはずである。

ここで我々には次のことが想起される。同じ農水省による干拓事業のために、岡山県児島湾中部を長さ1558 mの堤防で閉め切って形成された児島湖は、水質汚濁が著しいので問題になっている。これを改善するために、汚濁負荷削減や底泥除去などの対策が長年にわたり進められ、15年間で4480億円の巨費が投じられたという。それにも関わらず環境回復は思わしくなく、水質基準の達成は程遠いといわれる。堤防閉め切りのままでは、環境回復は困難であることを教える。

一方、中海・宍道湖においても、農水省による干拓事業が1963年に開始された。さらに加えて淡水化計画も発表され、農水省が設けた委員会から問題はないとの中間報告書が提出された。だが住民の反対が強いので、島根・鳥取の両県は報告書の妥当性を検討するために、14人の専門家からなる助言者会議を設けた。会議の委員たちは熱心誠実に検討し、1986年に「中間報告書の淡水化後水質シミュレーションは、基本的な点で問題であり、この水質予測結果は、特に夏季についてはそのまま信頼できない」と結論した。この結果、淡水化計画は中止になり、さらに干拓事業そのものも2000年に中止になった。これによって、閉鎖性が極めて強い本海域は、壊滅的環境破壊からは免れたといえる。

ところで有明海の場合には、1節に述べたように、農水省が有効な開門調査を実施しない科学的根拠として、有明海評価委員会の結論を利用していることが重要である。同委員会は2017年に全584頁にわたる報告書を提出した。これに対して諫早湾開門研究者会議（2017）や佐々木（2017）は綿密な考察を行った。それによると、有明海異変に影響する要因（ある事象、例えば貧酸素水塊の形成に関しては成層化、負荷量の増大、赤潮の多発など）については詳細に検討をしているが、それが発生した原因（例えば貧酸素水塊形成に対する堤防閉め切りの効果）についての検討と追究は避けている。そしてこのことが同委員会報告書の最大の特徴であると指摘されている。このことは同委員会が2006年に発表した報告書においても、有明海異変の要因・原因を考察した部分で、諫早湾干拓というキーワードが出てくるのは、わずかに3か所のみであることからも、うなずけることである。

以上のことから、評価委員会は農水省と委員会事務局の意向に沿って、有明海異変と干拓事業との関係の議論をできる限り避けて、長期にわたり原因不明との結論を導くことに汲々（きゅうきゅう）としていることが理解できる。これでは有明海の環境改善は到底望めない。ゆえに発足以来、このような振る舞いに終始した委員会は、衿持を失っていると断じざるを得ない（佐々木, 2017）。

だが3節に示した3例に見られるように、干拓事業と有明海異変との関係が極めて密接であることは明白である。またその関係を強く支持する研究も数多い。それゆえいずれ委員会委員は必ずや科学者の衿持を取り戻して、綿密な解析と、開門調査の必要性を理解して、開門の実施を要請し、有明海異変に対する諫早湾干拓事業の影響を明確に指摘することが期待される。

かくして有明海再生の道を開いて、有明海の環境回復に大きく貢献するであろう委員の功績は、後世に高く評価されるはずである。このこ

とを祈念して、委員の方々の氏名を記録に留めておくことは、意義深いと思われる。これらの方々は2017年現在において、岡田光正（委員長)、滝川清（委員長代理)、秋山壽一郎、岩渕光伸、上田直子、久場隆広、古賀秀昭、小松利光、清野聡子、樽谷賢治、内藤佳奈子、中田薫、中田英昭、中村由行、西村修、速水祐一、山口敦子、山口啓子、山田真知子、山本智子、小林政広の諸氏である。

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■ 編 集 後 記 ■

今号は11月に佐賀市で開催されるアジア湿地シンポジウムに合わせて、英語での諫早湾干拓問題の特集号としました。記事は裏表紙で紹介しているブックレット「諫早湾の水門開放から有明海の再生へ」の論文を要約・抜粋して英訳したものが中心ですが、ブックレットには収録していない論文や、その後の研究成果が含まれている記事もあります。後日、有明海漁民・市民ネットワークのウェブサイトにて今回の英文記事の日本語版を掲載する予定です。

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有明海の環境と漁業 第4号 2017年11月7日 発行（PDF ver.1.0）

編集・発行：有明海漁民・市民ネットワーク
監　　修：諫早湾開門研究者会議
定価 500円（本体463円）
ISSN 2432-4965

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有明海の環境と漁業
2017年11月7日発行　第4号

ISBN978-4-9909127-4-1
C9336 ¥463E

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