Anthropogenic decline of the peculiar fauna of estuarine mudflats in Japan

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Abstract: Mudflats are formed in the upper littoral zones in estuaries, especially in the innermost part of macro-tidal embayments (upper reaches of estuaries), providing a habitat for peculiar fauna and flora. The peculiar fauna and flora of estuarine mudflats appear to have been extirpated in many estuaries in Japan, along with the mudflats that have been damaged or destroyed by thoughtless and drastic coastal reclamation. At present, Ariake Bay, which constitutes the largest area of mudflats remaining in Japan, also has the greatest variety of species. The mudflat-specific species are almost or completely restricted to Ariake Bay, while populations of the same (or closely related) species are distributed along Asian continental coasts, which suggests they are continental relics. Some of the mudflat-specific species now restricted to Ariake Bay (e.g., the bivalve, *Tegillarca granosa*, the polychaete, *Hediste japonica*, the salt marsh plant, *Suaeda japonica*) previously enjoyed a wide distribution in Japan. Even within Ariake Bay, huge mudflats in Isahaya Bay were recently lost to a reclamation project there. The high productivity of benthic organisms in mudflats seems to benefit carnivores such as birds and fishes (e.g., Japanese eel). Conservation and restoration of mudflats are needed to conserve endangered species and to maintain traditional human fisheries and culture. From this aspect, restoration of the largest mudflats in Isahaya Bay in Ariake Bay is highly desirable.

Key words: Ariake Bay, continental relict, eel, endangered species, estuary, intertidal, Isahaya Bay, land reclamation, mudflats

Introduction

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 (McLusky & Elliott 2004). Since estuarine waters are typically rich in nutrients which have been carried there from the sea, rivers, or land adjacent to the estuary, high levels of primary production, which support large amounts of invertebrates, fishes and birds, occur in estuaries in comparison to the open sea or other coastal waters (McLusky & Elliott 2004). Though the number of species within estuaries is less than that in either the sea or freshwater, some species that are well adapted to the estuarine environments can markedly increase in biomass and productivity here (McLusky & Elliott 2004, Levinton 2009).

The high productivity of estuaries gives them an ecological role in providing nursery grounds for marine and freshwater fishes and crustaceans, as well as feeding areas for migratory shorebirds. Humans also depend on estuarine ecosystems for important and valuable goods and services (e.g., fishery catch of various clams and farming of seaweeds such as “nori”). Especially in Japan, our ancestors depended on bivalves and other organisms collected from shallow coastal waters, and left numerous shell mounds.

On the other hand, estuaries have been focal points of human settlement throughout history, and heavily disrupted by human activities such as overexploitation, pollution, and land reclamation. (Lotze et al. 2006). In Japan, the biggest four cities (with a total population of more than 2 million) are all located on the upper reaches of estuaries; viz., Tokyo and Yokohama in Tokyo Bay, Nagoya in Ise Bay, Osaka in Osaka Bay, Seto Inland Sea (Fig. 1).

In the present article, I aim to shed light on the present situation of the peculiar fauna of estuarine mudflats in Japan. It is shown that estuarine mudflats have, due to their physical and geographical characteristics, been severely destroyed by anthropogenic land reclamation, and that distributional ranges of many mudflat-specific species have been...
reduced drastically to very limited areas.

The importance of conservation for the largest mudflats in Ariake Bay is emphasized as they constitute the last remaining habitat for many endangered species.

**Characteristic location of mudflats**

Intertidal flats occur in (or occasionally outside) an estuary with sedimentation of sandy and muddy particles. Fine, light particles (mud) are separated from coarse, heavy particles (sand), and deposited in the upper littoral zones by tidal effects, forming mudflats in and around salt-marsh vegetation nearest to land (Sakakura 2004). Moreover, in general, typical mudflats develop in the innermost part of macro-tidal embayment (upper reaches of estuaries). Mud particles suspended in tidal currents are transported into the upper reaches of estuaries by “flood-ebb current asymmetry”, while mud is also deposited there when mud particles supplied by freshwater flows aggregate in reaction with salt ions (flocculation) and settle out (Sakakura 2004). Consequently, typical mudflats of fine-silt or clay particles are formed in the upper littoral zones in the innermost parts of macro-tidal estuarine embayments.

In Japan, the largest area of mudflats exists in Ariake Bay (also known as “Ariake Sea”, 96 km in axis length, 18 km in average width, 1,700 km² in total area, 20 m in average depth) in western Kyushu, Japan (Kamada 1980) (Figs. 1, 2). It is a unique macro-tidal embayment with a maximum tidal range of more than 6 m in the innermost area (Sato M & Takita 2000), whereas most Japanese coasts are micro-tidal with ranges less than 2 m (Sakakura 2004). The whole area of Ariake Bay could be regarded as a single estuary (Kikuchi 2000). In this bay, vast tidal flats are formed on the northern (innermost) and eastern coasts, where the largest river (Chikugo-gawa; flow-rate approx. 115 m³ sec⁻¹, averaged over a year) and several other large rivers flow, supplying large amounts of sand and mud particles (Sato M & Takita 2000). Yokoyama (2005) estimated that 76% of the total particles supplied to Ariake Bay by comes 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, and transported to upper reaches of the estuary, as mentioned above, and also displaced counterclockwise by the Coriolis effect (Shi...
moyama & Nishida 1999) to form extensive mudflats fringing the northwest coast of Ariake Bay. The finest mud particles (fine silt and clay) are transported farthest, into Isahaya Bay which is located in the western coast of Ariake Bay, producing typical soft mudflats there (Kamada 1980, Fujimagari & Makino 2001). These, however, were completely lost in the recent reclamation project mentioned below (Fig. 3). 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 bay (Fig. 2).

Depending on the sediment load of tides and rivers, mudflats have also formed in the upper littoral zones in the innermost part of other estuarine embayments on the coasts of the Pacific Ocean and East China Sea in central and western Japan, where tidal magnitude is relatively large (Sato M & Takita 2000), e.g., Tokyo Bay, Mikawa Bay, Ise Bay, Seto Inland Sea, and Shiranui Sea (= Yatsushiro Sea) (Fig. 1), though details of the original distribution of mudflats in these embayments are unknown. Macro-tidal environments similar to Ariake Bay are common on the Korean coast of the Yellow Sea (West Sea) which has a maximum tidal range of more than 9 m, while mudflats develop not only within estuaries but also along open coasts (Hong 2000, Sakakura 2004, Sato M & Koh 2004).

**Drastic reduction of mudflats by coastal developments**

In general, the upper littoral zones of estuaries, where mudflats occur, have been most severely damaged by anthropogenic coastal developments (e.g., reclamation, seawall construction), because they are most accessible from dry land. Moreover, throughout history in Japan, large coastal urbanization has been concentrated in the innermost parts of major embayments, where estuarine mudflats occur. Thus it is that, during recent coastal developments, mudflats have been so extensively reclaimed that most have been eliminated almost unnoticed. Hanawa (2006) estimated that the total area of sandy and muddy tidal flats on the Japanese coasts declined from 826 km$^2$ in 1945 to 495 km$^2$ (60%) in 2005.

In Tokyo Bay [defined here as the part north of Uraga Straits (the line from Kannon-zaki and Futtsu-misaki)] (area: 960 km$^2$, average depth: 15 m), the 136 km$^2$ of tidalflats in 1936 were reduced by coastal land reclamation for metropolitan development to 10 km$^2$ by 1990, a mere 7.4% of the 1936 figure. (Kamatani 1993) (Fig. 4). An Edo-period (mid 19th century) Hiroshige woodblock print shows that mudflats existed in the innermost part of the Tokyo Bay and that part of them was used as a salt farm (Fig. 5).

In Ise Bay (area: 1,740 km$^2$, average depth: 20 m) and the neighboring Mikawa Bay (area: 604 km$^2$, average depth: 9 m), the tidal-flat areas of 29.4 km$^2$ and 26.3 km$^2$ in 1945 were reduced to 11.5 km$^2$ (39.2%) and 13.7 km$^2$ (52.0%) by 1978, respectively (Sasaki 1997).

In the largest inland sea, Seto Inland Sea (area: 23,203 km$^2$, average depth: 38 m, Fig. 6A), the total area of tidal flats, 251.9 km$^2$ in 1898 was reduced to 117.3 km$^2$ (46.6%) by 1989–1990 (The Association for the Environmental Conservation of the Seto Inland Sea 1999). In particular, tidal flats in Osaka Bay (area: 1,447 km$^2$, average depth: 30 m) were reduced from 1.8 km$^2$ in 1945 to 0.15 km$^2$ (8%) by 1989–1990 (The Association for the Environmental Conservation of the Seto Inland Sea 1999). Vast mudflats in Kojima Bay in Okayama Prefecture (Fig.

![Fig. 4.](image-url) Maps showing Tokyo Bay in central Japan in 1936 (A) and around 1995 (B). Areas of tidal flats are shown in black, and additionally indicated by arrows in (B). A white asterisk in (A) means the estimated site of a view shown in Fig. 5. (A) after Mukai (1993), (B) after Furota (1997).
6B) (Kato 2006, Sato M 2006) were completely lost to land reclamation (14 km² during 1899–1912 and 38 km² after that) and enclosure of the innermost part of the bay (11 km²) by the construction of a dike in 1956 (Fig. 6C) (Dozen, 1987).

In Ariake Bay (Fig. 2), the total area of tidal flats, 267 km² in 1945 was reduced to 192 km² (72%) by 2000 (Hanawa 2006). Vast mudflats in the inner part of Isahaya Bay, covering up to 29 km² at spring tides (Kyushu Agricultural Administration Office 1991, Sato M & Takita 2000) were completely lost by enclosure of the inner bay area (36 km²) by the construction of a 7-km dike in April 1997 (Fig. 3) (Sato M & Takita 2000, Sato M & Koh 2004).

Overwhelming coastal reclamations have occurred also on the western and southern coasts of Korea, where the total tidal-flat area of 3,905 km² in 1964 was reduced to 2,815 km² (72%) in 1987, and to less than 2,393 km² (<40%) in 1998 (Hong 2000, Ahn & Je 2003).

Unique fauna in Ariake Bay in Japan

There are specific fauna and flora associated with estuar-
ine mudflats. They seem to have been extirpated in many estuaries in Japan because of the drastic reduction of mudflats by coastal developments. At present, the largest number of mudflat-specific species are found in Ariake Bay, which also has the largest area of mudflats remaining in Japan.

Ariake Bay is known to have peculiar fauna characterized by continental relicts, a result of the isolation of Japanese island populations from those on the Asian continental coast by transgressions during geological history (Sugano 1981, Shimoyama 2000, Tanaka 2009a). These continental relicts are sometimes referred to as “Ariake Bay indigenous species”, because their present distributions are almost or completely restricted to the Ariake Bay in Japan (Sugano 1981, Sato M & Takita 2000, Yamashita 2004, Sato M & Koh 2004).

The continental relicts mostly inhabit the inner part of Ariake Bay, and seem to depend on mudflats or related environments for at least some period in their life cycles. Among seven fish species well known as the continental relicts, two gobiids, *Boleophthalmus pectinirostris* (Linnaeus) [Japanese name: Mutsugorou] and *Odontamblyopus lacerpedii* (Temminck et Schlegel) [Warasubo] are inhabitants of mudflats, limited to the inner part of the Ariake Bay and the neighboring Shiranui Sea in Japan (Takita 2000, Takita & Ishimatsu 2009, Takegaki 2009). In another gobiid, *Acanthogobius hasta* (Temminck et Schlegel) [Hazekuchi], which also inhabits only the inner part of Ariake Bay and Shiranui Sea, the lower part of mudflats is used as its spawning ground, where adults burrow down into the mud, while juveniles grow in brackish waters with a high concentration of suspended mud particles in the upper reaches of estuaries (Takita & Ishimatsu 2009). In a catadromous cottoid species, *Trachidermus fasciatus* Heckel [Yamanokami], mature adults spawn egg masses in dead oyster or other bivalve shells in mudflats only in the inner Ariake Bay, juveniles come up rivers after spending the early developmental stage in estuaries, while adults live in freshwater (Onikura 2000, Takeshita & Onikura 2009). The muddy brackish-water area in the upper reaches of an estuary in Chikugo-gawa River is an important nursery ground for most of the continental-relict fishes (Tanaka 2009a, 2009b).

Several macrobenthic invertebrates inhabiting mudflats exclusively in Ariake Bay (and often neighboring Shiranui Sea) are also regarded as continental relicts, e.g., three crabs, *Elamenopsis ariakensis* Sakai [Ariake-yawaragani], *Ilyoplax deschampsi* (Rathbun) [Haragukure-chigogani], *Neoeriocheir leptognathus* (Rathbun) [Hime-mokuzugani] (Kosuge 2000, Iijima 2007), three gastropods *Pseudomphala miyazakii* Habe [Azuki-kawazanshou], *Onchidium sp.* [Yabegawamochi] (Fukuda 2000, Yamashita 2004), *Salinator takii* Kuroda [Umi-maimai] (Fig. 7) (Fukuda & Kosuge 2000, Yamashita 2004), and the Kumamoto oyster, *Crassostrea sikamea* (Amemiya) [Shikamegaki] (Sato S 2000, Sekino 2009).

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**Fig. 7.** A tiny gastropod *Salinator takii* crawling in the mud surface, and feeding on benthic microalgae on mudflats in Kashima in Ariake Bay in March 2008. Shell diameter: about 5 mm.

**Fig. 8.** Two dominant species of benthic diatoms collected from mudflats in Isahaya Bay in May 1996 (before enclosure of the bay). a. *Haslea nipkowii*, b. *Nitzschia gyrosigma*. Scale bar: 0.1 mm. After Sato M (2006).
Blooms of benthic diatoms are ecologically important as a major primary producer in tidal flats (Montani 2000, Yamaguchi et al. 2004). But, taxonomic study on benthic diatoms is lacking. Ohtsuka T (2000) preliminarily reported that more than 100 species of diatoms were found in a spoon of sediment collected from the surface of mudflats in Isahaya Bay in Ariake Bay in May 1996 (before enclosure of the bay). Later, Ohtsuka T (2005) identified the most dominant species as Haslea nipkowii (F. Meister) Poulin et G. Massé as new to Japanese fauna (Fig. 8a) (This species was previously known only from a type locality found on the Chinese coast), and described the second most dominant as a new species, Nitzschia gyrosigma Ohtsuka (Fig. 8b) whose type locality at mudflats in Isahaya Bay was destroyed before the publication of the description. These diatoms seem to be continental relicts, and to be the most important diet for many continental relict fish and invertebrate species such as Boleophthalmus pectinirostris and Salinator takii (Fig. 7).

Thus, Ariake Bay is special in having so many continental relicts. The lives of continental relicts are closely associated with estuarine mudflats and muddy environments. The various continental relict species belong to different trophic levels constituting a unique food web in mudflats, and yielding high bioproductivity. The present question is why their distributions are mostly restricted to the Ariake Bay in Japan. The characteristic distributions of continental relicts have previously been explained by the environmental similarity between the Ariake Bay and Yellow Sea, with large macro-tidal estuaries, and their geohistorically close relationship (Sugano 1981, Shimoyama 2000, Tanaka 2009a). However, there is also the possibility that some of the continental relict species had previously enjoyed a wide distribution around the Japanese coast, but all other Japanese populations have been extirpated by habitat loss due to anthropogenic coastal developments of estuarine mudflats. Some evidence supporting this possibility will be shown in the next section.

**Recent reduction of mudflat-specific species**

Reduction of the original wide distribution of the mudflat fauna in Japan into the present narrow one in the inner part of Ariake Bay has been well documented in some bivalves for which many fossil records are available. For example, Tegillarca granosa (Linnaeus) [Haigai] was once distributed in a wide range from Kyushu to Hakodate, in Hokkaido, about 6,000 years ago according to fossil records, and its living specimens were recorded in many embayments in central and western Japan until 100 years ago (Fig. 9, Sato S 2000, Sato S et al. 2004). At present, its distribution is limited to the innermost part of Ariake Bay and additional small habitats in Shiranui Bay and Imari Bay in western Kyushu (Yamashita 2004, Miyazaki 2008). The dense population of this species, inhabiting mudflats of Isahaya Bay in the inner part of the Ariake Bay, was recently extirpated by the reclamation project mentioned above (Fig. 10) (Sato S 2000, Sato M & Koh 2004).

A salt marsh plant, Suaeda japonica Makino [Shichimenso] inhabits mudflats only within the innermost part of Ariake Bay at present, but its distribution extended to Seto Inland Sea (the coasts of Suto-nada in Kyushu and Bisan-seto in Kagawa Prefecture) until the 1950s (Jinno 2000). Local populations in the Seto Inland Sea appear to have been extirpated by anthropogenic habitat loss. Its largest colony in Japan, which occurred in the Isahaya Bay in the inner Ariake Bay, was extirpated by the recent reclamation project, as was T. granosa.

Similar reduction of the distribution also occurred in the mudflat-specific nereidid polychaete, Hediste japonica
M. SATO (Izuka) [Ariake-kawa-gokai], which is one of three Asian sibling species inhabiting estuarine tidal flats (Fig. 11). Whereas H. diadroma Sato & Nakashima [Yamato-kawa-gokai] and H. atoka Sato & Nakashima [Hime-yamatokawa-gokai] are commonly found in a wide range of Japanese estuaries, the present distribution of H. japonica is limited to mudflats in the inner part of the Ariake Bay in Japan and on the Korean coast of the Yellow Sea (Sato M & Nakashima 2003, Sato M 2004, 2006) (Fig. 12). The extremely restricted distribution of H. japonica in Japan seems to be caused by the recent habitat loss. Its type locality (mudflats in Kojima Bay in the Seto Inland Sea, Izuka 1908) was lost in 1956 to land reclamation as mentioned above (Fig. 5). Before that, large numbers of swarming Hediste epitokes (sexually mature worms) were collected.

Fig. 11. Asian Hediste worms (Nereididae, Polychaeta, Annelida) inhabiting estuarine tidal flats. a, a live worm of Hediste japonica collected from mudflats in Higashi-Yoka, Saga Prefecture in Ariake Bay in October 1996; b, drawings of dorsal view of the anterior end of three Hediste species. After Sato & Nakashima (2003).

Fig. 12. Distribution of Hediste japonica. 1, “Bay of Miya” in Ise Bay. 2, Kojima Bay in the Seto Inland Sea (type locality). 3, Inner part of the Ariake Bay. 4, Inchon. 5, Saemangeum in Gunsan. 6, Suncheon Bay.

Fig. 13. A view of the inner Ise Bay (the old name: Bay of Miya), central Japan, shown in an Edo-Period woodblock print by Hiroshige Utagawa (1797–1858) entitled Miya, Shichi-ri-nosawashi, Atsuta-torii, Nezame-no-sato (“Seven League Ferry” at Miya, Gate of Atsuta Shrine, Nezame village), from the series Tokaido-gojusan-tsugi (Fifty-three Stations Along the Toukaidou Road, Marukiyo edition, c. 1847–51). Through coastal development, inner Ise Bay has been reclaimed to land and is now occupied by the central part of Nagoya City. The original print on paper is stored in Mie Prefectural Art Museum (Photo courtesy of the museum).
by local people to use as fertilizer for farmlands of a rush [Igusa] (Izuka 1921). There is no recent record of this species from the anywhere in the Seto Inland Sea.

Recently, we proved that the distribution of *H. japonica* formerly extended to Ise Bay in central Japan (Sato M & Sattmann 2009). A total of 11 *Hediste* specimens were collected from the innermost part (“Bay of Miya” is the old place name, Fig. 13) of Ise Bay around 1876 by Dr. Carl Koerbl, and donated to the Natural History Museum in Vienna by Dr. Richard von Drasche-Wartinberg in 1877. Since this collection has been safely preserved there, we were able to examine the specimens, and identify them as *H. japonica*. Through recent coastal development, the innermost part of Ise Bay has been almost completely reclaimed and is now Atsuta-ku, the center of Nagoya City in Aichi Prefecture. Thus the local population of *H. japonica* has been extirpated from Ise Bay (Fig. 12). In a survey of macrobenthic organisms in tidal flats at 157 sites covering the whole of Japan from 2002 to 2004, *H. japonica* was found at only seven sites within the inner part of Ariake Bay (Iijima 2007) (Fig. 14). The mudflats in the Ariake Bay appear to be the last habitat of *H. japonica* remaining in Japan; however, a recent reclamation project in Isahaya Bay caused the loss of the most important remaining habitat for this species. On the Korean west coast, which is the only known habitat for *H. japonica* outside Japan, muddy shallow habitats have been seriously damaged by recent land reclamation on a larger scale (e.g. 56 km² at Incheon National Airport, 400 km² in the Saemangeum area) (Hong 2000, Sato M & Koh, 2004, Sato S et al. 2007). Thus, *H. japonica* seems to be in danger of extinction due to severe habitat loss.

Our knowledge about fauna and flora in estuarine mudflats is limited at present because of the delay of taxonomic studies on macrobenthic invertebrates and meiofauna. There are probably many undescribed species still there. Some of them may well be extirpated before we are aware of their existence.

**Contribution of mudflat fauna in coastal ecosystem**

Mudflat-specific species often attain extremely high densities and biomasses. For example, the maximum density of a population of *Tegillarca granosa* (3–5 cm in shell length) reached 73 ind. m⁻² on mudflats in Isahaya Bay when its mass deaths occurred due to the enclosure of the Bay in 1997 (Sato S 2001, see Fig. 10). Maximum biomass of a population of *Hediste japonica* was recorded as much as about 1 kg m⁻² in wet weight in an estuary of the Omuta-gawa River in Ariake Bay (Hanafiah et al. 2006). Such large biomass of macrobenthic invertebrates on estuarine mudflats seems to support the lives of carnivores such as birds and fishes through food chains in estuarine ecosystem. *Hediste* worms are the most important dietary item for many migratory shorebirds (Iwamatsu et al. 2007). According to the late eighth century Japanese anthology of poetry, the Manyoshu (Anthology of Myriad Leaves) (Saito 1938), cranes commonly migrated to estuarine mudflats in central Japan, e.g., in the inner part of Ise Bay, during their wintering period, though they are not found in Japan at present except for a few spots of freshwater or coastal wetlands. In ancient Japan where estuarine mudflats were widespread, benthic organisms such as *Hediste japonica* may have been an important food item even for cranes.

Current studies on the Japanese eel (*Anguilla japonica* Temminck et Schlegel) [Unagi] suggest that estuarine mudflats may be important in maintaining natural eel resources, which are required for commercially valuable aquaculture (Ozawa & Hayashi 2007). The Japanese eel, widely distributed in eastern Asia from Taiwan, through eastern China, and north to Korea and Japan (Kotake et al. 2007), spawns far offshore in the ocean to the west of the Mariana Islands in the western North Pacific (Tsukamoto 1992). Previously, the Japanese eel was regarded as a catadromous fish with a freshwater growth stage, but recent fine studies (Tsukamoto
et al. 1998, Tsukamoto & Arai 2001, Kotake et al. 2003, 2005, 2007) demonstrated that the Japanese eel needs not be catadromous, but has variable life histories with or without migration to fresh waters, and that eel reproduction is mainly maintained by populations that grow in estuarine or coastal areas (Fig. 15). This finding suggests that estuarine mudflats in Japan and neighboring countries supply important foraging places also for the eel (as a temporary stage in the catadromous migration of freshwater migrants, and over a growth period of several years for estuarine residents).

Some eels collected from mudflats (probably estuarine residents) are called “Ao” (meaning “blue” in Japanese) by local people in the inner part of Ariake Bay (Junji Kubo in Saga Prefecture, personal communication) and in the former Kojima Bay in Seto Inland Sea (Yuasa 1983, Dozen 1987), and are known as the best to eat in both locations. They were caught in mudflats with a traditional iron implement called “Unagi-kaki” in both bays (Dozen 1987, Takita & Ishimatsu 2009) and Ise Bay (Toba Sea-Folk Museum 1988).

We observed that several individuals of the eel (probably the estuarine residents) ate epitokes of *Hediste diadroma* during their reproductive swarming around high tide at night on 23 March 2008 in an estuary of the Omoi-gawa River in Kagoshima Bay. Photographed by Yoshiteru Tachiyama.

![Fig. 16.](image)

**Fig. 16.** Photographs showing reproductive swarming of epitokous worms of *Hediste diadroma* (a) and a Japanese eel individual eating the epitokous *Hediste* worms (b, c) just after high-tide at night on 23 March 2008 in an estuary of the Omoi-gawa River in Kagoshima Bay. Photographed by Yoshiteru Tachiyama.

been caused by reduction of estuarine mudflats.

**Conclusion**

Due to anthropogenic habitat loss, the peculiar fauna of estuarine mudflats is in danger of being driven to extinction before we have even sufficiently studied it. The reduction of the high-productivity mudflat-specific benthic fauna, probably causes a reduction of food supply for coastal carnivores including migratory shore birds and some commercially important fishes, leading to marked degradation of the unique mudflat ecosystem. Conservation and restoration of estuarine mudflats is essential to preserve the many endangered species and to maintain traditional human fisheries and culture that depend on the high productivity of the mudflat ecosystem.

Conservation of the inner part of Ariake Bay is the most important in Japan, because here remain mudflats as the last habitat for Japanese populations of many endangered species such as *Hediste japonica*. In this respect, restoration of the former largest mudflats in Isahaya Bay is strongly recommended.

In Suncheon Bay in the southern coast of Korea, a huge area of the coastal wetlands including estuarine mudflats has been conserved and partially restored (Kim, 2009). The upper part of the mudflats is covered with salt marsh vegetation including the reed *Phragmites communis* Trinius [Yoshi] and *Suaeda japonica* (Fig. 17). Cranes regularly visit during their wintering period. Here we can observe mudflats in their original state, like those lost in Isahaya bay, and probably similar to those seen in embayments in ancient Japan.

In June 2009, a survey on the macrobenthic fauna on the mudflats of Suncheon Bay was carried out by Korean and Japanese biologists (Hong et al. 2010). Here we found dense patches of *H. japonica*, a new observation of this
species in southern Korea (Fig. 12), and many other mud-flat-specific species known as continental relicts in Japan. Efforts of Suncheon City for the conservation and restoration of natural mudflats seems to have a great potential to find successful coexistence of a local human society and a natural coastal ecosystem with estuarine mudflats.

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