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Stocks and fisheries of asari in Japan

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Abstract: Asari clam is one of the most important fishery resources in Japan. The clam has been utilized as not only a food but also a recreational harvestable species. Main habitat of the asari extends from tidal area to shallow subtidal area of sandy soft bottom. Asari is harvested by hand raking or short-handled basket raking in tidal areas and long-handled basket raking, dredging, helmet diving in subtidal areas. Major areas of asari harvest are Tokyo Bay, Mikawa Bay, Ise Bay, Suo Nada and Ariake Bay. Annual harvest of the asari in the major areas, however, decreased largely after late 1980s except Mikawa Bay. Stock decline of natural asari is remarkable and seriously problematic for coastal fisheries in Japan. Along with application of the various countermeasures intended to restore the natural stocks of asari, a number of factors have been discussed to be responsible for the asari decline. Some of these are decrease of suitable habitat areas, deterioration of water and substrate quality, erosion of the clams by strong wave disturbance, new predators and parasites, oligotrophication, and excess harvesting. We still have not determined significant factors responsible for the asari decline in Japan. In the discussed factors, we compared the effect of five factors; blue tide, river flood, strong wave disturbance, infection of sea spider, and hypoxia on clam larvae, based on the studies in Tokyo Bay. The impacts (mortalities) of the factors for the total asari stock by the blue tide in Sanbanze in 2008, the river flood in Sanbanze in 2007, winter wave mortality in the three areas in 2009–2010, and infection of sea spider in Kisarazu in 2009 were calculated to be 0.16，0.07，0.95，0.30, respectively. Among these factors, winter wave mortality showed the most significant effect on the asari stock in Tokyo Bay. Comparing the properties of the estimated factors, the factors that affected wider areas and longer period with higher mortality were supposed to give severer impact for the asari stock. In order to take effective countermeasures for the decline of asari stock in Japan, further assessment of the impact of the suspected factors is required to be progressed.

Key words: stock decline, causative factors, assessment, blue tide, winter wave mortality, sea spider

Asari is one of the most important fishery resources in Japan. Populations of asari are naturally maintained all over the coastal bay areas in the country. The clam has been utilized as not only a food but also a recreational harvestable species at least since eighth century AD. Asari is favored by common people because it inhabits abundantly in shallow sandy coast near urbanized areas and can be harvested easily as a palatable seafood.

Annual production of asari in Japan, however,

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declined during late 1980's and 1990's to ca. 40,000 t, after reaching its maximum of ca. 160,000 t in mid 1980's. Stock decline of natural asari is remarkable and seriously problematic for coastal fisheries in Japan.

A number of factors have been discussed to be responsible for the asari decline (National Conference on Asari Stocks, 2006). Some of these are decrease of suitable habitat areas by the land reclamation, deterioration of water and substrate quality due to coastal development, physical unstabilization of bottom substrate by strong wave disturbance, predators and parasites newly invaded during recent years, oligotrophication with strict regulation of waste water quality control, and excess harvesting.

There have been few discussions to discriminate the asari clam groups, distributed over Japanese Archipelago, into ecologically independent populations (stocks). Based on the reports on the spatial exchange of clam larvae among local clams within some bay areas (Hinata and Tomisu, 2005, Mizuno *et al.*, 2009, Tezuka *et al.*, 2008, Nishihama *et al.*, 2011), we assume the asari groups in the major harvested areas, Tokyo Bay, Mikawa Bay, Ise Bay, Suo Nada, Ariake Bay, as the independent asari stocks in this presentation. In this hypothesis, many of the discussed factors, which recognized to have apparent effects on the decrease of local clams in a bay area, have uncertain effects on the decrease of asari stocks in a whole bay area.

In order to design a restoration of the asari stocks, precise determination of causative factor(s) for the decline of asari stock is essentially important. Few studies, however, have been conducted to evaluate the quantitative effects of the factors for the decline of asari stocks.

In this presentation, we introduce firstly the present status of asari stocks and harvesting in Japan. Then we discuss the causative factors on the asari decline, presenting quantitative assessment of the impact of the factors which pointed to be responsible for the asari decline in Tokyo Bay, based on the recent results of field and laboratory studies.

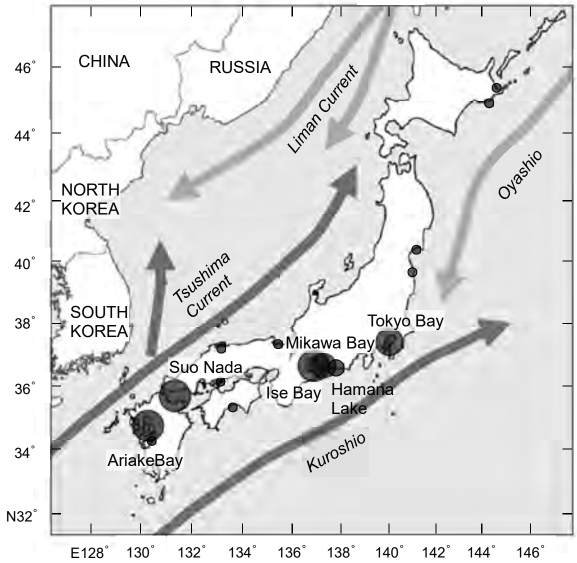

Fig. 1 Major (large shaded circles) and sub-major (small shaded circles) areas of asari clam harvest in Japan. Dark and light shaded arrows indicate warm and cold sea water current, respectively.

Harvest of Asari

Major areas and harvesting: Coastal areas in Japan can be divided into northern half and southern half based on the temperature of sea water currents flowing along the coastal areas (Fig. 1). Areas where the asari can be harvested are scattered all over the coastal areas in Japan. Major harvest areas locate in the southern half of Pacific coast; Tokyo Bay, Hamana Lake, Mikawa Bay, Ise Bay, Suo Nada and Ariake Bay. The reason why major areas locate in the southern area is not due to their marine environment but simply due to that there are many large bay and shallow areas. All of the clams being harvested in Japan are natural clams, except the clams harvested from some culture trials using artificial juveniles.

Clams are harvested by various methods; hand rake, basket rake, dredge and helmet diving (Fig. 2). Applied method depends mainly on the water depth of the place where harvesting is operated. Among these methods, short-handled basket rake ("Joren" or "Koshimaki"), which developed for the harvesting in tidal area, is used most frequently. Recreational harvest is important leisure industry in many areas.

* Statistical Yearbook of Production in Marine Fisheries and Aquaculture 1968–2010, Ministry of Agricultrue,Forestry and Fisheries.

Fig. 2 Methods for clam harvesting. Hand rake (a), Short-handled basket rake (b), long-handled basket rake (c), dredge (d), helmet diving (e) and recreational harvest (f).

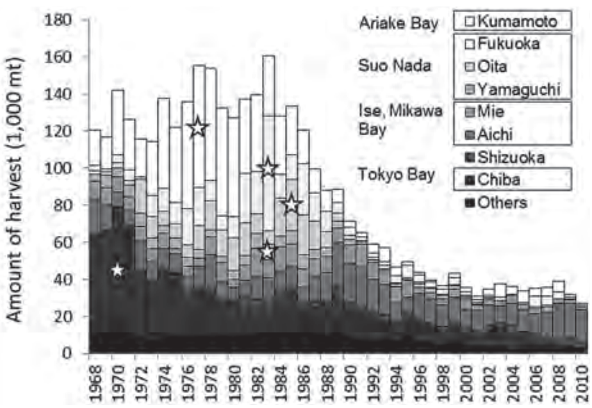

Fig. 3 Changes of the prefectural amount of asari harvest from 1968 to 2010. Star symbols indicate years of peak harvest in the major prefectures whose production decreased.

Production in the major areas: Asari harvest declined largely in the major prefectures after 1980s except Aichi and Shizuoka Prefecture (Fig. 3)*. The year of the peak production in Chiba prefecture (Tokyo Bay) is 1970. That of Kumamoto prefecture (Ariake Bay) is 1977, and Fukuoka, Oita and Yamaguchi prefecture (Suo Nada) is mid 1980s. Although the total production of the asari in Japan appears to have begun to decrease in late 1980s,

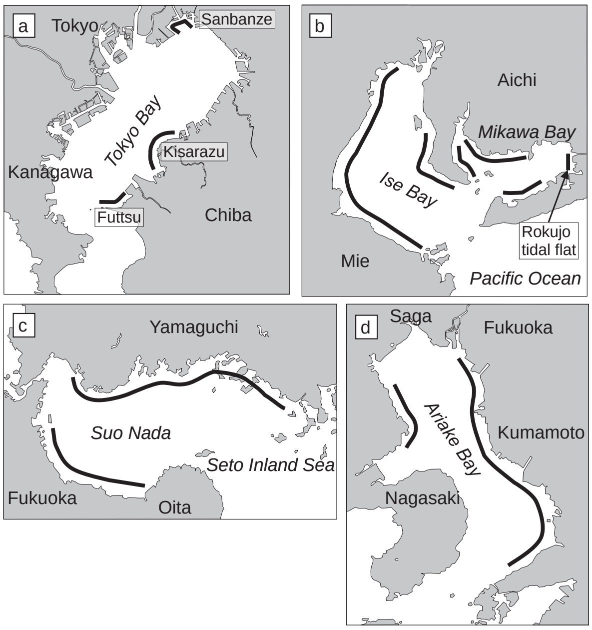

Fig. 4 Locations of the clam harvesting areas (black curves) in five major areas. Tokyo Bay (a), Mikawa and Ise Bay (b), Suo Nada (c), and Ariake Bay (d).

initiation and length of the periods of decrease in the major areas have time lags. The cause of the asari decline seems not to have affected simultaneously in the major prefectures.

Coastal area of Tokyo Bay has been highly developed for industry, commerce and residence (Fig. 4a). Most of the coastal areas in Tokyo Bay were wide tidal flat in early 1960s. In the present, shallow or tidal areas, where the clam can be harvested, remain in three separated places due to the land reclamation during 1970s–1980s. Some of the problems which depress asari production are common to the other major areas; *i.e.* mortality due to blue tide, river flood and strong wave disturbance in winter (Toba, 2002; 2004). Additionally, parasitic arthropod *Nymphonella tapetis* "sea spider" caused mass mortality in Kisarazu after, 2007 (Miyazaki *et al.*, 2010; Kobayashi and Toba, 2014).

Harvest of asari in Mikawa Bay has been maintained stable (Fig. 3b). Transplantation of juvenile clams from Rokujo tidal flat to the other coastal areas sustains substantially the clam harvest in Mikawa bay (Ishida *et al.*, 2005). Rokujo tidal flat, estuary of Toyokawa River, locates innermost of the bay and have an abundant natural spat fall every year (Kamohara *et al.*, 2014). Hypoxic water often threatens survival of the clams particularly in subtidal zone during warm water season (Suzuki *et al*., 2011).

Contrary to Mikawa Bay, natural spat fall in Ise Bay, which locates next to Mikawa Bay, has been decreasing (Mizuno *et al*., 2009) (Fig. 4b). Juvenile clams settle mainly in the estuaries in southern part of Mie Prefecture. In addition to the spreading hypoxic water from northern urbanized and industrialized area to the southern bay, excess harvesting may have damaged the asari stock in Mie Prefecture after 1990s (Mizuno and Maruyama, 2009). Mortality of juveniles occurs more often in recent years caused by the river flood with increasing heavy rain (Mizuno *et al*., 2009; Hanyu, 2015). Proliferation of asian mussel *Musculista senhousia* or sand dollar *Astriclypeus* sp., hampered growth and harvest of the clams considerably in spatially occupied subtidal areas.

Suo Nada locates easternmost of Seto Inland Sea and is surrounded by three prefectures (Fig. 4c). Harvest of the asari in Suo Nada, which exceeded 30,000 t in 1980s, decreased to near 0 t in 2010. Heavy harvesting effort using helmet diving and water injection dredge may have collapsed adult spawners of clam stock (Yamaguchi Prefecture, 2006; Ooita Prefecture, 2009). Heavy predation by eagle ray *Aetobatus flagellum* greatly depresses the asari production after 2000s (Fukuda and Zenitani, 2009). Migration of eagle ray extended to Seto Inland Sea with elevating water temperature. Additionally, oligotrophication, which is due to the strict regulation of waste water quality, is discussed to suppress organic production in the entire bay (Hamaguchi, 2011).

In Ariake Bay, as well as in other areas, asari harvest decreased in 1980s and did not recover (Fig. 3d). Strong harvesting effort (Nasu *et al*., 2008) and spreading hypoxia (Fujii and Yamamoto, 2002) are pointed as the causative factor. River flood and strong wave disturbance in winter frequently causes mortality. Heavy infection of *Perkinsus olseni* is also discussed to be one of the causative factors (Hamaguchi *et al*., 2002; Waki and Yoshinaga, 2013).

Alien species *Mercenaria*: Natural colonization of exotic clam species, ocean quahog *Mercenaria*

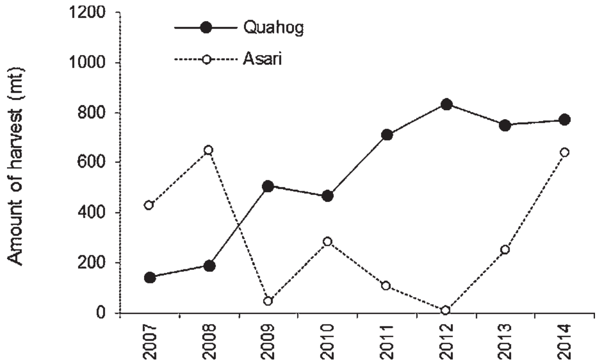

Fig. 5 Changes of the harvest of quahog and asari in Sanbanze, Tokyo Bay

mercenaria, was identified firstly in Sanbanze, Tokyo Bay, in 1998 (Hiwatari and Kohata, 2005). The quahog is considered to be introduced to Japan unintendedly with ballast water of ships from North America. Harvest of the quahog has been increasing to near 1,000 t in 2014 and it has become an important local fishery resource in Tokyo Bay (Fig. 5). The increasing harvest of quahog is contrasted to fluctuating harvest of asari. Quahog is reported to be able to tolerate low DO condition extended period by complete and sustained valve closure (Grizzle *et al*., 2001). This tolerance may be able to survive quahog and increase its stock size in Sanbanze where native clams often suffer by hypoxic water. Quahog, however, is designated as invasive alien species in Japan. Although there is no legal restriction, artificial enhancement or culture of the quahog should be avoided.

Assessment of the Causative Factors of the Asari Decline

Factors to be assessed: After decrease of asari production became obvious in many areas in 1990s, numbers of the phenomenon were presented as possible responsible factors for the asari decline (Table 1). Presented factors can be grouped into five categories; coastal development, global warming, deterioration in water quality, immigration of troubled factors, and changes of fisheries activity. This table is the mixture of the factors which effect is apparent or not. For example, the land reclamation never fails to bring a clam decline through a

Table 1. Suspected factors responsible for the decline of manila clam.

Categories	Causative factor	Directly affected factor
Coastal development	Land reclamation	Decrease of suitable habitat area
	Perpendicular seawall	Changes of current and wave, decrease of current velocity
	River improvement	Decrease of sand supply to estuaries, increase of mud
	Heat island	High water temperature, short time heavy rain, strong wind
	Land subsiding	Decrease of suitable habitat area, intrusion of strong wave to shallow zone
Global warming	High temperature	High water temperature, changes of predators, food plankton and harmful plankton
	Extreme weather	Strong typhoon, heavy rain, bomb cyclone, river flood
	Elevation of sea level	Elevation of tidal level, intrusion of strong wave to shallow zone, change of current
	Climate change	High water temperature, increase of cloudy and rainy weather
Degradation of water quality	Eutrophication	Blue tide, hypoxia, red tide
	Pollution	Organotin, endocrine disrupter
	Excess regulation of waste water quality	Oligotrophication
Immigration	Disease and parasites	BRD, Perkinsosis, sea spider
	Predators	Eagle ray, new moon snail
	Transplantation	Genetic disturbance, competition
Changes in fisheries	Simplification of fisheries target species	Excessive harvesting effort

decrease of habitat areas. On the other hand, concerning on increase of mud and/or decrease of sand in the sediment due to river improvement, quantitative evidence which can evaluate its impact on a stock is not presented. As a result, we still have not reached a mutual understanding which factors are significant for the decline of asari stock. As an example of determining the significance of factors, we compare the effect of five factors; blue tide, river flood, strong wave disturbance, sea spider, and hypoxia on clam larvae, based on the studies in Tokyo Bay.

Tokyo Bay is surrounded by three prefectures; Chiba, Tokyo and Kanagawa (Fig. 4a). In these prefectures, harvest of asari in Chiba is overwhelming those of the other prefectures (Fig. 6). Therefore, we can tentatively assume the asari stock in Chiba as the asari stock in Tokyo Bay. The decline of the harvest in Chiba from 1960s to 1970s is apparently due to land reclamation. Asari harvest, however, decreased gradually and steadily after 1980s in spite of unchanged area of harvest in this period. In the followings, we examine the decrease after 1980s based on the clam density investigated

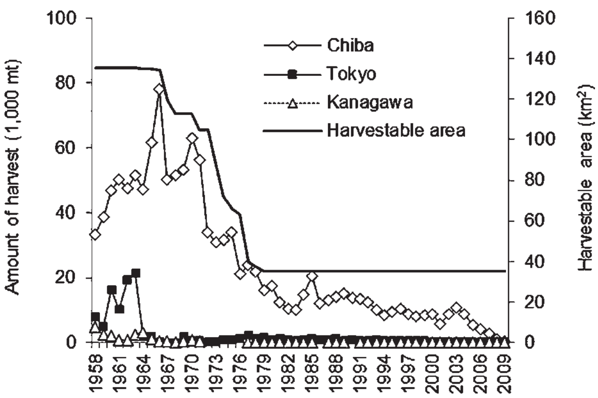

Fig. 6 Changes in the harvest of asari in three coastal prefectures in Tokyo Bay (Chiba, Tokyo and Kanagawa) and areas for the clam harvest in Chiba Prefecture.

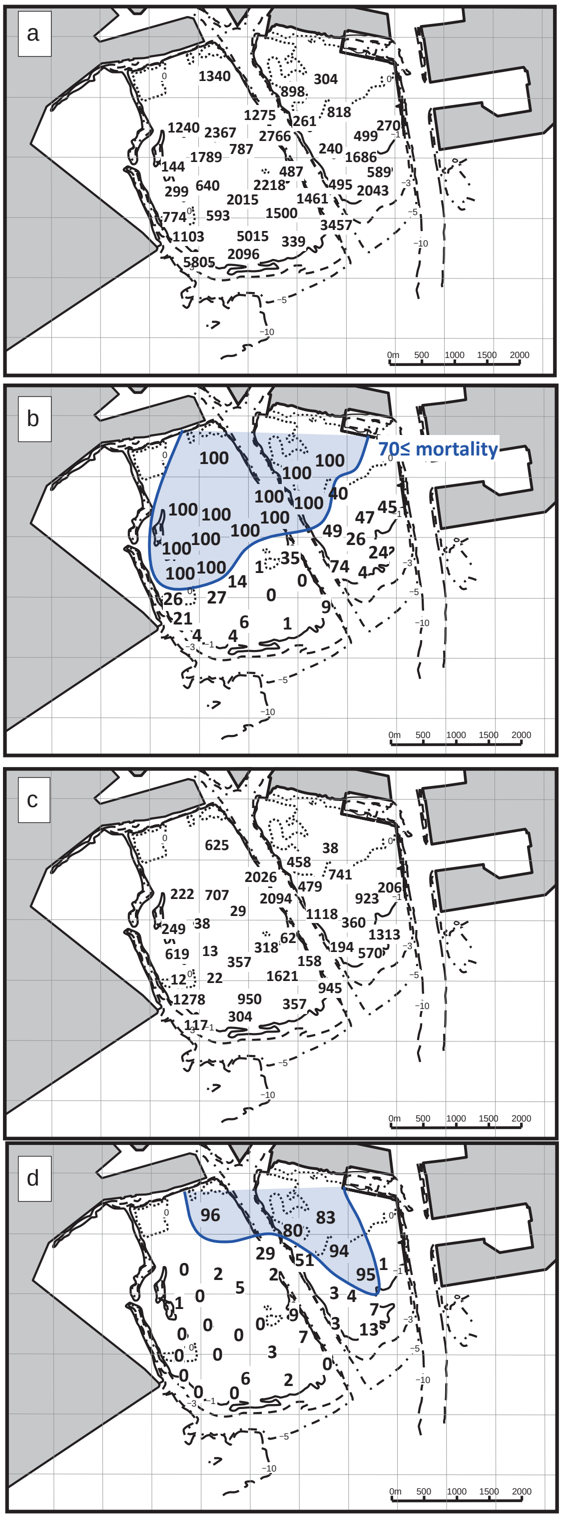

Fig. 7 Estimation of the impact of the mortality events in blue tide in 2008 (a, b) and river flood in 2007 (c, d) in Sanbanze. Figures a and c show the clam densities (inds m^{-2}) before the mortality events in the sampled sites, b and d show the calculated percent mortalities of the clams after the events. Shaded areas in b and d indicate mortalities higher than 70 %.

bimonthly in three areas in Chiba; Sanbanze, Kisarazu and Futtsu. In these areas, clam densities have been investigated using quantitative sampling gears and 2 mm square mesh sieve since 1980s.

Blue tide and river flood: Mass mortality of the clams due to blue tide occurred in Sanbanze in September 2008. Amount and rate of the mortality caused by blue tide could be estimated by the spatial density of the clams before and after the mortality event. Figs. 7a and 7b show the clam densities before the blue tide and calculated ratios of the mortality in sampled sites, respectively. Mean mortality and total amount of dead clams, which calculated from contour maps of previous density and mortality, were estimated to be 39% and 5,500 t, respectively. Likewise, mean mortality and amount of dead clams caused by the river flood in September 2007 were estimated to be 20% and 1,900 t, respectively (Figs. 7c, d).

Annual harvest and density of the clams in Sanbanze have been fluctuated and decreased since 1980s (Fig. 8a). In Sanbanze, mortality due to blue

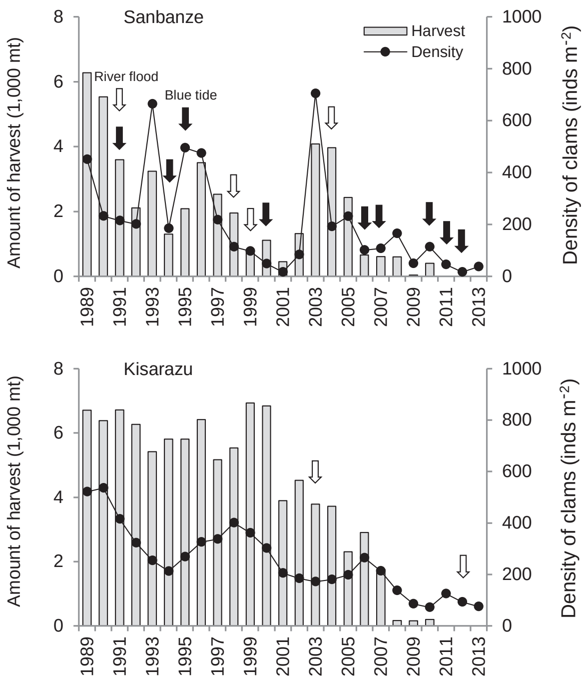

Fig. 8 Changes in the harvest and density of asari in Sanbanze and Kisarazu. Vacant and solid vertical arrows indicate the occurrence of the mortality due to river flood and blue tide, respectively.

tide or river flood occurred frequently in this period. In contrast, Kisarazu did not suffer blue tide during recent 25 years (Fig. 8b). The impact of blue tide and river flood differs largely with the areas. These influences have a marked locality in Tokyo Bay.

Winter wave mortality: Densities of the clams in Sanbanze and Kisarazu change regularly in every year with peak and bottom period in summer and winter, respectively (Figs. 9a, b). The ratio of the clam density in February to that in October in former year, which represents survival of the clams during winter (influence of harvesting was excluded), has been <0.1 every year in Sanbanze (Fig. 9c). In Kisarazu, survival during winter is decreasing to <0.6 in recent years (Fig. 9d). Winter mortality is the common phenomenon which gives significant impact on the asari stock in Sanbanze and Kisarazu.

Based on a number of investigations and experiments, we consider the cause of the winter mortality is erosion of the clams due to strong wave disturbance (Shibata *et al.*, 1997; Kakino, 2000). Clams sustained and remained under a cover net which spread over bottom surface of the tide land during winter, while ambient clams without cover net disappeared. Low temperature and poor nutritional condition in winter may depress the burrowing activity of the clams lower.

One of the significant driving factors for sediment transport is wave shear stress. In the field study in Kisarazu, the positive relationship was found between significant wave amplitude and velocity of wind in shoreward direction. Tidally changing water depth has also a relationship to the wave amplitude (Toba *et al.*, 2011; Toba and Kobayashi, 2011). The wave amplitude, which directly relates to the wave shear stress, is influenced by both strength of the wind and water depth. In the depth range of 0–2 m, increasing depth intensifies bottom shear stress with increasing intrusion of high wave from offshore to tidal area. Most of the harvestable area in Sanbanze is subtidal (±0–−2 m in mean low water level in spring tide) mainly because of the land subsiding due to intensive pumping up of underground water during the period of coastal development in 1960s–1970s.

Maximum wind velocity, which monitored at the meteorological observatory in Chiba City from 1964 to 2010, has not changed markedly in these 40 years (Fig. 10a). On the other hand, the changes of the

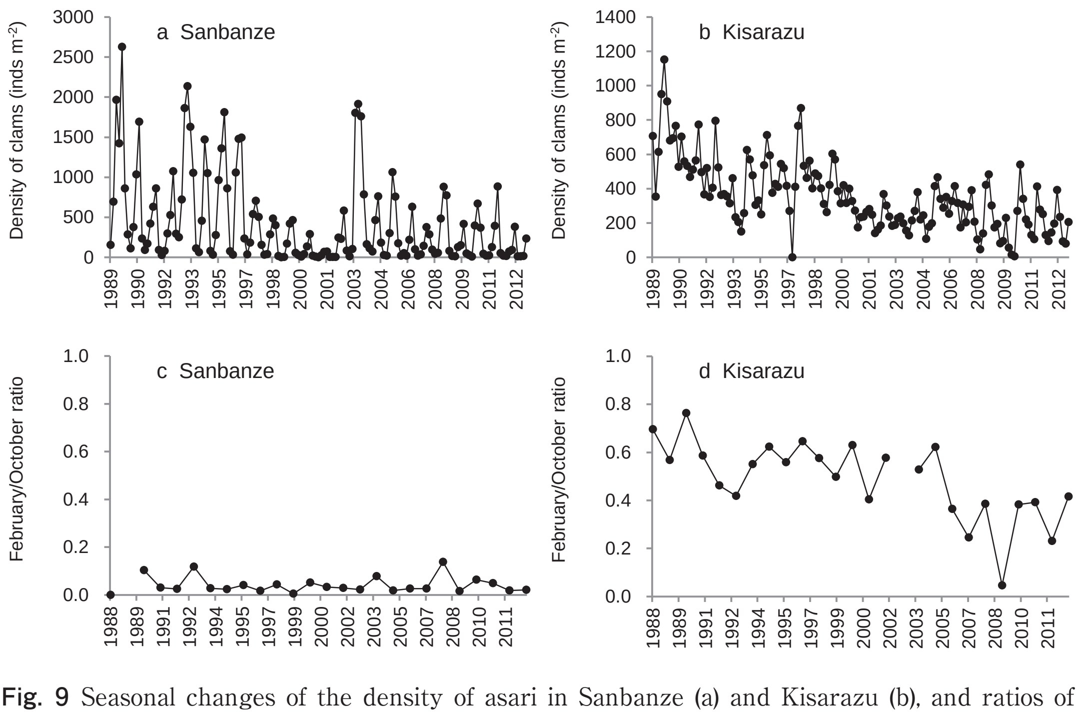

Fig. 9 Seasonal changes of the density of asari in Sanbanze (a) and Kisarazu (b), and ratios of densities in February to those in October in former year in Sanbanze (c) and Kisarazu (d).

mean tidal height, which measured at four of the automatic tide-gauge stations in the coast of Tokyo Bay from 1968 to 2008, obviously show the elevation tidal level during these 40 years (Fig. 10b). The increasing erosion of the clams in winter in Kisarazu may be caused by elevating tidal height.

Sea spider: Sudden mortality, caused by heavy infection of sea spider, occurred in Kisarazu in 2007 (Kobayashi and Toba, 2014) (Fig. 11). There had been few reports on the sea spider in last 90 years so that we had very little information on its biology. The route of infection and the reason of sudden outbreak are still not known. Infected clams are sucked body fluid by the sea spider. In our study, the prevalence of sea spider infection had a peak period in summer. Mortality of intensively infected clams occurred in this peak period.

The ratio of intensively infected clams (>5 sea spiders/clam) has been decreasing since first outbreak in 2007 (Fig. 12a). Comparing the spatial clam density before (2005–2006) and after (2007–2012) the outbreak of sea spider infection in Kisarazu, apparent decrease is found in 2009 (Fig. 12b).

Hypoxia on clam larvae: Low DO condition was experimentally confirmed to lower not only the survival but also the swimming activity of the clam larvae (Toba *et al.*, 2008). The larvae which encounter low DO water in natural environment may cease swimming and sink to the deeper layer of poorer condition of DO. And the vertical swimming position of the clam larvae was found to shift from

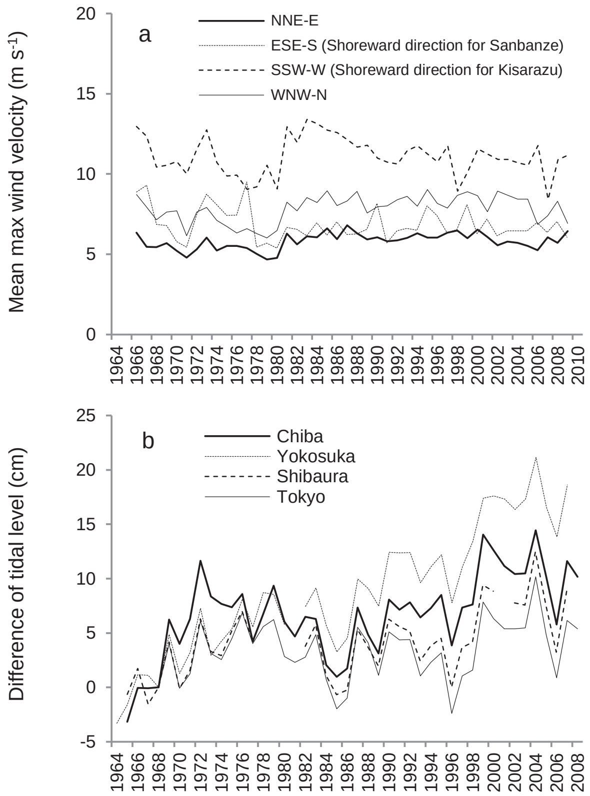

Fig. 10 Changes in the mean maximum wind velocity (a) and difference of mean tidal heights (b), calculated from hourly maximum wind velocity monitored at Chiba Meteorological Observatory and hourly tidal heights measured at four automatic tide-gauge stations in Tokyo Bay, respectively. Mean maximum wind velocity is divided into four directions. Tidal heights are the relative values as 1968 = 0 cm.

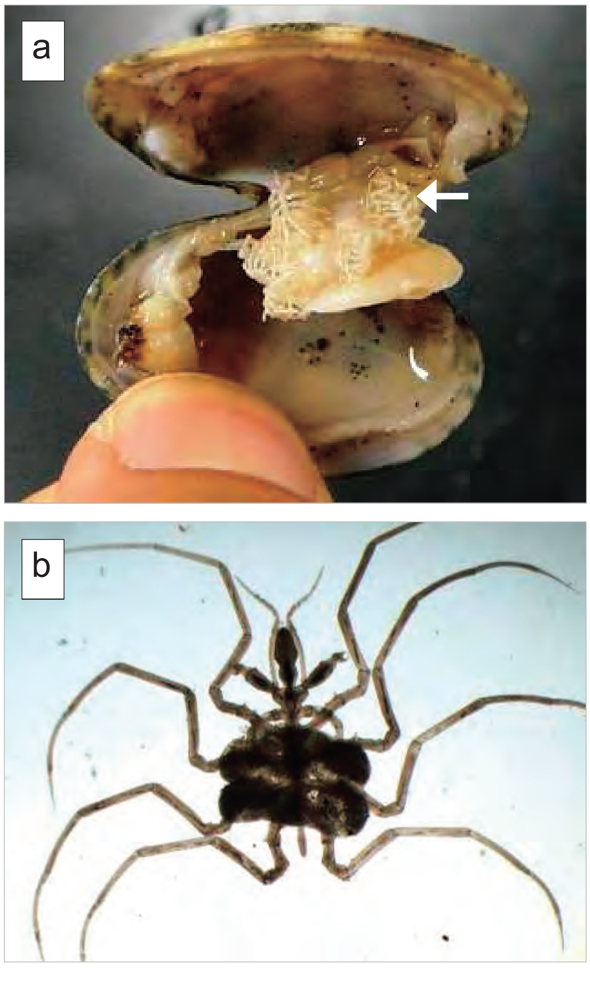

Fig. 11 Asari infected by larval sea spider (a, arrow) and free living adult of sea spider carrying egg sacks (b).

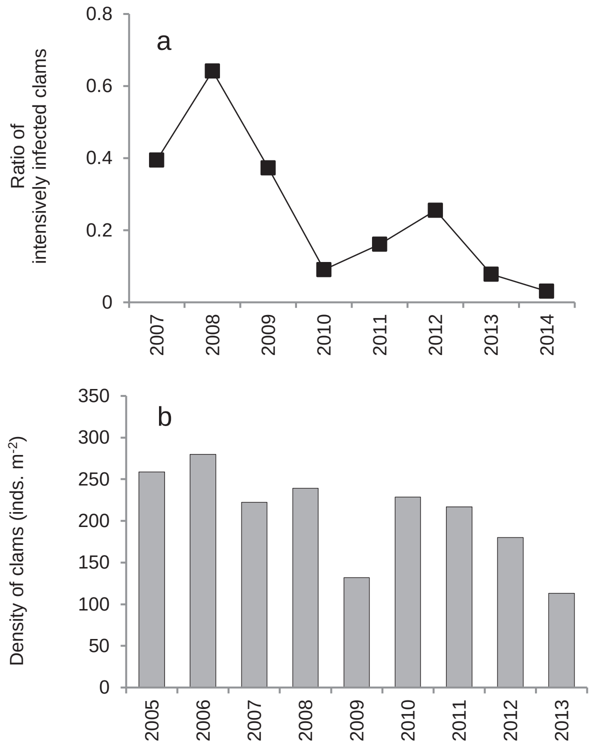

Fig. 12 Changes in the ratio of intensively infected clams (>5 sea spiders clam^{-1}) after outbreak of infection in 2007 (a) and spatial clam density in Kisarazu from 2005 (before outbreak) to 2013 (b).

surface to bottom layer with their growth even in normal DO condition (Toba *et al.*, 2012). Additionally, from May to October, low DO water is continuously formed in the bottom layer over wide extent in Tokyo Bay (Fig. 13) (Chiba Prefectural Fisheries Research Center, 2012). Moreover, the period when low DO water spreads over the bottom layer coincides with the period of spawning of adult clams in Tokyo Bay (Toba *et al.*, 1993; 2007). Those facts strongly imply that low DO water affects the larval survival in the natural environment in Tokyo Bay.

Comparison of the impacts of the factors: The impacts of the factors for the asari stock in Tokyo Bay were evaluated using total mortality calculated by decrease of number of clam individuals in the events in three local areas. Table 2a shows the calculation of the total mortality by the blue tide in Sanbanze in 2008. Total mortality was calculated by the clam densities before the event, areas of harvest, and local mortalities in the events in three areas. In this blue tide event in Sanbanze, mortalities in the other two areas were assumed to be 0. As a result,

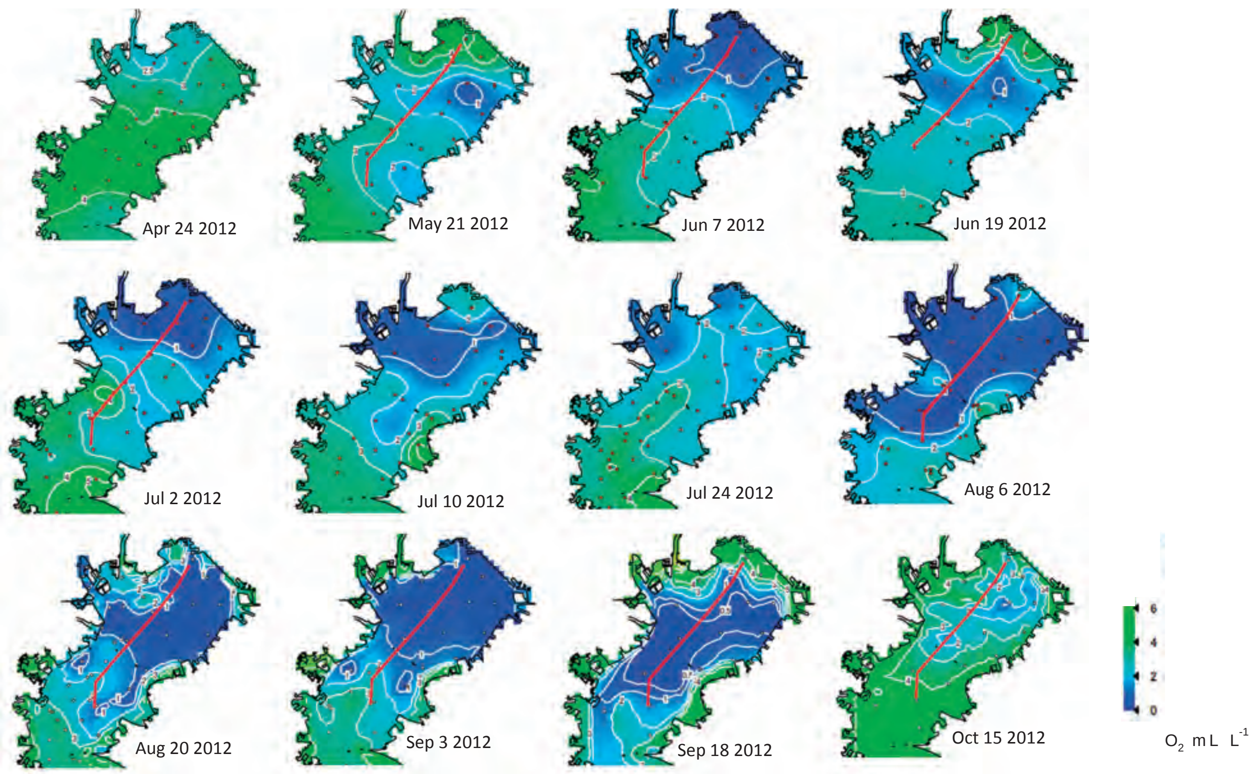

Fig. 13 Seasonal change of DO concentration in the bottom layer in 2012 in Tokyo Bay (Chiba Prefectural Fisheries Research Center).

the impact (mortality) by the blue tide in Sanbanze in 2008 was estimated to be 0.16 for the total clam stock in Tokyo Bay. In the same way, impact of the river flood in 2007, winter wave mortality during 2009–2010 and infection of sea spider in 2009 were calculated to be 0.08, 0.95 and 0.30, respectively

Table 2 Estimation of the impacts of the mortality events for the clam stock in Tokyo Bay.

a. Blue tide in Sanbanze in September 2008

Local area	Clam density before the mortality events (inds m^{-2})	Harvested area (ha)	Previous amount of the stock (10^6 inds)	Local mortality*	Remained amount of the stock (10^6 inds)	Total mortality
Sanbanze	467	526	2,456	.38	1,523	
Kisarazu	439	707	3,104	0	3,104	
Futtsu	330	71	234	0	234	
Total			5,794		4,861	.16

* Mortalities in the areas except Sanbanze were assumed to be 0

b. River flood in Sanbanze in September 2007

Local area	Clam density before the mortality events (inds m^{-2})	Harvested area (ha)	Previous amount of the stock (10^6 inds)	Local mortality	Remained amount of the stock (10^6 inds)	Total mortality
Sanbanze	287	526	1,510	.19	1,223	
Kisarazu	308	707	2,178	0	2,178	
Futtsu	214	71	152	0	152	
Total			3,840		3,553	.07

c. Winter wave mortality in three areas in October 2009–February 2010

Local area	Clam density before the mortality events (inds m^{-2})	Harvested area (ha)	Previous amount of the stock (10^6 inds)	Local mortality	Remained amount of the stock (10^6 inds)	Total mortality
Sanbanze	416	526	2,188	.98	44	
Kisarazu	235	707	1,661	.89	183	
Futtsu	214	71	152	.93	11	
Total			4,001		198	.95

d. Sea spider in Kisarazu in June–August 2009

Local area	Clam density before the mortality events (inds m^{-2})	Harvested area (ha)	Previous amount of the stock (10^6 inds)	Local mortality	Remained amount of the stock (10^6 inds)	Total mortality
Sanbanze	141	526	742	0	742	
Kisarazu	388	707	2,743	.38	1,701	
Futtsu	32	71	23	0	23	
Total			3,508		2,466	.30

(Table 2b–d). The largest impact for the asari stock in Tokyo Bay was estimated to be given by winter wave mortality.

The factors related to the decline of asari stock can be characterized in terms of some aspects; *i.e.*, spatial extension of the effects, intensity of mortal pressure, continuity and length of affected period, repeatability, and time occasion of occurrence. (Table 3) Comparing these characterized properties and estimated impacts of exampled events among the examined factors, the factor which affected wider areas and longer period with higher mortality was supposed to give severer impact for the asari stock. In the estimated factors, winter wave mortality belonged to the factors of severe impact. Although the impact of hypoxia on larval survival could not be estimated due to limited quantitative data, this factor seemed to be included in the factors of severe impact according to above characterization.

In this presentation, the asari stock in Tokyo Bay as an example, we compared the estimated impacts of four factors which have been indicated to be responsible for the asari decline. Present estimation should be required further detailed quantitative data because it was based on the data of the clam size of larger than 2 mm mesh. However, we consider that present estimation could illustrate an outline of the significance of the impacts of the factors. Acquisition of quantitative data and estimation of impact is to perform also with the other factors which did not discuss in this presentation due to insufficient data. In order to take effective countermeasures for the decline of asari in Japan, based on the precise determination of the cause of the decline, further assessment of the impact of the suspected factors is required to progress.

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Table 3. Comparison of the properties of the factors affected on the mortality of the clam stock in Tokyo Bay.

Property	Blue tide	River flood	Winter wave mortality	Sea spider	Hypoxia on larvae
Spatial extension	Partial	Partial	Whole area	Partial	Whole area
Mortal pressure	Partial	Partial	Near Whole	Partial	?
Continuity	Transient	Transient	Successive	Transient?	Successive
Affected period	Short	Short	Long	Long?	Long
Repeatability	Repeatable	Repeatable	Repeatable	?	Repeatable
Time occasion	Irregularly	Irregularly	Regularly	Irregularly	Regularly
Exampled impact	0.16	0.07	0.95	0.30	?
Evaluation	Light	Light	Severe	Light	?

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