水研センター研報，別冊第１号，33－40，平成16年
Bull. Fish. Res. Agen. Supplement No. 1, 33-40, 2004

Influence of environmental changes in the tidal flats on the filtration and respiration of bivalve mollusks

Junya HIGANO*

Abstract Manila clam *Ruditapes philippinarum* and the other filter feeding bivalves in tidal flat are not only commercially important as seafood, but also ecologically significant because of their filtration activity. The volume of water filtration by bivalves in Ariake Sound is estimated to be equivalent to daily water exchange on the tidal flat in 1970s. However, the annual catch of Japanese littleneck has been decreased during the past 20 years in Japan. Especially, rapid decrease in the clam population in Ariake Sound since 1980s forced to depress the nationwide production. Recent coastal changes such as land reclamation, dike, port, barrage, and dam construction presumably brought about the environmental impact for filter feeding bivalves through water and sediment movement. Higher intertidal zone and supralittoral zone are intercepted by artificial structure such as dike and breakwater. Consequently suspended sediments are prevented from depositing at the higher intertidal zone and are drifted in littoral zone. High concentration of mud particles suppresses the water clearance of the clams. On the other hand, reduction of water current by barrages encourages the stratification. Hypoxia and anoxia often occur in subtidal zone of eutrophied sheltered coast under the stratified layer in summer. Complex effects of mud increase and oxygen shortage are considered to be physiologically harmful to filter feeding bivalves. The ecological function of tidal flat has been destroying and it disturbs the recovery of the bivalve resources.

Key words: bivalves, coastal change, filtration, Manila clam, reclamation

Transition on production of filter feeding bivalves in tidal flats

Many kinds of filter feeding bivalve mollusks inhabit in the tidal flat buried. Some of these are not only commercially important, but also ecologically important as a nutrient recycling. In fact, Manila clam, *Ruditapes philippinarum* Adams & Leeve, is the most abundant infaunal bivalve in tidal flat of Japan. Major production localities of Manila clam and the other commercially important filter feeding bivalves on sheltered inlets in Japan are listed as; Tokyo bay, Mikawa Bay, Ise Bay, Seto Inland Sea and Ariake Sound crossing southern half of Japan(Fig. 1). Fig. 2 shows the annual production of Manila clam in main prefectures and localities (Ministry of Agriculture, Forestry and Fisheries, Japan, Statistics and Survey Division, 1954-2001). There are three chronological stages in the clam production. The production from Tokyo Bay had occupied more than half of national production at the first stage in 1960s. At the second stage, the depletion of Manila clams in Tokyo bay was attributed to land reclamation in 1960s to 1970s, and

2003年６月12日受理 (Received on June 12, 2003)
* National Research Institute of Aquaculture, Fisheries Research Agency 422-1 Nakatsuhamaura, Nansei, Watarai, Mie 516-0193 Japan
Email: higa@fra.affrc.go.jp

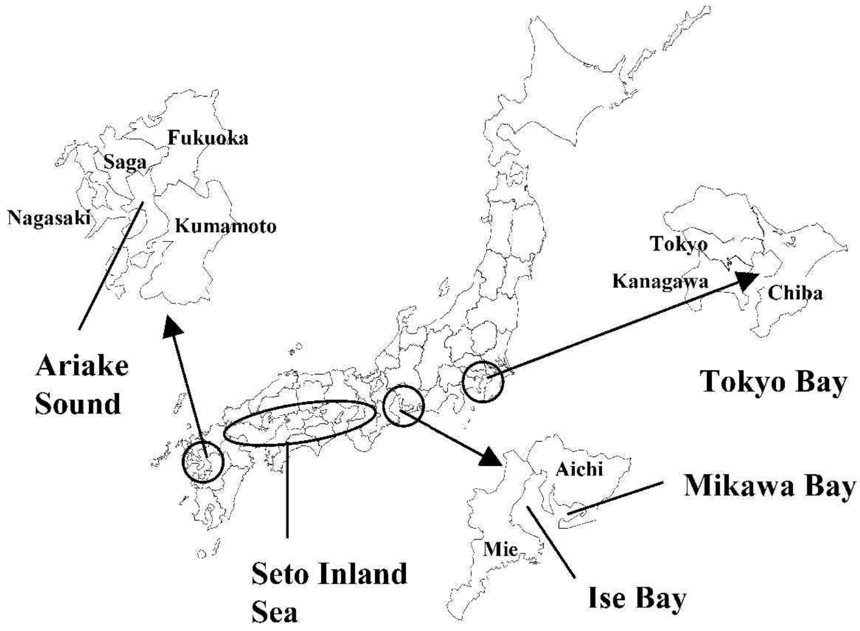

Fig. 1. Main bays and estuaries where *Ruditapes philippinarum* and other filter feeding bivalves inhabiting in their tidal flats

it was compensated by increase of the clam production in Ariake Sound that had the largest tidal flat in Japan. The annual catch had been maintained more than 100 thousand tons until mid 1987 since 1960. However, constant decrease of the clam in Ariake Sound since 1980s forced to depress even national production at the third stage. Only the production in Aichi Prefecture has been maintained through about 50 years. The other commercially important species of filter feeding bivalves has also decreased their production. Poker-chipped venus, *Meretrix lusoria*, is one of the most valuable clams in Japan, but decreased its production earlier (Fig. 3) than on Manila clam. National production of Poker-chipped venus has exceeded 10 thousand tons a year until 1966. It decreased very rapidly in 1970s by losing their habitat especially in Tokyo Bay. The clam was considered to be predominant before increasing the modern human activities because it is found dominantly in shell middens. It is difficult to explain the reason why *M. lusoria* had decreased so rapidly by environmental changes because there are few references (Kawamoto, 1967; Sagara, 1981) of environmental tolerance of *M. lusoria* than *R. philippinarum*. However,

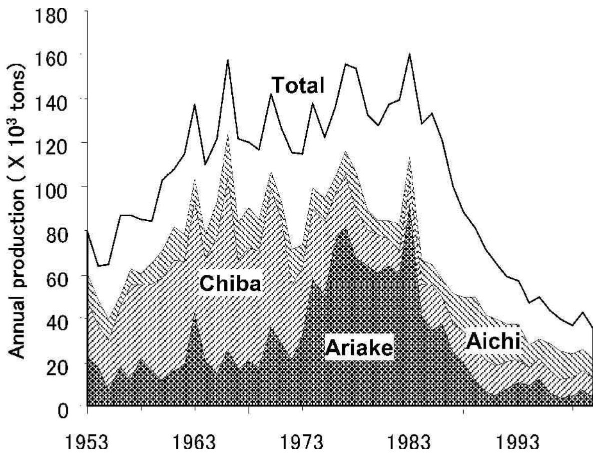

Fig. 2. Annual production of *Ruditapes philippinarum* in Japan; Aichi-Pref., Chiba-Pref. and total of four Prefs. in Ariake Sound

the fact that *M. lusoria* had started decreasing prior to Manila clam indicates this species prefers more natural habitat to have a dynamic estuarine circulation connecting the river mouth to tidal flat nearby.

There are several causes for explaining the rapid decrease of bivalve resources in tidal flat (Table 1). Over-catching is a commonly recognized cause on most of commercially important species inhabiting in the bottom sediment. Actually, the fluctuation of annual production of *R. philippinarum* and *M. lusoria* reflect the influence of over fishing and recovering by regulation of catch. The other causes are deeply concerned with environmental impacts by human activities. Physical alteration of coastal area may affect physical properties of habitats and chemical uses in watershed and sea area may cause the incompetence in their reproduction. Decrease of filter feeding bivalves must affect the coastal ecosystem by reducing their filtration.

Table 1. Causes of rapid decrease in filter feeding bivalves in tidal flats and its effects on the ecosystem

What are possible causes?
•Over catching
•Decrease of habitats
Land reclamation
•Change of food supply
•Change of bottom substrata
•Anoxic or hypoxic water
•Toxic chemical substances
•Disease and parasites
•Combining effects of hydrodynamics and organic load
What are main effects to the ecosystem?
•Decline of filtration capacity
•Change of nutrient cycle
•Increase of red tide
•Increase of oxygen deficiency in the substrata

Depression of filtration by bivalve mollusks

Manila clams and the other filter-feeding bivalves play an important role in purification of water through their filtering activity. Outbreak of exotic bivalves reportedly affected the phytoplankton density in the sheltered sea area such as San Francisco Bay (Alpine and Cloern, 1992). In Ariake Sound, frequency of red tide increased in 1990s whereas Tokyo Bay and Mikawa Bay have had the increase in 1970s-1980s. This is caused by not only eutrophication being connected to urbanization around the bays but also depression of grazing pressure by filter feeders.

Based on the fisheries statistics (Statistics and Survey Division, Ministry of Agriculture, Forestry and Fisheries, 1954-2001) and clearance rate of Manila clam estimated by Akiyama *et al.* (1986), I tried to estimate the daily clearance rate by filter feeding bivalves in Ariake Sound. In the calculation, it is assumed that the average harvested size was 35-40 mm in shell length which have specific clearance rates of 0.83 L/hr/g WW at 24 ℃ and 0.23 L/hr/g WW at 10 ℃, where WW is flesh wet weight. Ratio of flesh wet weight to total wet weight of Manila clam was averagely 0.4, thus total catch could be converted to the flesh wet weight by multiplying 0.4. For the bloody cockles and the other bivalves, 1.676 L/hr/g DW at 24 ℃ and 0.635 L/hr/g DW at 10 ℃ derived from the clearance rate of ark shell, *Scapharca broughtonii* (Fujiwara, 1986 and Yamamoto *et al.*, 1996), where DW is flesh dry weight. The duration of filtration by Manila calm assumed to be 22 hr a day as the average drying period at low tide was two hr. For the other bivalves, no drying period was considered.

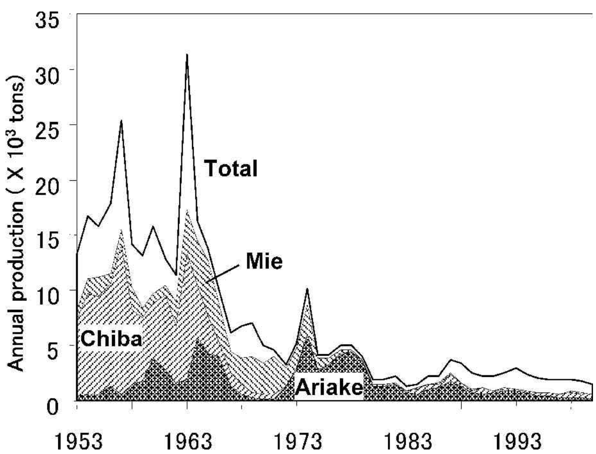

Fig. 3. Annual production of *Meretrix lusoria* in Japan; Mie-Pref., Chiba-Pref. and total of four Prefs. in Ariake Sound

Fig. 4 shows the annual change of daily clearance rate of bivalves inhabiting in Ariake Sound calculated under the condition that described above. This calculation contains many assumptions, but it is considered to approximate real situation. It fluctuates year by year and more than 300 million kL/day before 1990. But in recent decade it has decreased continuously and reached one tenth of the highest value in 1970s. Although total clearance rate by all bivalves was equivalent to daily water exchange rate on the tidal flat in spring tide (tidal rage is ca. 5 m) before 1990, that in 1996 to 2000 reached to only less than daily water exchange rate in neap tide (tidal rage is ca. 3 m) (Table 2). It is estimated that the clearance rate in winter is much less than daily water exchange rate in neap tide and nearly equal to daily river water discharge. Depression of clearance rate means the depression of all kinds of purifying and producing process by bivalves around tidal flat. It is connected to elimination of phytoplankton or other suspended matter, feces and pseudofeces production providing food for deposit feeders, retaining the nutrient to the bodies of bivalves and releasing inorganic nutrients to the water column enhancing primary production. The very low level of clearance rate in recent years presumably accelerates environmental deterioration in Ariake Sound.

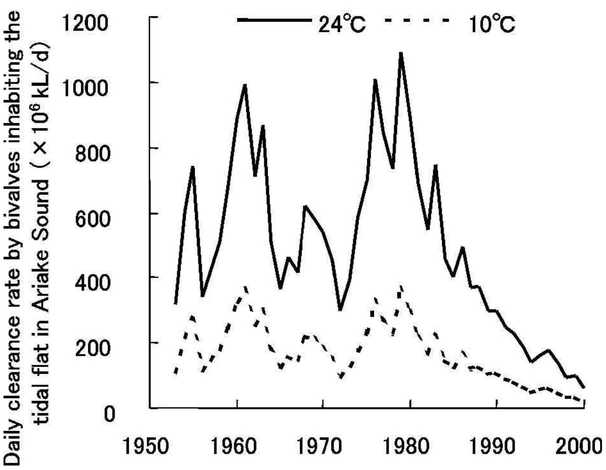

Fig. 4. Daily clearance rate of filter feeding bivalves in Ariake Sound calculated from statistical data of their annual productions (see text for calculation)

Coastal changes of sheltered sea area in Japan

Tidal flats in sheltered inlets or bays are formed by the relation between tidal current and sediment movement. As, in general, flood-tide currents are usually stronger than the ebb-tide currents, sediment moved into the inner estuary on the flood being left behind on the ebb (Little, 2000). Especially, at the upper part of the tidal flats tidal currents velocities are very low and finer sediments are deposited, then sediment in flats usually are sorted as finer at the higher than the lower parts (Little, 2000). Bloody cockles, *Anadara* spp. and the other filter feeding bivalves inhabiting higher intertidal zone may trap fine sediments through their biodeposition and contribute to forming tidal flats (Fig. 5).

In Japan, coastal line has been artificially changed for many years. Especially in sheltered bays, reclaimed lands and artificial struc-

Table 2. Comparison among total volume of Ariake Sound, water exchange, water discharge from rivers and clearance rate of bivalves (Unit : $\times 10^6$kL)

Total water volume		34,000	
Daily water exchange ontibal flat		Spring tide	Neap tide
	50 years ago	1,015	189
	Present	761	142
Daily discharge from rivers (average)		21.9	
Clearance rate by *R. philippinarum*		24℃	10℃
	Mid 1970s-mid 1980s	400-600	100-200
	1996-2000	23-51	6 -14
Clearance rate by Total bivalves		24℃	10℃
	Before 1990	400-1,000	100-370
	1996-2000	61-177	21-63

tures such as dikes, breakwaters and jetties have replaced natural coastal line. Reclaiming tidal flats is the easiest way in order to extend farmland, industrial zone and residential areas. Ariake Sound has been gradually reclaimed for a long time since the sixth century in accordance with natural land forming. After Meiji era (from 1868), huge undertaking of reclamation was started and the shoreline moved forward up to 5 km (Satoh, 2000). Tokyo bay was reclaimed at the very rapid rate after 1945 (Koike, 1990) and natural coastal line remains only 9.7 % whereas 19.6 % in Ariake Sound in 1984 according to Coastline Survey, 3rd National Survey on the Natural Environment (see: www. biodic. go. jp / reports / 3-2 / hyo/ w064_001. html). In other words, the pace of recent coastal changes such as reclamation in tidal flat, construction of dike, port, dam and barrage is very rapid and exceed the natural processes. It presumably brought about negative ecological impact for filter feeding bivalves through hydrodynamic changes of water and sediment movement. Higher intertidal zone and supralittoral zone are intercepted by artificial structure such as dike and break water. Consequently decreasing area of tidal flat caused the habitat decrease and increasing suspended mud by prevention of their depositing at the higher intertidal zone (Fig. 5). Dams and barrages often store the sand at the water reservoirs. It sometimes causes not only the decrease of reservoir capacity but also coastal erosion. Very fine sediment particles like silt and clay do not easily settle even in calm water as far as they are still in fresh water. In downstream region of dams and barrages, thus, fine sediments allow to discharge higher ratio in comparison with sand particles.

Both USA and Japan have a peak of dam construction around 1960 to exploit the energy and water supply (see: www. wec. or. jp/ center/ shiryou/ image/ download/ B-24.pdf). Japan still continued dam construction until 1990s mainly for water utilization despite USA put the brake on it after 1960s. This may have a possibility to make sediments in sheltered bays muddy and to change sediment property not suitable for originally inhabited bivalves.

Environmental Impact for filtration and respiration

How does coastal changes affect filter feeding bivalves? As I described above, coastal changes bring about the loss of habitat, depression of tidal current and accumulation of fine sediments. Fig. 6 indicates that these factors eventually affect the bivalves on both oxygen deficiency and high suspended load. Hypoxia and anoxia often occur in subtidal zone of eutrophied sheltered coast under the stratified layer in summer. Most of the bivalves can switch to anaerobicbiosis to maintain their lives and survive several days in anoxic condition (Hochachka, 1984; Nakamura *et al.*, 1997).

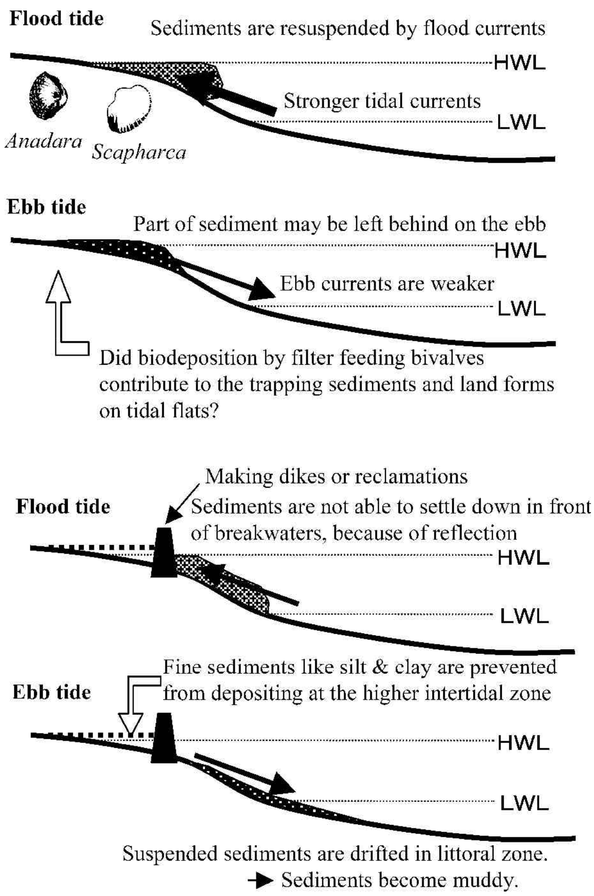

Fig. 5. Conceptional illustrations of land formation on upper level of tidal flat, and the impact of land reclamation and construction of artificial structure around high water level

However, elongation of anaerobicbiosis requires consumption of reserve substances like aspartic acid and glycogen. The accumulation of metabolites will indicate the limit to tolerate anoxia (Hochachka, 1984). Hydrogen sulfide is generated in anoxic layer of sediment and affects bivalves to inhibit aerobic respiration. Bivalves can also survive in relatively high concentration of hydrogen sulfide, but bivalves have to respond as same as under anoxia. Combined effects of hypoxia and hydrogen sulfide may act as anoxia, thus oxygen deficiency is extremely dangerous and should be noticed its effect on bivalve physiology.

High concentration of suspended particle suppresses the water clearance of the bivalves and increases pseudofeces ejection (Bayne, 1993). The increase of several tens mg/L of suspended mud mixed with food algae brings down the clearance rate and ingestion rate of food algae (Bricelj & Malouf, 1984). Increase of suspended particles may cause the excess energy expenditure for pseudofeces ejection and owe deficit on energy budget. The bivalves under the high turbidity should show low growth rate. Highly concentrated muddy water may clog the gill of bivalves and force to close the valves. The bivalves have to wait until the overlaying water replaced sufficiently clear for resuming respiration. So, high concentration of turbid water presumably affects the bivalves in almost same manner as anoxia.

Conclusions and further studies

Environmental changes in tidal flat in recent

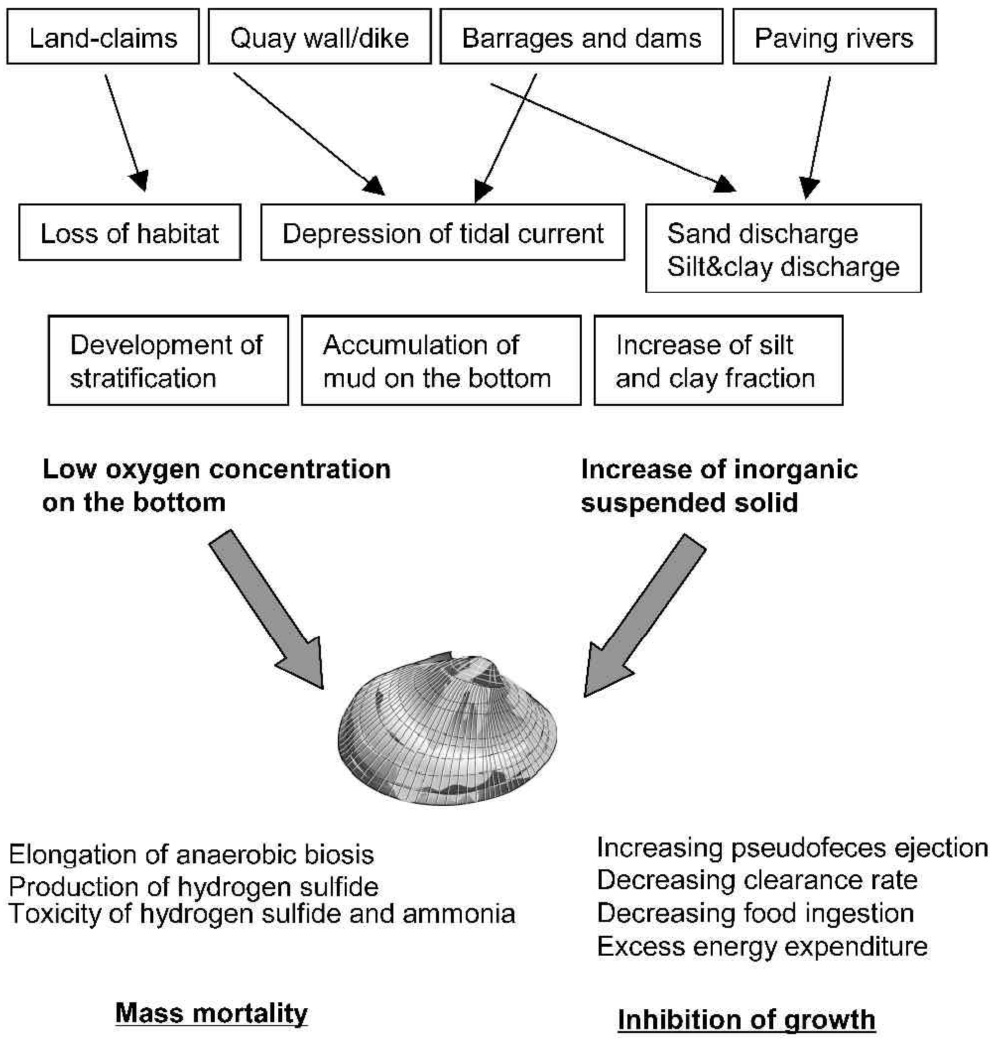

Fig. 6. Conceptual flow of coastal changes affecting to the depression of Manila clam resources

years probably affect the depression of the standing stock of filter feeding bivalves by high sediment load and oxygen deficiency. Consequently, the decrease of bivalve stocks may affect the surrounding environment. Once the ecological function of tidal flat has been degraded, it is very difficult to recover the proper bivalve resources. Under this situation, the natural recovery of ecosystem cannot be expected, and then the problem must be solved by human efforts. Quantitative assessments of causes and effects between environmental changes and bivalve's depression are strongly needed. Responses of the bivalves to single and compound environmental factors have to be clarified associating with their reproductive cycles. We also need to find out the suitable species for bioremediation. For example, the physiological and ecological evaluation of more tolerable species to turbid and anoxic condition will help design the habitat disposition. Availability of mechanical devices for improvement of water circulation and oxidation has to be considered at the same time. For example, the introduction of natural energy like wind and solar power to these devices and estimation of their cost-benefit should be inquired. Basically, efforts for eliminating negative factors and propagating the bivalve's stocks are essential to maintain coastal ecosystems.

References

Akiyama A., 1985: Teisei seibutsu no kyodou to shokumotsu rensa (behaviour of benthos and food web). in "Choukantai shuuhen kaiiki ni okeru joukakinou to seibutsu-seisan ni kansuru kenkyuu (Studies on purification and production in intertidal sea areas) report on 1984" (eds. by Tokai Regional Fisheries Research Institute and Nansei Regional Fisheries Research Institute) pp.99-104. (in Japanese)

Alpine A. E., and Cloern J. E., 1992: Trophic interactions and direct physical effects control phytoplankton biomass and production in an estuary. *Limnol. Oceanogr.*, **37**(**5**), 946-955.

Bayne B. L., 1993: Feeding physiology of bivalves: time-dependence and compensation for changes in food availability, in "Bivalve filter feeders in estuarine and coastal ecosystem processes" (ed. by Dame F. R.), Springer-Verlag, Berlin Heiderberg, pp.1-24.

Bricelj V. M., and Malouf R. E., 1984: Influence of algal and suspended sediment concentrations on the feeding physiology of the hard clam *Mercenaria mercenaria. Mar. Biol.*, **84**, 155-165.

Fujiwara M., 1986: Influence of temperature on filtration rate of young cockle and ark shell. *Bull. Kyoto Ocea. Fish. Sci.*, **10**, 19-24. (in Japanese)

Hochachka P. W., 1984: Biochemistry of adaptation of hypoxia-strategy of the oraganisms to survive without oxygen, Kouseishakouseikaku, Tokyo, 194pp.

Kawamoto N., 1967: Report on the cause of mass mortality of *Meretrix lusoria* in the coast of Chiba preferture, Nourin Toukei Kyoukai, Tokyo (in Japanese)

Koike K., 1990: Artificial beach construction on the shore of Tokyo Bay. Japan. *Jour. Coastal Res.*, SI No.6, 45-54.

Little C., 2000: The biology of soft shores and estuaries, Oxford University Press, New York, 252 pp.

Ministry of Agriculture, Forestry and Fisheries, Statistics and Survey Division, 1954-2001: Annual report of catch statistics on fisheries and Aquaculture in 1953-2000, Nourin Toukei Kyoukai, Tokyo

Nakamura M., Shinagawa A., Toda K., and Shigeru N., 1997: Tolerance of 4 bivalves from lake Shinji and Nakaumi to environmental factors. *Suisanzoshoku*, **45**(**2**), 179-185. (in Japanese)

Navarro E., and Iglesias J. I. P., 1993: Infaunal filter-feeding bivalves and the physiological response to short-term fluctuations in food, in "Bivalve filter feeders in estuarine and coastal ecosystem processes" (ed. by Dame F. R.), Springer-Verlag, Berlin

Heiderberg, pp.25-56.

Newell R. I. E., and B. L. Bayne., 1980: Seasonal changes in the physiology, reproductive condition and carbohydrate content of the cockle *Cardium* (=*Cerastoderma*) *edule* (Bivalvia: Cardiidae). *Mar. Biol.*, **56**, 11-19.

Sagara J., 1981: Ecology, and physiology of *Tapes* (Ruditapes) *philippinarum* and *Meretrix lusoria*. *Aquabiology*, **3**(**2**), 102-105. (in Japanese)

Satoh M. (Ed.), 2000: Life in Ariake Sea: Biodiversity in tidal flats and estuaries, Kaiyusha, Tokyo, 396pp. (in Japanese)

Yamamoto K., Tamura I., and Tochino M., 1996: Effects of water temperature on filtration volume and ciliary movement of gills in the Japanese ark shell, *Scapharca broughtonii*. *Journal of National Fisheries University*, **45**(**2**), 95-101. (in Japanese)