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The present situation and problems of oyster culture in Hiroshima Bay

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Abstract Hiroshima Bay including its adjacent area is one of the most important oysters farming areas in Japan. During 1980s, the oyster production in Hiroshima Bay was about 30,000 metric tons (t) scale by fresh meat weight (FMW) a year. In the early 1990s, the oyster production began to decrease and was about 20,000t in 2000. We analyzed the present situation and problems of oyster culture in Hiroshima Bay to show the problem solution. This decrease in oyster production in the 1990s was caused directly by typhoon damages; shellfish poisoning by *Alexandrium* spp.; and mortality by harmful dinoflagellate *Heterocapsa circularisquama*: and was caused by dense cultivation indirectly. The postponing of harvesting the oyster caused by shellfish poisoning prolonged the oyster culture period. The prolongation of the culture period in a limited culture ground caused eventually dense cultivation of oyster. Aged and large-sized oysters took much feed, therefore growth of all oysters in culture grounds were slowed down under low feed level. The low growth rate accelerated prolongation of a culture period. These vicious spirals promoted dense cultivation, and changed the environment of the culture ground into favorable environment for *H. circularisquama*. To analyze these situations, an oyster culture process model was built. This model showed that the reduction in oyster biomass in the culture grounds is needed to escape from the vicious spiral, and shortening of the culture period was the most effective method for this reduction without reducing harvest magnitude.

Key words: oysters, Hiroshima Bay, culture process

Introduction

We present a model to describe the difficulty that oyster culture in Hiroshima Bay including its adjacent area is facing currently. We have examined possible improvement of the culture process by this model.

Hiroshima Bay is located in the western part of the Seto Inland Sea (Fig.1). Oyster culture in the bay had begun at a tidal flat of estuary before 450 years ago. About 60% of a Japanese oyster are produced currently in Hiroshima Bay. The oyster hanging culture method by rafts of bamboo spread over the Hiroshima Bay after 1960. Kusuki (1991) had reviewed the history and technology of oyster culture in Japan.

The changes in annual oyster production by fresh meat weight (FMW) in Hiroshima prefecture after 1965 is shown in Fig. 2. The Hiroshima Fisheries Experimental Station (2001a) reported the relationship between the changes in oyster production and oyster culture technology as follows. In 1960s, the oyster production increased to 30,000t by spread of the hanging raft culture. However, in 1969 and 1970, the oyster production decreased by outbreak of red tide and dense settlement of serpulid worm (Arakawa, 1971). In 1970s, the volume of production increased to 30,000t

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again. The recovery of production was achieved by development of a culture technique: hanging down deeply and migration of a raft seasonally, to avoid the red tide and the settlement of the other periphyton. In 1980s, improvement of the culture technology provided both reliable production of 30,000 t scale and the extension of a culture period. In 1990s, the oyster production began to decrease. In September 1991, a severe typhoon damaged 40% of the rafts, and the harvest was about 1 month late. In the early spring of the next year, harvest was stopped because a shellfish poisoning had exceeded safety regulation. The harvest suspension by shellfish poisoning in early spring occurred afterwards for several years. In addition, red tide of *H. circularisquama* occurred in autumn 1995 (Matsuyama *et al.*, 1997), and it delayed the oyster to gain weight. In summer 1998, mass mortality occurred by the red tide of *H. circularisquama*. In the next harvest season the oyster production was decreased to about 16,000 t. However, the oyster survived grew well. The Hiroshima Fsheries Experimental Station (2001a) estimated that the decreasing of oyster production after 1990 was caused by shortening of a harvest period by a shellfish poisoning and delay of growth or mortality by *H. circularisquama* directly. However, they thought that there were problems of production structure as arranging a lot of rafts in a limited culture ground and extending a culture period.

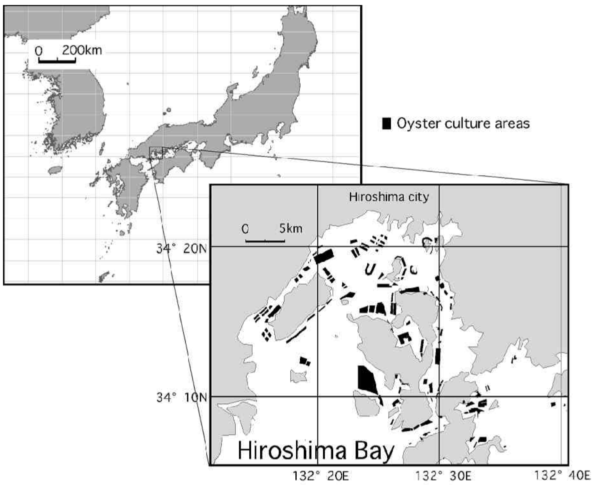

Fig. 1. Location of oyster culture areas in Hiroshima Bay

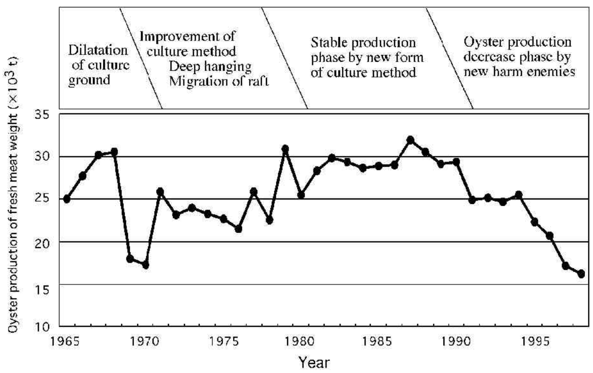

Fig. 2. Changes in cultured oyster annual production by fresh meat weight (FMW) in Hiroshima Prefecture. The data listed here can found in the "Annual Report of Production on Fishery and Aquaculture, Statistics and Survey Division", Ministry of Agriculture, Forestry, and Fishery, Japan.

In late years, studies of shellfish poisoning, red tide plankton, and that about evaluation of contribution degree of oyster culture in material circulation of Hiroshima Bay are pushed forward (Songsangjinda *et al.*, 1999). However, there are no concrete measures to elucidate their effects on oyster culture. In this study, we describe an approach to analyze the oyster culture methods in Hiroshima Bay by an oyster culture process model.

Materials and Methods

Oyster culture process model

1. Basic structure of the model

This oyster culture process model consists of physiological changes of an oyster and culture process of a raft unit in one culture ground. For modeling of feed competition among oyster, the structure that the quantity of feed in the culture ground decreases according to the biomass increases was built in this model. The calculation was carried out by one-day unit during one year from 1 October to 30 September. The relationship of increase in weight of an oyster and a quantity of chlorophyll in the culture ground, the relation of a size of oyster and a quantity of spawning eggs or death rate are determined by the findings of Hiroshima Fisheries Experimental Station (2001b).

2. Individual scale

Oyster repeats physiological change of gametogenesis and growth seasonally. In winter, oyster grows well. In summer; however, spawning reduces the weight. On 30 September, FMW for individual starts from 1g. The weight of oyster in this paper is expressed by FMW. The weight gain a day (*WG*) of an oyster from October to May was expressed by following equation:

$$WG = 0.0512QC - 0.0130,$$

where *QC* is the quantity of chlorophyll (μg/L). The *QC* decreases by an oyster biomass (*OB*) in a culture ground. Environmental factors as water temperature, salinity and dissolved oxygen are not considered. The weight does not change in June and September, and decreases according to weight of June by spawning in August from July. Starting weight of September (*Ws*) is given by

$$Ws = -0.02\ Wjun^2 + Wjun \quad (Wjun \leqq 30\text{g}),$$

$$Ws = 0.4\ Wjun \quad (Wjun > 30\text{g}),$$

where *Wjun* is the weight of June.

3. Raft scale

Initial population is 250,000 oysters a raft. Some oysters die in July and August. Number of September (*Ns*) is given by

$$Ns = Njun \quad (Wjun < 10\text{g}),$$

$$Ns = Njun\ \{1 - (Wjun/90)\} \quad (10\text{g} \leqq Wjun < 90),$$

where *Njun* and *Wjun* are number of June and weight of June, respectively.

4. Culture ground scale

Quantity of chlorophyll (*QC* μg/L) in culture ground is constant, however, when biomass of oyster (*OB*) exceeds a fixed quantity, it decreases by competition. *QC* is given by

$$QC = 2.7 \quad (OB < 14{,}000\text{t}),$$

$$QC = 37{,}800/OB \quad (OB \geqq 14{,}000\text{t}).$$

5. Harvest

Oysters more than 5 g (FMW) are harvested. The raft that contains the heaviest oyster in culture ground is harvested sequentially. Total of 6,300 rafts are harvested in one year, with the speed of 28 rafts a day during 16 October to 28 May in this model. The oyster biomass (*OB*) is a total of weight of all individual of a culture ground. Gross production of the year is provided by summing daily harvest.

6. Production economy

Money earned in a day is calculated from gross weight of the oyster that harvested on one day and unit prices of the day. The Unit price of Hiroshima oyster is generally high until December, but tend to gradually fall from January. The change of unit price set it as follows. The price of oyster is 1,200 yen a kg from October to December. The unit price decreases by a rate of 5 yen/kg/day from 1,200 yen/kg during January to February, and 1 yen/kg/day from March to May. A gross production amount of money of the year is provided by a total of daily production sales.

Estimation of oyster production under different culture patterns

The basic pattern of oyster culture in Hiroshima Bay is classified into 3 patterns according to the length of the culture period. In the 1-year-culture method called "Waka", oyster spats are collected in the summer, grown in the winter, and harvested before the following summer (less than 12 months old). In the 2-year-culture methods called "Yokusei" and "Ikisu", oyster spats are hardened on intertidal racks for 2 to 3 months and 6 to 10 months, respectively, after spat collection in summer, grown under rafts over the next summer, and harvested during the following harvest season (13-23 months old). In the 3-year-culture method called "Nokoshi", oyster spats are hardened by the same method as in the "Yokusei" method, grown over two summers, and harvested during the following harvest season (25-35 months old). The combination of these culture methods in Hiroshima Bay had changed as follows: In the 1960s, oysters were produced by a combination of the 1 and 2-year-culture methods. Only a 2-year-culture method was used from the 1970s to the beginning of the 1980s. In the latter half of the 1980s, the 3-year-culture method has been introduced in addition to the 2-year-culture method, and its ratio has increased after the consecutive outbreak of shellfish poisoning (Fig. 3). We estimated oyster production by the number of rafts needed, the gross production, the total amount of money earned, oyster growth and oyster biomass in five patterns of a combination of culture methods. In patterns 1, 2, 3, 4 and 5, the oysters were cultured only by a 1-year-culture method, a 1-year-culture and 2-year-culture method, a 2-year- culture, a 2-year-culture and 3-year-culture, and by only a 3-year-culture, respectively.

Estimation of impact of shellfish poisoning on the oyster production

When the quantity of shellfish poison in oysters would exceed safety regulation, the oyster harvest in Hiroshima Bay would be halted. Oysters that aren't harvested would be left in the culture ground until the next harvest season beginning in October. Shellfish poisoning of oysters had occurred in Hiroshima Bay every spring from 1992 to 1998, except in the year 1994. The mass mortality of oysters caused by the *H. circularisquama* red tide occurred subsequently in summer, 1998 (Fig. 4). We evaluated the impact of the suspension of harvest caused by shellfish poisoning on oyster production by using this oyster culture process model, as follows: In the initial year, 90 % of the 2-year-cultured oysters and 10 % of the 3-year-cultured oysters would be harvested (year 0). In every spring during next five years, the harvest would be suspended during the final 20 days of the harvest period due to shellfish poisoning occurred (years 1-5). In the summer of the fifth year (year 5), the *H. circularisquama* red tide occurred and oyster mortality would be assumed 100 % and 50 % in case of the 3-year-cultured and the 2-year-cultured oysters, respectively.

Results

Estimation of oyster production under different culture patterns

Fig. 5 shows the simulated result on the number of raft needed, gross production, and total amount of money earned under each oyster culture pattern. These five culture patterns correspond to the historic changes in the culture methods used in Hiroshima Bay. The culture methods in the 1960s, and from the 1970s to 1980s and 1990s, are almost equivalent to patterns 1 or 2, 3, and 4, respectively. The shift in culture methods from pattern 1 to pattern 3

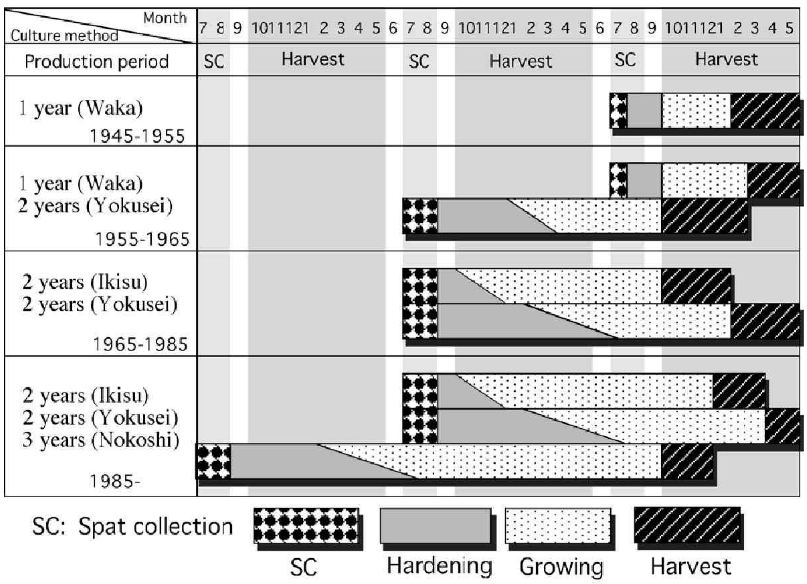

Fig. 3. Transition of oyster culture methods in Hiroshima Bay

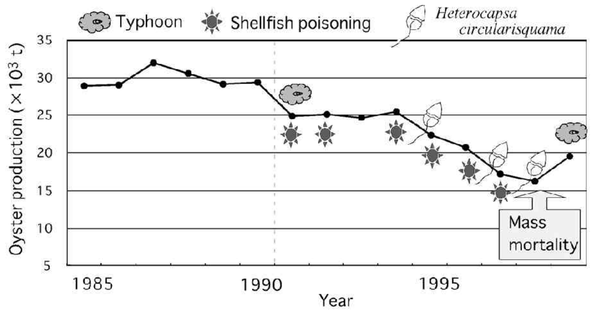

Fig. 4. Changes in annual cultured oyster production by fresh meat weight (FMW), and events which caused a production decrease in Hiroshima prefecture.

caused an increase of 12,600 in the number of rafts needed, which was twice the number used (6,300) in pattern 1. In pattern 3, both the gross production and the total amount of money earned was at its maximum. The shift in culture methods from pattern 3 to pattern 5 caused a further increase in the number of rafts needed, to 18,900 from 12,600. In patterns 4 or 5, the gross production and the total amount of money both decreased. Fig. 6a shows the changes of in the individual weight of harvested oysters in each harvest pattern. The shifts from pattern 1 to pattern 3 raised the oyster size of the harvest at the beginning, but reduced the oyster size of the harvest by the end of the exchange. The shifts from pattern 3 to pattern 4 raised the oyster size of the beginning harvest inconsiderably. However, the shifts from pattern 4 to pattern 5 reduced the oyster harvest size of all periods compared with pattern 3. A change of biomass under each culture pattern is shown in Fig. 6b. Fig. 6c shows the ratios of oyster age in each biomass of patterns 1, 3 and 5. The shift from pattern 1 to pattern 5 raised maximum biomass about 3 times.

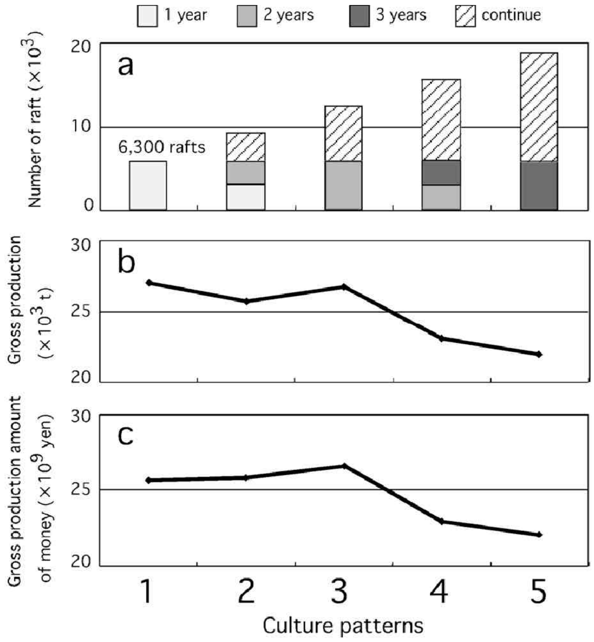

Fig. 5. The variation of: a) raft composition at the harvest of 6,300 rafts, b) estimated gross oyster production during each year, c) estimated total production of money in each culture pattern.

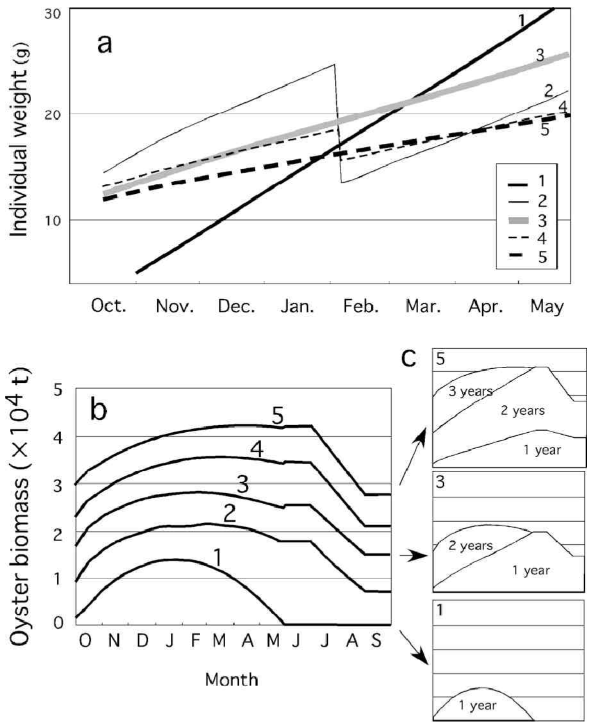

Fig. 6. Changes in the estimated: a) individual weight of oysters in each culture pattern, b) oyster biomass in each culture pattern, c) age composition of oysters in the biomass of patterns 1,3 and 5. The numbers in this figure correspond to each pattern in Fig. 5.

Estimation of impact of shellfish poisoning on the oyster production

Fig. 7 illustrates the annual changes in the number of rafts and gross production on the condition that the mass mortality occurred after shortening of the harvest period by 20 days continued for 5 years. One year later, the gross production of oysters decreased because the harvest had been halted for 20 days, and the production decreased gradually thereafter. This gradual decrease in production was due to the postponement of the harvest schedule, which caused the increase in the ratio of the 3-year-culture, the change of the harvest size (Fig. 8a) and the increase in oyster biomass in the culture ground (Fig. 8b). Five years later, the harvest size in 1 December increased to 15.9 g from 14.9 g, but the harvest size in 1 May decreased to 19.8 g from 23.0 g (Fig. 8a). The increase of biomass for 5 years was remarkable in June, just before spawning. The biomass reached 1.34 times of the initial year (Fig. 8b). Due to the mass mortality which occurred in the summer of the 5th year, gross production in the 6th year decreased to about 16,000 t. However, individual oysters survived, showed high growth rate due to the decrease in the biomass (Fig. 8b).

Discussion

This oyster culture process model simulated the oyster culture production structure of Hiroshima Bay, reproducing each changes of the harvest size, gross production, and the total amount of money earned. This model enabled to obtain a long-term guide for selecting a culture method.

In the 1980s, oyster had been cultured mainly by the 2-year-culture method and the production had been constant approximately 30,000 t in Hiroshima Bay. But in this period, the 3-year-culture method was introduced to a small percentage and was effective because large size individuals were available to be harvested in the early period of harvest seasons, when the unit price was high. However, the induction of the 3-year-culture method caused an increase in the oyster biomass in the culture ground, delayed individual growth, and then prolonged the culture period, which led to a vicious spiral (Fig. 9). In the 1980s, we thought that the vicious spiral illustrated in Fig. 9 already existed. The progress of this vicious spiral was not rapid, but after the 1990s. The outbreak of shellfish poisoning caused a sharp increase in oysters cultured by the 3-year-culture method because the harvest had to be postponed to the next harvest season, and that caused an acceleration of the spiral. It can be considered that

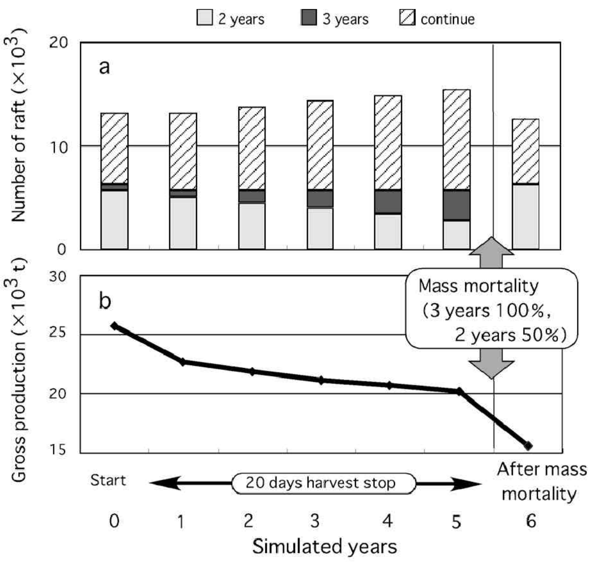

Fig. 7. The simulation of the shortening of the harvest period caused by shellfish poisoning and mass mortality by *H. circularisquama*. a): changes in the number of rafts, and b): changes in gross oyster production in that year.

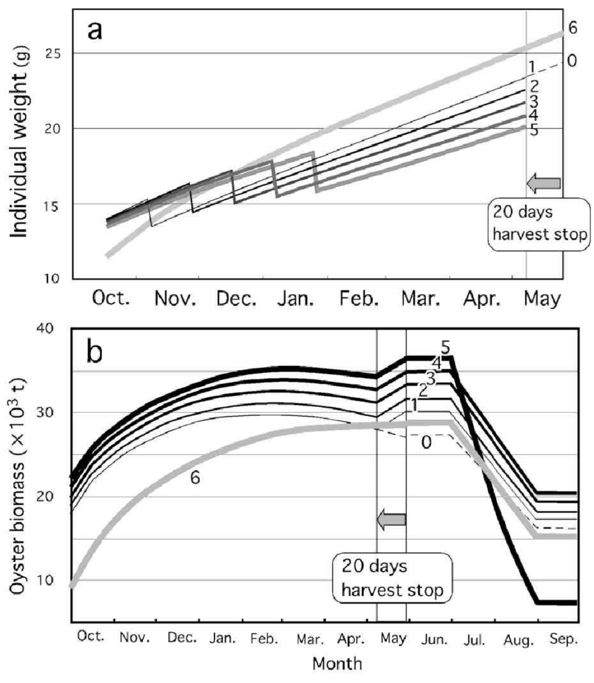

Fig. 8. Changes in the estimated: a) individual weight of oysters, b) oyster biomass under shortening of harvest period caused by shellfish poisoning and mass mortality by *H. circularisquama*. The numbers in this figure correspond to each year in Fig. 7.

dense cultivated grounds, where there is no competition with other plankton and the flow of water is stagnant are favorable environment for *H. circularisquama* to increase (Fig. 9).

Oyster biomass in culture grounds has to be decreased in order to halt this vicious spiral. The most effective method for this purpose is to shorten a culture period. In other words, it would be optimal to culture oyster only by the 2-year culture method rather than combinate with the 3-year one. To confirm this efficacy, we are currently analyzing the carbon flow in an individual scale and in a raft scale. We also plan to combine our analyses, and build an oyster culture model of a culture ground scale in the future.

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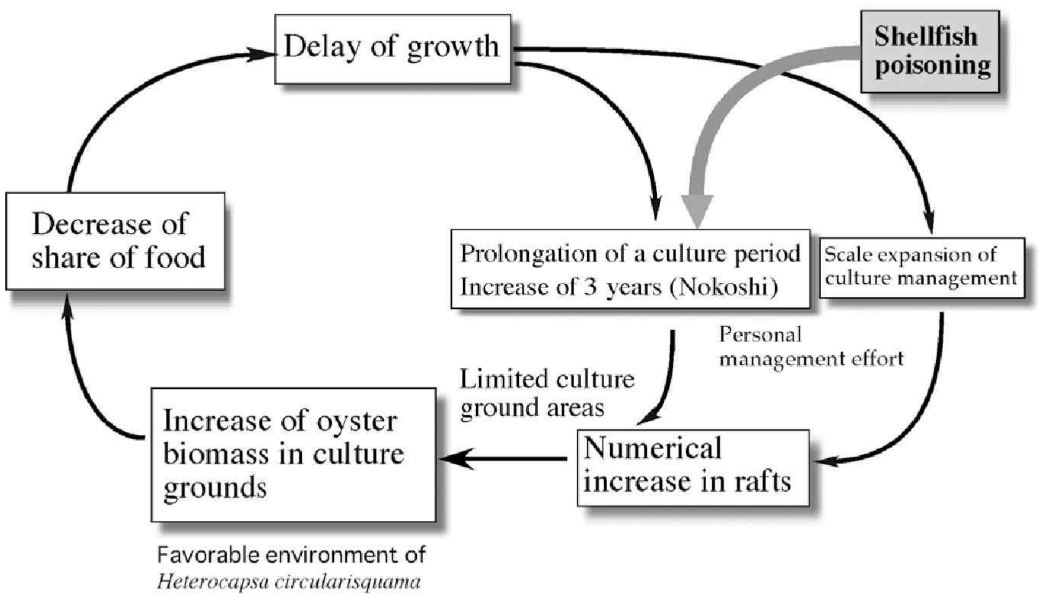

Fig. 9. The vicious spiral of oyster culture in Hiroshima Bay

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