水 研 機 構 研 報, 第42号, 67 − 73, 平 成28年
Bull. Jap. Fish. Res. Edu. Agen. No. 42, 67−73, 2016

An a-priori evaluation model for restoration of fisheries population of the Manila clam and a countermeasure example in Ise Bay

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Abstract: The national production of the Manila clam, *Ruditapes philippinarum*, fishery has been continuously declining since the mid 1980s in Japan. The total production of asari in Ise Bay exceeded 10,000 tons per year in 1980's. However, it started to decrease in the mid 1990s, and it has been less than 5,000 tons. Fisheries Agency of Japan has been implementing stock enhancement programs, including fisheries management, fishing ground development and reseeding as countermeasures for the production decline. In order to attain successful stock enhancement, it is first of all necessary to elucidate the causes of stock depletion in each stage in life cycle of the clam. Then, one must make a plan to remove or reduce the effects of the elucidated causes taking into account what measures should be applied to what location to what extent. In the present study, we introduce about two topics. First topic is about the development of an a-priori evaluation model for restoration of the asari clam in Ise Bay. And the second topic is an example of countermeasure for asari stock recovery in Ise Bay. In Ise Bay, asari juveniles often do not survive until adult stage. So we have developed an effective juvenile collection method for transplantation and we are trying to develop a nursery ground for high growth and low mortality of asari.

Key words: Manila clam, *Ruditapes philippinarum*, asari, Ise Bay, a-priori evaluation model, nursery ground, spawning ground

Asari is one of popular seafood in Japan: however, the fishery production of asari is decreasing and has almost no sign of restoration in Japan. The production of asari in Ise Bay has also been declining, which was around 10,000 t per year from 1980 to 1995 and then sharply dropped to the current level of less than 5,000 t per year for a decade (Fig. 1).

Water currents transport the eggs and larvae of asari for several weeks. The larvae must reach an appropriate habitat to settle on the bottom and start the benthic life. The amount of spawned eggs and arrival of larvae to fishing ground are important factors determining the new recruitment level. For the benthic stage after the settlement, parameters such as food availability, dissolved oxygen (DO) level, predation, wave conditions and fishing intensity are important to determine the stock level. For

2016年 1 月29日受理（Received on January 29. 2016）
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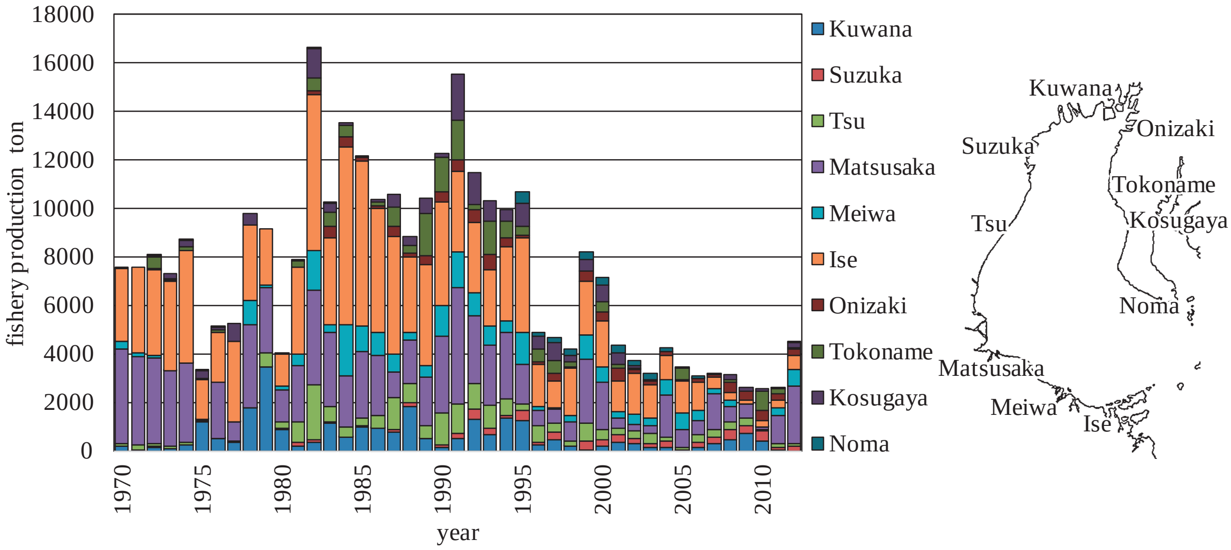

Fig. 1. The trend in annual production of asari in Ise Bay

each fishing ground, we need to identify causes of population decline and design countermeasures. We have to decide what operations should be done at what size at what location to effectively restore fishery population of asari.

This report describes two topics. The first topic is about the development of an a-priori evaluation model for restoration of the asari clam in Ise Bay. This model quantitatively determines the effects of size and location of spawning ground and nursery ground on the recruitment, taking into consideration the life cycle characteristics of asari. The second topic is an example of countermeasure for asari stock recovery in Ise Bay. In Ise Bay, asari juveniles occur at high density in many locations, but they often do not survive until adult stage. Therefore, we have developed an effective juvenile collection method for transplantation to a nursery ground for higher growth and lower mortality of asari.

An a-priori evaluation model for restoration of the asari clam

Configuration of model components: The outline of the model components is shown in Fig. 2. This model consists of 5 parts dealing with two life stages of asari. First of all, we assume that one adult clam larger than 20 mm in shell length produces 500,000 eggs, and we estimate the total number of eggs produced in each fishing ground based on this value. Spawning of asari occurs in spring and autumn in Ise bay.

To evaluate the amount of larval transportation, we calculate the connectivity among fisheries grounds based on the hydrodynamic simulation in Ise Bay during the 15-day planktonic stage of asari. Then, we calculate the number of larval settlement in each fishing ground.

We then calculate the mortality and the growth of the settled asari based on our previous field studies. We give different mortality rate for each fishing ground depending on the disturbance of the sea bottom by wave action. One of the conditions for mortality estimate is that asari cannot live in areas deeper than 4 m because of hypoxia. Finally, we obtain the number of adult asari larger than 20 mm in shell length, and the next life cycle is followed with the calculated values as the initial conditions.

Transportation of planktonic larvae of asari: Planktonic larvae of asari are transported passively by hydrodynamic force. We assumed that hydrodynamic force consists of 3 factors: wind driven force, river discharge and ocean current. We performed a principal component analysis and cluster analysis of the hydrodynamic data of Ise Bay from 1983 to 2003 to classify them into groups. We found that the hydrodynamic characteristics could

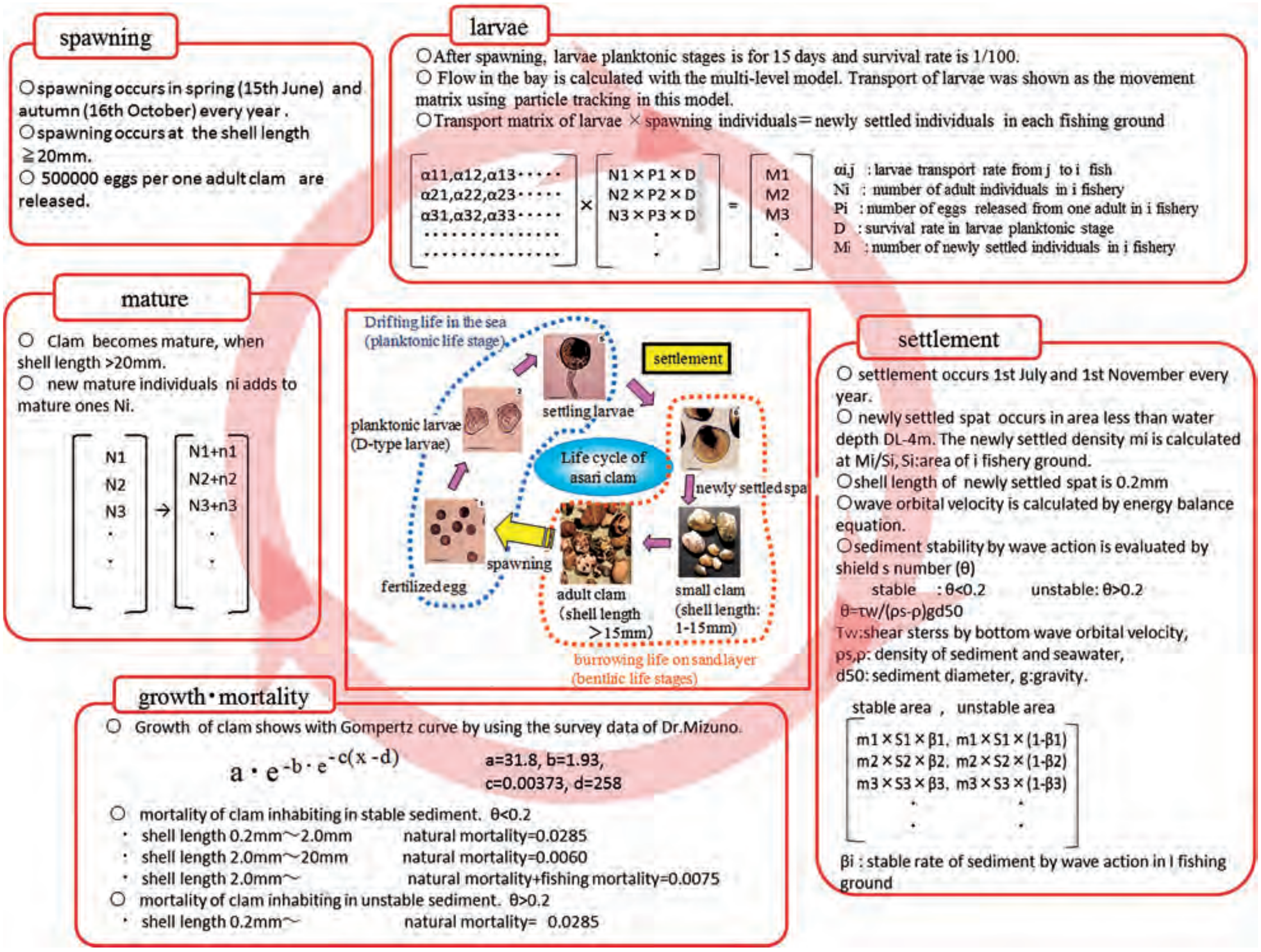

Fig. 2. An a-priori evaluation model for restoration of fisheries population of the Manila clam

be classified into 5 groups in spring and 6 groups in autumn. Years that belong to the same group have similar hydrodynamic pattern and thus similar transportation pattern of asari larvae.

The current in Ise Bay was calculated with the multi-level hydrodynamic model. The transportation of asari larvae was calculated with the particle tracking method concerning the vertical migration. Transportation of larvae of asari were expressed with matrixes from the calculated results of each groups. The model estimated that the larval transportation between Ise Bay and the adjacent Mikawa Bay is little, and the larval transportation is more active in spring than in autumn.

Mortality and growth of asari: The mortality and growth of asari were studied in our previous studies in Ise Bay. Growth pattern of asari can be described by Gompertz model. In Ise Bay, asari juveniles often fail to grow up to commercial size. One of the mortality causes of asari juveniles is the suspended load transport by wave action. Asari juveniles can be washed up to unfavorable places by strong waves and die. The Shields number from 0.2 to 0.5 causes the suspended load transport of asari juveniles. Therefore, in this model, the natural mortality of asari was expected to be high with the Shields number (θ) exceeding 0.2.

$$\theta = \tau_w / [(\rho_s - \rho) g D_{50}]$$

where τ_w is the bottom shear stress by water wave $=1/2\ \rho f_w u_{orb}^2$, u_{orb} is the bottom wave orbital velocity, f_w is friction factor $=\exp[5.213(k_s/A_{orb})^{0.194}]-5.977$, k_s is the hydraulic (Nikuradse) roughness length$=2.5D_{50}$, A_{orb} is the bottom wave amplitude$=u_{orb}T/2$, T is the wave period, D_{50} is the median grain size, ρ_s is sand density, ρ is the sea water density, and g is the gravitational acceleration.

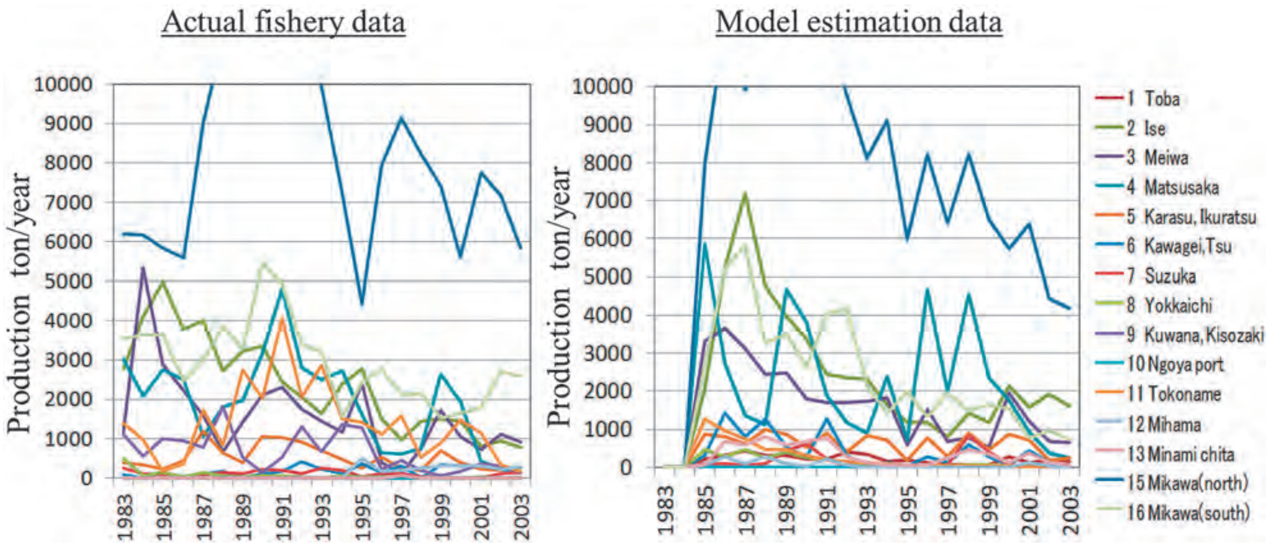

Fig. 3. The model estimations for the annual production of asari in Ise Bay

In Ise Bay, it takes about two years for asari to reach harvestable size of 20 mm; therefore, fishing mortality is applied to asari older than two years old on top of the natural mortality.

Model estimations for the annual production of asari in Ise Bay: The validity of this model is shown in Fig. 3. The left graph shows the actual annual production of asari in Ise Bay, and the right is the model estimations. Although there are some minor differences, the model estimations are roughly the same as the actual data.

Evaluation of a spawning ground or a nursery ground by an a-priori evaluation model: In order to increase asari production by more than 1000 tons by 2003, what should be the size and location of a spawning ground or a nursery ground developed in 1988? We want to derive answers for this kind of question using this model. Spawning grounds are to be developed in such a way that we can expect increased egg production and larval supply to the bay. Nursery grounds are to be designed to have stable sediment under strong wave environments to increase survival of asari juvenile.

The estimated increase of asari production by development of nursery or spawning grounds of variable scales is shown in Fig 4. The left figure shows the effect of nursery ground development and the right figure spawning ground development on the increase in asari production. Developing a nursery ground from region 3 to 6 is estimated to be effective, and spawning ground should be developed in region 7 and 11. In order to increase asari production by more than 1000 tons in 2003, we should develop a 100 ha nursery ground and spawning ground with 100 million spawners in these fishing grounds in 1988.

There are three large rivers flowing into Ise Bay, creating water current towards the bay mouth. Therefore, we suggest that spawning grounds (source) should be developed at inner part of Ise Bay and the nursery (sink) in western part of the bay to optimize the source-sink dynamics of larval supply and juvenile settlement.

Example of countermeasures for asari stock recovery in Ise Bay

Development of Collection device for asari juveniles: In Ise Bay, asari juveniles often fail to grow up to the recruitment size of 2 mm. Some of the causes of the juvenile mortality are disturbance of sediment by strong waves and river discharge after a storm event. For this, fishers in Matsusaka, Ise Bay collect juveniles for transplantation every year. They use a rake with fine mesh to collect juveniles and transplant them to places with better survival.

We have developed a device to help the fishers

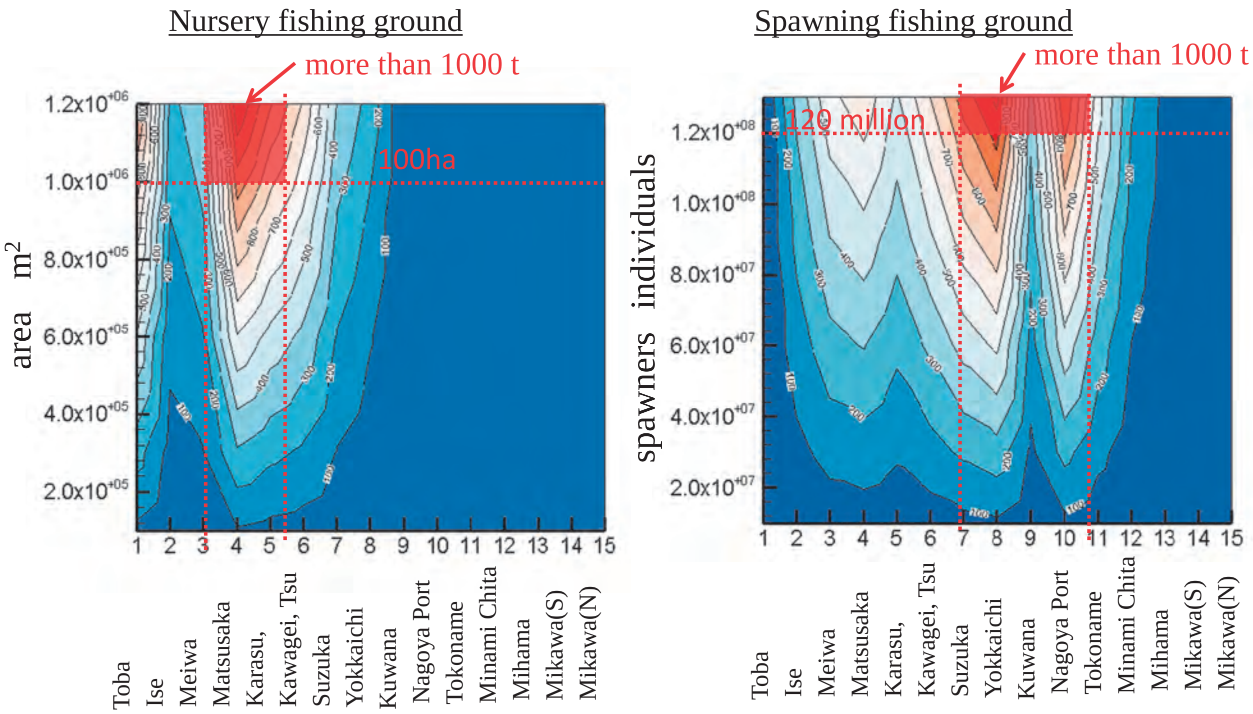

Fig. 4. estimated production increase of asari by development of nursery or spawning grounds of variable scales

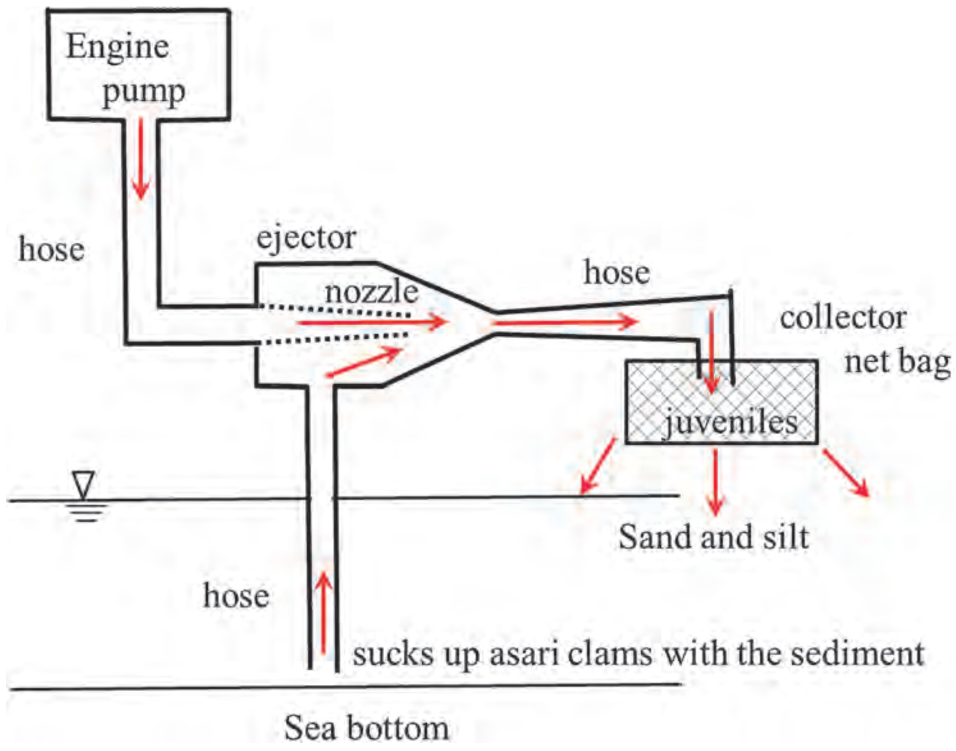

Fig. 5. Mechanism for collecting asari juveniles

collect asari juveniles more efficiently (Fig. 5). A strong current produced by the engine pump creates suction in the ejector, and this sucks up clams with the sediment. Sand and silt are washed through the net, leaving asari juveniles larger than 4 mm in shell length behind.

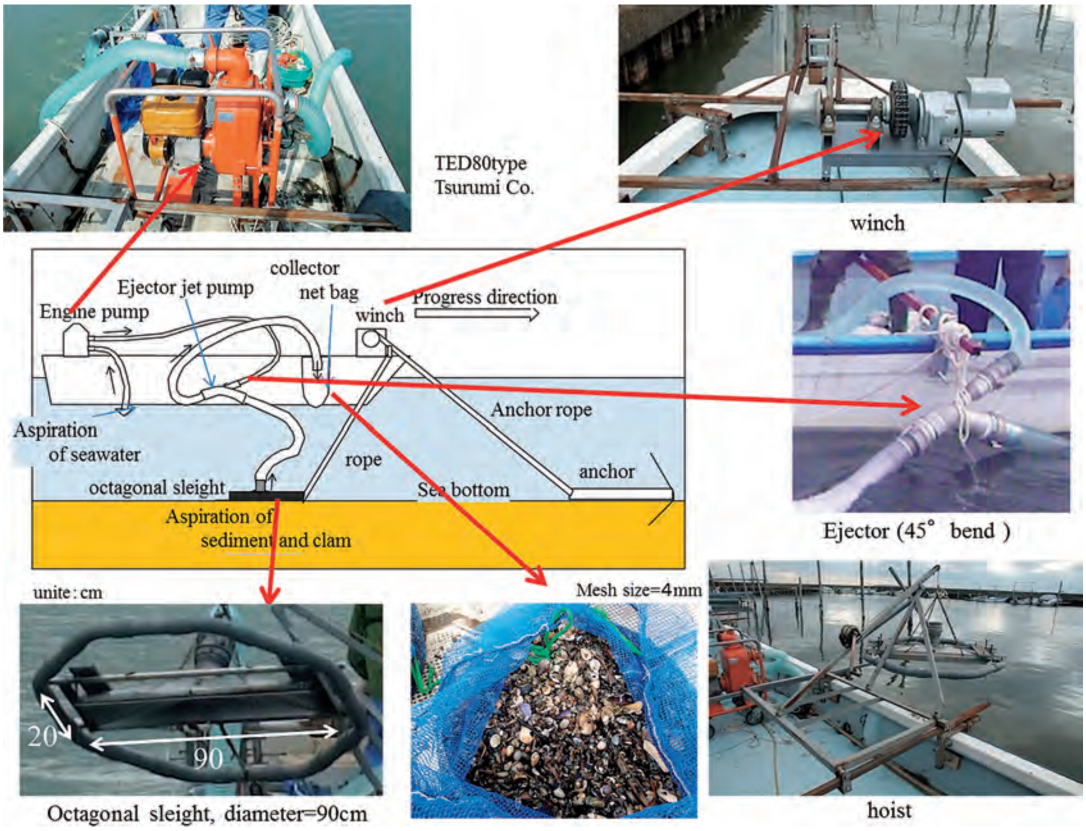

Fig. 6. Collection device of asari juveniles

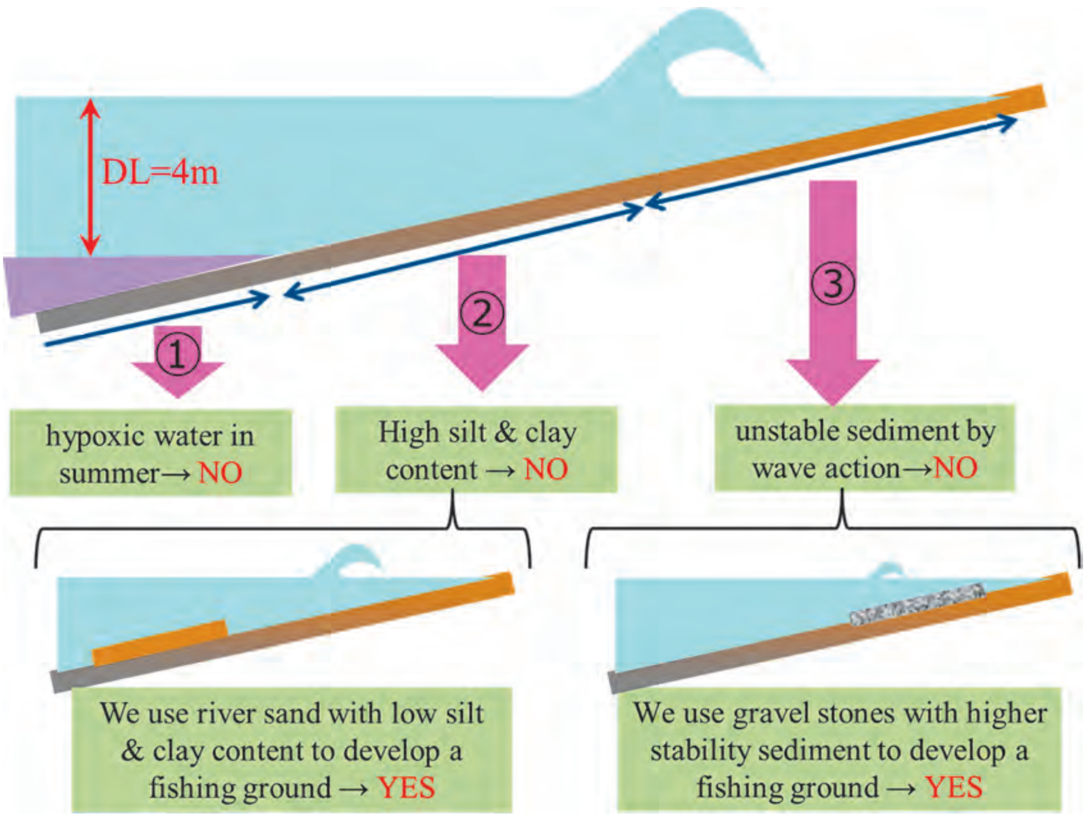

Fig. 7. Concept for fishing ground development of asari

It takes about 1 hour to install the collection device to a boat (Fig. 6). For the operation, we at first anchor the boat and go astern for about 100 m. Start the asari collection device and slowly winch up the anchor rope as we collect asari. We transfer the collected asari to another boat for transportation and releasing. In this example, 5 people worked for 4 days to transplant about 4 million individuals of asari juveniles.

Fig. 8. Development of two sediment types of asari fishing grounds

Development of effective asari fishing ground: The concepts for asari fishing ground development is shown in Fig. 7. Ise Bay has a problem of anoxic water. So a fishing ground must be developed in areas shallower than 4 m where anoxia does not occur. We use river sand with low silt and clay content to develop a fishing ground because fine particle sediments are not suitable for asari habitat. It is important to stabilize the sediment by using gravel stones in areas with strong waves.

We developed two fishing grounds (50 m by 50 m) in collaboration with Mie prefectural government in October 2014 (Fig. 8). For one ground we used river sand and for the other ground gravel stones. The median grain size was 0.75 mm for the river sand and 4 mm for the gravel stones. We are monitoring the efficiency of the grounds in terms of growth and survival of asari. About seven months has passed after the release, and so far the growth and survival of asari are good.

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