Shellfish collected from the coastal waters of Rayong Province in Thailand (Photo: Akito Sato)

Fishery Resource and Habitat Rehabilitation:
Improving the Productivity of Tidal Flats

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This article which was presented at the Second Meeting of the Regional Advisory Committee on Fisheries Management in Southeast Asia (RAC) convened by SEAFDEC in Bangkok, Thailand in September 2009, introduces the functions of tidal flats, provides views on diagnosing tidal flats as well as countermeasures for rehabilitation, and presents examples of case studies in Japan based on the "Guideline for Improving the Productivity of Tidal Flats (February 2008)" compiled by the Fisheries Agency of Japan. It is envisaged that making known such useful information on the conservation of tidal flats, would boost the efforts of the Southeast Asian countries in improving the productivity of their respective tidal flats.

Functions and Values of Tidal Flats

Tidal flats, also sometimes known as coastal shallow sandy/ muddy seashores, are geographical features formed by piles of mud and/or sand at the bottom of coastal sea waters (**Fig. 1**). In many cases, the biodiversity of tidal flats are high, encompassing a large number of marine resources such as shellfishes, crustaceans and juveniles of fishes. In fact, many research reports have indicated that flatfishes thrive in coastal shallow sandy seashores in a bay during their juvenile stage.

Tidal flats have multiple functions such as fishery production, water quality purification, biodiversity support, and provider of waterfront amenities for people. Among the tidal flats' functions, the functions related to "water quality purification" and "biodiversity support" defer in a tidal flat with abundant shellfishes and in a tidal flat with few shellfishes.

Fig. 1. Landscape of a typical tidal flat in Japan
Photo: Guideline of the Productivity of Tidal Flats, Fisheries Agency of Japan.
(Source of succeeding photos is also "The Guideline")

It should be noted that the value of a tidal flat could be determined by its fishery production, such as the amount of bivalves. In particular, bivalves are typical fishery resources in tidal flats in Japan, where the tidal flats are being managed in order that bivalves can thrive and the productivity of tidal flats could be improved or maintained.

The aforementioned Guideline illustrates the value of the functions of Ishiki tidal flat located in an area of 10 km^2 at Mikawa Bay of Aich Prefecture as an example of typical tidal flats in Japan. At first, the value of its "Fishery Production" function is worth five billion yen/year. Included within this value, is the production from laver (*Nori*) aquaculture which is worth two billion yen/year. Every year the laver production from Ishiki tidal flat is about 200 million pieces by board paste.

In addition, the value of short-necked clam is worth one billion yen/year, from production of 4000 tons/year, while the value of its nursery function is about two billion yen/year, considering that shrimp production reaches 70-100 tons/year and other aquatic species such as flatfish, mud crab and goby are also being caught. Moreover, the value of the "Water Quality Purification" function is worth about four billion yen/year. Although the total amount of productivity evaluated in this example may not be so important, various important values of tidal flats as well as seaweed beds and coral reefs, could be well understood. Furthermore, since the values of tidal flats are strongly influenced by the productivity of the fishing grounds, it is necessary to manage fishing grounds so that the productivity is improved or maintained.

Basic Concepts in Diagnosing Tidal Flats

The basic concept of investigating the environmental conditions of tidal flats focuses on two important diagnoses, *i.e.* diagnosis of the fishing grounds (diagnosing the physical/biological environments on site) and diagnosis of the fishery resources (diagnosing the conditions of the bivalve resources, if necessary including other important fishery resources). These two diagnoses should be done in order to clarify the factors that could possibly obstruct the productivity of tidal flats and to develop the necessary countermeasures for their conservation and rehabilitation.

Diagnosing the fishing grounds

Physical environment of tidal flats

The distribution of bivalves in tidal flats is strongly affected by the elevation of topographies and changes in the sediments. Alterations of the topographies and sediments of tidal flats generally occur due to the changes of the flow of water current and supplies of sand/mud brought about by the influence of natural conditions or human activities. In particular, changes in the sediments including the varying particle size distributions and silt contents brought about by the accumulation of floating mud, drift sand and stiffened sea bottoms, affect not only the physical environment habitat of the bivalves but also their feeding environment. Therefore, when an increase in mud or a stiffened sea bottom leads to a decrease in the bivalve resources, such changes (*e.g.* supplies of mud and current of water flow) should be given attention. In particular, the experience in Japan could be referred to by the Southeast Asian countries considering that there are lots of tidal flats in the region where the supply of sand from rivers has decreased due to construction of dams resulting in the worsening of the physical environment of such tidal flats.

Biological environment of tidal flats

The primary production in tidal flats is contributed mainly by microalgae at the sea bottom, phytoplankton and large-scale seaweeds. In particular, benthos at the sea bottom which influence microalgae and phytoplankton play important roles for the survival and growth of bivalves. The distribution of benthos depends greatly on the characteristics of the sea bottoms, which are especially affected by the flow of water current such that when there is little current flow in locations where silt contents or sludge accumulate, the variety of the species and biomass of benthos could decrease. On the other hand, if the current flow is excessively rapid, the sediments at the sea bottom become unstable resulting in the possible decrease of the variety of species and biomass of the benthos. Therefore, in order to maintain the fishery resources or biodiversity, promoting a balance between the sediment stability and current of the water flow should be given attention.

Diagnosing the bivalve resources

Tidal flats could encompass few juvenile bivalve resources due to less number of drifting larvae or when the settlement of the larvae on the sea bottoms could not occur or when the larvae decrease after settlement. The presence of few drifting larvae could be mainly because of insufficient parent bivalve or interceptions of the drifting larvae network within the life cycle of bivalves (**Fig. 2**, **Fig. 3**). The reasons for the unsettlement of larvae or depletion of juvenile bivalves could be silt accumulation, low oxygen content of the water or high water temperature. On the other hand, in the case of tidal flats having sufficient juvenile bivalve resources but production is still low, it is necessary to identify the principal causative factors such as predators or extreme environmental changes. If there are no conspicuous factors, the reasons could be considered as unsuitable sediments, inadequate water quality, and low oxygen content in the water, among others.

Fig. 2. Networks of bivalve larvae *(Source: The Guideline)*

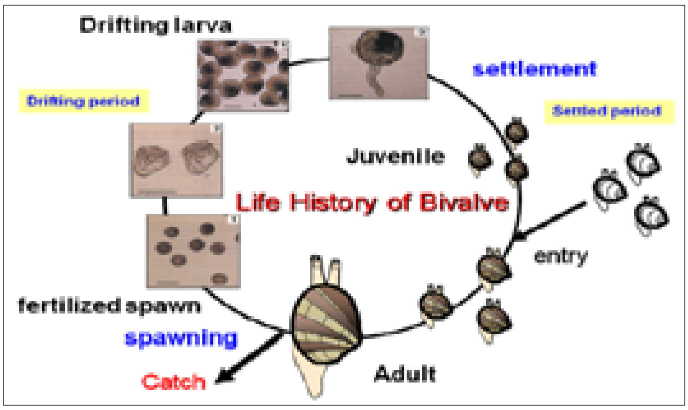

Fig. 3. Life History of bivalves *(Source: The Guideline)*

Countermeasures for Improving the Productivity of Tidal Flats

The larvae networks (in wide-ranging waters)

The larvae of bivalves drift for several days and sometimes spread to wide areas according to the natural and geographic conditions of the wide-range of waters. To maintain a sufficient supply of bivalve larvae in such case, and to increase stable bivalve production in tidal flats, not only the countermeasures within each tidal flat but also the integral countermeasures for the adjacent tidal flats should be promoted from the point of view of wide-ranging larvae networks.

Improvement of the environment of fishing grounds

Installation of bamboo fences and covered nets in fishing grounds

It is necessary to improve relevant and nearby areas that also influence the life cycle of bivalves, such as the areas where the parent bivalves as sources of the larvae supply inhabit in high density, the larvae settlement areas as well as the breeding areas of juvenile bivalves.

In general, the settlement rate of drifting larvae could be increased through the installation of bamboo fences (**Fig. 4**), while the survival ratio of juvenile bivalves could be improved by the installation of covered nets (**Fig. 5**). Nevertheless, such bivalve conservation management has to take into consideration the season and the specific sites of the installations as well as maintenance, because installation of bamboo fences and covered nets may also have negative influence on the settlement of the drifting larvae and the survival of juvenile bivalves due to the attachment of periphytons on the bamboo fences and covered nets or the accumulation of sediments.

Fig. 4. Bamboo fence installed to promote settlement of drifting larvae *(Photo: The Guideline)*

Fig. 5. Installation of covered nets to protect the juveniles of short-necked clams *(Photo: The Guideline)*

Sand capping, waterway dredging and cultivation of sea bottoms

Countermeasures such as sand capping of sea bottoms are often adopted to improve the muddy or stiffened sea bottoms. By covering an area with favorable sand, the sea bottom that has become muddy could be improved. On the other hand, in cases where there is little exchange of water current flow, artificial waterways could be dredged to provide channel for the nutrients to flow or to prevent the accumulation of drifting mud on the fishing grounds.

Furthermore, interfering with the conditions of the fishing grounds by cultivating the sea bottom would improve its environmental conditions considering that this would loosen the hardened sediments, promote removal of unwanted algae, deoxidize the beds near the sea bottom surface, and dissolve the nutrients necessary for the growth of the bivalves.

Countermeasures against predators and harmful microorganisms

Since the effect of predators such as the manta ray as well as the sea snail, *Neverita didyma* and starfish on the bivalve resources could vary according to the location and season, it is necessary to gather information about the influence of such predators and the effect of the countermeasures in neighboring waters. On the other hand, harmful microorganisms could prey on the bivalves indirectly through the sediments or waters in the tidal flats. In particular, large concentration of harmful microorganisms (algal bloom or red tide) in the waters could affect the bivalve resources. In order to eliminate harmful microorganisms from the sediments of the sea bottoms, countermeasures by manually removing them and cultivation of the sea bottoms are conducted by the Japanese fishermen. As for the occurrence of harmful microorganisms in the waters such as “red tide”, although studies on countermeasures are advancing, still there are no practical measures to prevent the occurrence of such phenomenon in advance.

Fishing activity management

In promoting fishing activity management, two factors should be taken into consideration. One is “entry management” which could be achieved by preventing the over-fishing of parent bivalves in order to increase the larvae supply, and “growth management” by preventing over-fishing of immature or young adult bivalves. Entry management is aimed at allowing parent bivalves to spawn in fishing grounds. On the other hand, growth management is aimed at preserving immature or young adult bivalves and securing their growth up to the later stage when the larvae could be considered as parent bivalves and capable of spawning sufficiently. In the case of growth management, the density of the parent bivalves and the degree of their maturity should be taken into consideration.

Handy Method of Monitoring Bivalve Distributions

In Japan, distribution survey of bivalve resources such as the short-necked clam is one of the most important surveys conducted to advance resources management. Distribution surveys are usually implemented in the same sites and the same period every year, even if a distribution survey done only once could result in sufficient data, because changes of the bivalve resources could be visually monitored. Distribution surveys of bivalve resources could be easily implemented, provided that manpower and several handy tools (**Fig. 6**) are readily available for sampling and analyzing the samples. In Kumamoto Prefecture located in the southwest of Japan, distribution surveys for bivalve resources are conducted every year at each fishing ground in tidal flats with the cooperation of the fishermen, staff of fishery research stations and staff of local government officers (**Fig. 7**).

The tools for sampling include a square frame, small shovel, sieve, plastic bag, shoulder bag, and neutral formalin (to be used in case storing of samples for later analysis is necessary). In addition, the tools for analyzing samples as in the case of short-necked clam distribution survey conducted at the Kumamoto Prefecture, include a sieve, Petri dish, pair of tweezers, and pair of calipers. For analyzing the samples, after selecting short-necked clams from the samples and measuring the length, alive and dead samples are determined by smashing the shells. Only data from live samples are considered, and from such samples, the distribution density and length distribution of bivalves

Fig. 6. Survey tools for sampling and analyzing samples
(Photos: Resource Management Manual of Short-necked Clams in Kumamoto Prefecture, Kumamoto Fisheries Research Center)

Fig 7. Procedures in sampling short necked clams *(Photos: Resource Management Manual of Short-necked clams in Kumamoto Prefecture, Kumamoto Fisheries Research Center)*

in certain sampling points are calculated to obtain the basic data for resources management.

Although bivalve resources may be only one of the marine resources in tidal flats, a distribution survey of bivalves is important considering that bivalve production could serve as a typical index of productivity of tidal flats, and distribution survey could be relatively an easy method to undertake.

Management of the Matsuo Tidal Flat: An Example of Management Activities

Description of the Matsuo tidal flat

Matsuo District in Kumamoto Prefecture is a small fishing village facing the Ariake Sea, where about 120 fishermen are engaged in part-time farming and part-time fishing. The main fishing activity in the district is gathering bivalves mainly the short-necked clams. In a tidal flat that expands from river estuaries, short-necked clam fishery is carried out only in sand-capped fishing grounds of about 25 hectares which have been improved by the local government in the late 1980s and early 2000s (**Fig. 8**). In the Matsuo District, the productivity of short-necked clams is maintained every year through appropriate management activities conducted by the fishermen themselves.

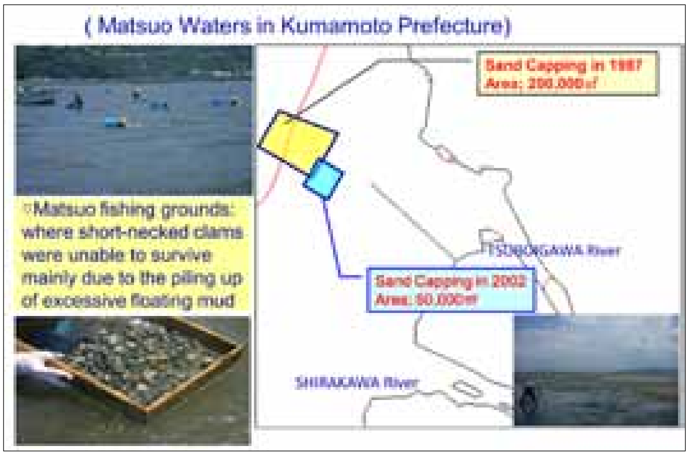

Fig. 8. Sand-capped area in Matsuo tidal flats
(Sources: Kumamoto City and Matsuo Fishery Cooperative)

Trend of short-necked clam production

The history of tidal flat management adopted by the fishermen of Matsuo Fishery Cooperative in the Matsuo District and the trend of short-necked clam production are illustrated in **Fig. 9**. The Matsuo tidal flats had been favorable fishing grounds of short-necked clams for a long time. However, production of short-necked clams had decreased during the 1980s mainly because of the outflow of drifting mud from the rivers as well as from other tidal flats near the Ariake Sea. As an initial remedy, the fishermen transplanted mother clams in the tidal flats to increase the short-necked clam resources, but the resources did not recover. Recognizing that the environmental conditions of fishing grounds for short-necked clams had worsened, the fishermen initiated a tidal flat capping in 1982 using sand, which in effect had been continued for a few years. However, during the 1990s there were still almost no production of short-necked clams, therefore, as their next self-managed action to improve the productivity of the tidal flats, the fishermen in Matsuo implemented management activities in the sand-capped fishing grounds. As a result, from 1999, the next year of implementation of the fishermen's self-

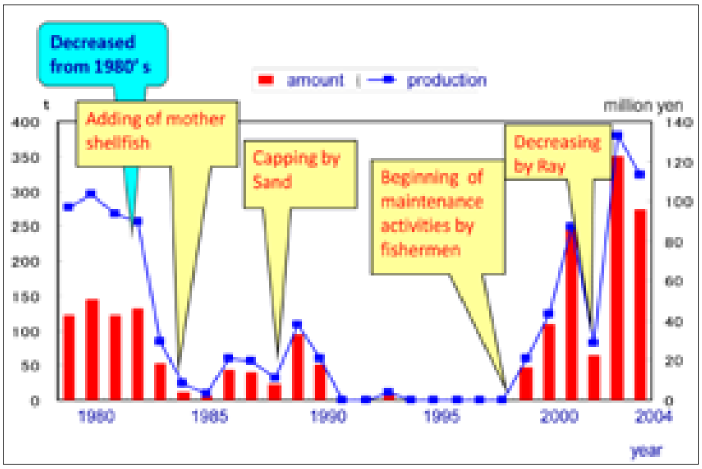

Fig. 9. Trend of short-necked clam production in Matsuo tidal flats *(Sources: Kumamoto City and Matsuo Fishery Cooperative)*

management activities that included installation of bamboo fences and placement of covered nets (**Fig. 10a** and **Fig. 10b**), production of short-necked clams had increased.

In the midst of the fishermen's intensified management efforts, the short-necked clams in Matsuo's improved fishing ground were devastated by manta rays in 2002. It was not initially known that the rays ate the short-necked clams until the fishermen caught a number of rays and discovered a lot of short-necked clams in their stomach. The fishermen therefore, started to catch the rays to protect the short-necked clam resources. Since then, the resources of short-necked clams have recovered and production of the clams has been sustained to a level of about 300 tons per year.

Fishing ground management by fishermen

In the Matsuo District, installation of bamboo fences to promote the settlement of drifting larvae, installation of covered nets to protect the juvenile short-necked clams and transplantation of juvenile bivalves to disperse the high density of juvenile short-necked clams, have been implemented as a fishing ground management by the fishermen themselves. After the rays appeared, countermeasures were soon taken to reduce the pressure by catching the rays. Furthermore, fences using poles were installed to protect the coastal fisheries from floating driftwood and garbage flowing from the rivers. In addition, the fishermen participate in patrolling the fishing grounds to prevent poaching of the bivalves.

Resources management activities

The Fishery Cooperative of Matsuo has been strengthening its efforts in bivalve resource management after the implementation of the fishing ground management and observing that the resources have started to recover. Concretely, field surveys on the distribution of short-necked clam resources have been carried out to assess the status of the resources at important periods such as before the start of fishing activities and during the period of spawning in spring and autumn of each year. Moreover, fishing activity policies and plans for a year are decided among the fishermen based on the results of the field surveys.

Such procedures have motivated the fishermen in voluntarily managing the fishing grounds by themselves, without being compelled by the Fishery Cooperative and the Kumamoto City Government. The resources management effort of the Matsuo fishermen could be considered a typical example of successful resource management activities which are carried out by the fishermen, resulting in the improvement of the fishery resources through proper fishing ground management activities.

Fig. 10a. Bamboo fence installed to promote settlement of drifting larva *(Source: Kumamoto City and Matsuo Fishery Cooperative)*

Fig. 10b. Covered net to protect the juvenile short-necked clams *(Source: Kumamoto City and Matsuo Fishery Cooperative)*

Change in fishermen's attitude

Fishermen in the Matsuo District have recognized that fishing ground management is an important aspect of fishery management together with resources management. Through the implementation of management activities, the fishermen became aware of the fact that the favorable environments of short-necked clam fishing grounds are developed by the short-necked clams themselves. When there are less short-necked clams in tidal flats, the once favorable fishing grounds are changed into waste grounds, but it is possible to support favorable fishing grounds through the efforts of fishermen within their capabilities so that short-necked clams could continue to breed.

Discussion

1. Tidal flats as well as seaweed beds and coral reefs have various important functions and values, and the values of tidal flats are strongly influenced by the productivity of the fishery resources.
2. "Fishery resources management" and "Fishing grounds management" are the two wheels of the same vehicle for improving the productivity of tidal flats.
3. Foremost, the fishermen have been using their fishing grounds, showing that the presence and activities of fishermen are indispensable for the effective management of fishery resources and fishing ground in tidal flats.

Way Forward

1. Considering that the coastal environments are becoming worse year by year, the need to modify policies from being protection-oriented to being regeneration-oriented has become an urgent concern.
2. The aforementioned bivalve resource distribution survey could be a tool which the countries in the Southeast Asian region could adapt in assessing their respective tidal flats, and is relatively easy to implement.
3. Management of tidal flats mainly by the fishermen could be feasible by implementing an activity first at one model site with the cooperation of administrators and researchers who have interest in the management activities of the pilot site in each country.
4. SEAFDEC intends to support a program on the rehabilitation of fishery resources and their habitats/ fishing grounds starting in 2010 under the Japanese Trust Fund V.

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