DEVELOPING A STOCK ENHANCEMENT PROGRAM BASED ON ARTIFICIAL SEEDLINGS: ACTIVITIES OF THE JAPAN SEA-FARMING ASSOCIATION (JASFA) IN THE LAST DECADE

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ABSTRACT

The Japan Sea-Farming Association (JASFA) was established in 1963 as the Seto Inland Sea Farming Association and reorganized in 1979 as JASFA. JASFA has been engaged in the task of developing techniques relating to the farming fishery process. The term of farming fishery, in Japanese, Saibai-Gyogyou, means the ideal fishery system which is composed of stock enhancement and fishery management. Farming fishery is based on the artificial seedlings technique which was constructed on some components, i.e., broodstock management, induced spawning, incubation of fertilized eggs, and rearing of fry and juveniles. Stock enhancement of the farming fishery was constructed on the intermediate rearing in nursery grounds to acclimatize artificial juveniles to the natural environment in releasing areas, seed release, management for released artificial seed in prerecruit periods, and fishery management.

INTRODUCTION

Oshima (1984) reviewed the historical development of the Japan Sea-Farming Association as follows. In 1961, the Japan Fisheries Agency (JFA) established a plan to promote coastal fisheries by developing stock enhancement technology utilizing potential and untapped productivity of the sea. The plan was put into action in 1962, and the Seto Inland Sea was selected as a model littoral zone of stock enhancement for the ranching of juveniles. The Seto Inland Sea Culture Fishery Center was established as the base of operation for the intended technological development. Furthermore, the Seto Sea Fish Farming Association was established in 1963, which operated the center by commission from the government. This name was derived from the abbreviation of “Fish Farming Promotion Actualization Center.” This is the first time that “fish farming” was used. Recently, the term “farming fisheries” and “sea farming” have been used to express fish farming. In this paper, farming fisheries consists of stock enhancement based on artificial seedlings. In 1978, the Seto Inland Sea Fish Farming Association was reorganized and renamed the Japan Sea-Farming Association (JASFA) to develop the needed technology and to overcome the transitional period of financial difficulties. JASFA is mandated by JFA to develop stock enhancement techniques based on artificial seed production. The system and administrative roles of farming fisheries are summarized in Figure 1. The national government has been engaged in the technological development of highly migratory and migratory species. The prefectural governments are playing important roles in the development and commercialization of migratory and nearshore species. Public corporations and fishery cooperatives are organizations in charge of operating farming fisheries for coastal species, except for the technological development of some species such as the Japanese spiny lobster. The national government takes responsibility for the technological development of nearshore species such as the Japanese lobster because of the difficulties and high risks involved which are beyond the capabilities of prefectural governments (Matuoka 1996).

Figure 2 shows the locations of 16 national sea-farming centers operated by JASFA. National centers are located over a wide area ranging from the Akkeshi Station, Hokkaido, in the subarctic zone (close to latitude 43° N), to the Yaeyama Station,
Progress of artificial seed production, release, and catch

The technology of artificial seed production is making steady progress. In 1995, seed for stock enhancement was produced by 284 facilities for 80 species. The total production number was 3640 million individuals and the total release number was 11 billion individuals including natural seed (Morita 1997). The numbers of artificial seed production and release in 1995 were 3600 million for 80 species and 3000 million for 69 species, respectively. The role of JASFA, as shown in Figure 1, is the technological development for highly migratory species, migratory species, and coastal water

Okinawa, in the subtropical zone (close to 24°N). Thirty-nine prefectural governments have been constructed and are operating 53 prefectural sea-farming centers (Fig. 3). Public corporations and fishery cooperatives have constructed sea-farming centers.

Process of technological development in farming fisheries

The process of technological development in farming fisheries is schematically described in Figure 4, which shows the case of Atlantic bluefin tuna (Fushimi et al., in press.). This figure focuses on artificial seed production. The technique of artificial seed production is composed of four parts, i.e., broodstock management, induced maturation and spawning, larval rearing, and live feed culture. Artificial seed produced in sea-farming centers are transported to release areas, and then are reared in nursery grounds to acclimatize to the natural environment, or released immediately if the size of juveniles is adequate for survival in the natural environment. Fishery management methodology has to apply to artificial seed in pre-recruit and post-recruit periods in order to maintain optimal yield from them.

Figure 1. Schematic explanation of roles in farming fisheries in Japan (after Japan Fisheries Agency). JASFA denotes Japan Sea-Farming Association.

Figure 2. Locations of the JASFA Stations.
species. Target species number and number of seed production of JASFA in 1995 were 36 species and 120 million individuals, respectively, excluding Mollusca and Echinodermata (JASFA 1997a). Public corporations and fishery cooperatives engaged in intermediate rearing and releasing operations numbered 1387.

Over 1 million seed each are produced for 33 species, and over 10 million seed each for 11 species. They are three species of Pisces: Japanese flounder Paralichthys olivaceus, red sea bream Pagrus major, and black sea bream Acanthopagrus schlegeli; three species of Crustacea: kunuma prawn Penaeus japonicus, swimming crab Portunus trituberculatus, and speckled shrimp Metapenaeus ensis; four species of Mollusca: scallop Patinopecten yessoensis, short-neck clam Tapes philippinarum, Yeso abalone Nardotis discus hannai, and disk abalone Nardotis discus discus; and one species of Echinodermata: northern green sea urchin Strongylocentrotus intermedius. Annual fluctuations of the number of seed production, release, and catch in some species are described as follows:

**Japanese flounder Paralichthys olivaceus**

Figure 5 shows annual fluctuations of the number of seed production, release, and catch of Japanese flounder. The numbers of seed production and release are increasing steadily, and quantity of seed production and releases have surpassed that of red sea bream in 1995. Quantity of seed production in 1995 was 31 million individuals and release was 23 million individuals, respectively. Mean annual seed production and release numbers are 19 million and 13 million individuals, respectively. Mean annual catch is 6800 tons, which fluctuated between 5100 (1990) to 8200 (1986) tons, and catch has been increasing since 1991.

**Red sea bream Pagrus major**

The technological development of farming fisheries in Pisces is represented by red sea bream, and good results in the technological development of this fish have been leading new trials for another species. The numbers of seed production, release, and catch of red sea bream are shown in Figure 6. Mean annual seed production and release numbers are 26 million and 19 million individuals, respectively.

Mean annual catch is 14,000 tons, and annual catch fluctuated between 13,000 tons (1988) to 16,000 tons (1984). Recently, it has become apparent that sport fisheries land similar quantities; thus, regulation and symbiosis with sport fishing are new problems to solve (Imai 1994, Imai et al. 1994, Imai 1996, and Shinoda 1997).

**Black sea bream Acanthopagrus schlegeli**

The numbers of seed production, release, and catch of black sea bream are shown in Figure 7. Mean annual seed production and release numbers are 9 million and 6 million individuals, respectively.

Mean annual catch is 3900 tons, and annual catch fluctuated between 3600 tons (1994) to 4,300 tons (1984). This fish encounters the same
Figure 4. Schematic explanation of technological development in stock enhancement of Atlantic bluefin tuna (after Fushimi et al., in press).
problems as red sea bream, i.e., regulation and symbiosis with sport fishing.

**Kuruma prawn Peneaus japonicus**

The technological development in farming fisheries of kuruma prawn has attained the role of pioneer in this field accompanied by red sea bream. The first guidebook publication of the kuruma prawn farming fisheries was issued by JASFA in 1986 (Kurata et al. 1986).

The numbers of seed production, release, and catch of the kuruma prawn are shown in Figure 8. Mean annual seed production and release numbers are 510 million and 305 million individuals, respectively.

Mean annual catch is 3000 tons, and annual catch fluctuated between 2300 tons (1993) to 3400 tons (1984). It seems that abundance of the kuruma prawn has been recovering by farming fisheries, because the mean annual catch had
declined to 1000 tons in the late 1960s. The case of Hamana Lake, a brackish lake in Shizuoka prefecture, is well known (Fushimi 1983).

Swimming crab *Portunus trituberculatus*

The technological development of farming fisheries in the swimming crab has played an important role in this field, too. A monograph and manual of seed production was published by JASFA recently (Hamasaki 1996, JASFA 1997b).

The numbers of seed production, release, and catch of the swimming crab are shown in Figure 8. Mean annual seed production and release
numbers are 52 million and 28 million individuals, respectively.

Mean annual catch is 3900 tons, and annual catch has fluctuated between 3000 tons (1993) to 5300 tons (1986). Mean annual catch in the late 1960s declined to nearly 1000 tons, thus abundance of the swimming crab has recovered by farming fisheries, too.

New frontier of farming fisheries

Exploitation of the field of farming fisheries has been continuing within JASFA, using the accumulated experiences and knowledge of over 30 yr. Technological developments in various JASFA activities are making steady progress, some of which are briefly described below.

Development of biocontrol for seed production of the swimming crab

Results of seed production of the swimming crab is influenced by the flora of microorganisms. Bacterial strain PM-4, isolated from a crustacean culturing pond, improved the growth of swimming crab larvae and repressed growth of Vibrio anguillarum in seawater. Methodology to apply this finding has been developed, and production of swimming crab larvae was greatly increased by adding the bacterial strain PM-4 to their culture water (Nogami and Maeda 1992, Nogami et al., in press). It is expected that this will be used in crustacean seed production.

Development of rearing larvae of Japanese spiny lobster Panulirus japonicus

Since 1899, many Japanese marine biologists have tried to rear phyllosoma of P. japonicus: the first success to 3 instar was attained in 1958 (Nonaka et al. 1958). After that, the rearing period was gradually improved, and last stage phyllosoma was attained in 1981 (Inoue 1981). The first successful rearing of juveniles was realized in 1989 (Yamakawa et al. 1989, Kitaka and Kimura 1989). Success in rearing larvae of P. japonicus was not reproduced due to difficulties in rearing. JASFA established the Minami-Izu Station in 1988, to engage in the development of rearing larvae of P. japonicus. Subsequently, the JASFA Minami-Izu Station has attained the complete rearing of phyllosoma of the lobster. It seems that development in hardware of the rearing system for phyllosoma is the main reason for this success (JASFA 1993). The JASFA Minami-Izu Station had produced 134 puerculi and 48 juveniles in 1994, and 284 puerculi and 114 juveniles were produced during 1990-1996.
Development of broodstock management and rearing larvae of Pacific bluefin tuna *Thunnus thynnus*

In JASFA, the development of broodstock management of Pacific bluefin tuna (PBT) had started in 1985 at the Yaeyama Station in Okinawa, established in 1985. Broodstock of PBT was reared in net cages, and we observed very rapid growth rate, but very low survival rate, due to high water temperature in the subtropical area. The JASFA Amami Station further north was established in 1995, and has been engaged in the development of broodstock management of PBT.

The first spawning success of PBT broodstock of JASFA was attained in 1997. The first successful spawning was observed for the 9-10 age group reared in 40-m round-shaped net cages 10 m deep on 13 May 1997, and 1,500,000 fertilized eggs were collected from this broodstock. Spawning of 7 age groups had been induced by rising water temperature in early July 1997, and 3,600,000 fertilized eggs were collected in just 2 days. Subsequently, egg quality of these fertilized eggs was examined. Experimental rearing of PBT larvae was begun at the Amami Station in 1997 (Yamazaki 1997).

Development of farming fisheries of Pacific herring (resident type) *Clupea pallasii*

Pacific herring *Clupea pallasii* has shown drastic stock abundance fluctuation, especially in the Hokkaido-Sakhalin stock. Local stock of Pacific herring (resident type, RT herring) has been inhabiting off eastern Hokkaido; their spawning ground is distributed in the Zostera zone of brackish lakes, i.e., Notsuke Bay, Furen-ko, Akkeshi Bay, and Yudo-numa, and their migrating area is limited to the coastal area of eastern Hokkaido. The JASFA Akkeshi Station, established in 1981, has been engaged in the technical development of farming fisheries for RT herring since 1983 at Notsuke-ko. Population parameters of released RT herring were estimated recently, and the stock abundance of RT herring is recovering since artificial seed release was begun, with an estimated recovery rate at 6%. It is a successful example of the technological development carried out by the JASFA Akkeshi Station on seed production, intermediate rearing, large scale marking techniques for oolith using Alizarin-complexone (ALC), application of statistical survey techniques for the fisheries market, and foundation of a cooperative system for stock enhancement trials by fishery cooperatives, administration, and research.

Development of seed production and release of coonstripe shrimp *Pandalus hypsinotus*

Coonstripe shrimp *Pandalus hypsinotus* is one of the important target species for the deep sea pot fisheries, and the JASFA Obama Station, established in 1983, has been engaged in the technical development of this shrimp. The JASFA Obama Station has developed techniques for artificial seed production and subsequent release in 200 to 300 m water depths. Survival rate of seed production and density of post-larvae have been consistently attained at 70% and 7000 individuals/m³, respectively. Experimental artificial seed release has been carried out at Toyama Bay in 200 to 300 m depths, and results of this experiment point to the success of stock abundance recovery by artificial seed release.

Many species of the *Pandalus* group are important commercial fisheries, and technological developments by the JASFA Obama Station have attracted the attention of people concerned with the deep sea pot fishery. The technique of seed production for sandfish *Arctopous japonicus* developed by the JASFA Notojima Station is unique. Larvae have been reared by using natural plankton, composed mainly of Copepodite, collected by nighttime. Trials of stock enhancement based on seed release have been continued in Akita Prefecture, because of the drastic decline in abundance.

According to this brief overview of activities in farming fisheries, it is evident that the presence of farming fisheries is essential for exploiting and maintaining marine resources by the Japanese coastal fisheries. This review focuses on an overview of the main activities and some new frontiers. We have faced many problems to solve in order to establish the needed technology of farming fisheries, and continuing efforts are required.
ACKNOWLEDGMENTS

I wish to express sincere thanks to Dr. Izumi Nakamura and Mrs. Reiko Nakamura, Kyoto University, for editing scientific and English names of aquatic organisms. I thank the technical staff of JASFA, particularly Kinya Nogami, Tetsuo Morita, Syunekai Masumoto, Shigenori Suzuki, Masato Aritaki, Keita Hattori, Taizo Morioka, and Shintaro Sekine for helpful discussions.

LITERATURE CITED


EFFECTS OF COVERING A TIDAL FLAT WITH SAND FOR STOCK ENHANCEMENT OF TONGUEFISH: A FEASIBILITY STUDY AT ARIAKE SOUND IN KYUSHU, JAPAN

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ABSTRACT

Ariake Sound is characterized by a high tidal range of about 6 m at the innermost part, and is known to have high productivity of commercially important species. However, the production of certain species has shown decreasing trends due to overfishing and deterioration in environmental conditions. Tonguefish are important species for gill net and trawl fisheries in this sound because of their high commercial values, but the annual catch of Cynoglossus abbreviatus has been decreasing markedly during the last decade. We assumed that covering the muddy tidal flat with sand as a means of habitat restoration would enhance the stock of these fish. In order to study the effects of sand covering on growth and survival of tonguefish C. abbreviatus and C. joyneri juveniles, we carried out periodic samplings by small beam trawl at the innermost part of the sound. A sand-covered area made in 1991, at about the lowest low water level, to increase the production of short-neck clams was selected as the survey area. The gear was towed along the lines set on the sand-covered area and a nearby muddy area as a control. The periodic samplings revealed that occurrence of C. abbreviatus in the sand-covered area increased with growth, but was not the case for C. joyneri. Since the large juveniles of C. abbreviatus changed their prey animals from copepods to gammarids and mysids which were known to be abundant in the sandy area, it was suggested that covering the mud with sand provided beneficial effects at least for the growth and survival of this species.

INTRODUCTION

Ariake Sound in Kyushu is characterized by a wide tidal range of 6 m at the innermost part, and a large (263 km²) tidal flat that accounts for 40% of the Japanese tidal flats (Sugano 1981). High productivity of this sound due to these topographic features supports various kinds of fisheries including laver culture whose annual output is about 40 billion yen (ca. $330 million).

Fauna in the sound is unique and many species exist only here in Japan. Some of these species are regarded as continental relics, including the tonguefish Cynoglossus abbreviatus. The fishing of tonguefish is conducted only in the sound and a part of the Seto Inland Sea (Ohsaka and Koshiishi 1997). Another tonguefish, C. joyneri, inhabits the coast in the southern part of Japan, but some taxonomic studies are still ongoing since some morphological differences were found between the fish in the sound and in other waters. These two species, together with C. robustus, are important species for gill net and trawl fisheries in the sound because of their high commercial value, but the annual catch of these fishes has been decreasing during the last decade.

The decreasing trends in catches of tonguefish and other commercially important species can be attributed to overfishing and deterioration in environmental conditions. The reduction of sandy tidal flats is thought to be one of the serious environmental changes. An attempt to cover a muddy tidal flat with sand to restore the production of the short-neck clam has been carried out, and some positive achievements have been demonstrated (Ueda and Yamasita 1997). The sand covering of the muddy flat is predicted to make conspicuous changes in terms of the burrowing condition and food organism distribution for tonguefish juveniles that inhabit the tidal flat as their nursery ground. This research is to study the effect of this manipulation on the enhancement of these species.
fish. We hypothesized that covering the muddy flat with sand produces positive effects on the growth and survival of tonguefish by means of beneficial change in feeding conditions.

MATERIALS AND METHODS

A sand-covered area made from 1991 through 1995 in an attempt to increase the production of short-neck clams was selected as the survey area. The muddy area of 300 m by 900 m at about the lowest low water level was covered with a sand layer 40 cm thick (Fig. 1). Sampling was carried out on the days of the spring tide of May, June, and August in 1994 and 1995. A beam trawl net with a 2-m-mouth width and 2.1-mm-mesh aperture was used as the sampling gear. The net was towed by a boat along the two 200-m lines, one set on the sand-covered area made in 1991 and the other set on a nearby muddy area as a control (Fig. 1). Samplings by the beam trawl net along each line were performed five times serially, two times at flood tide, one time at high tide, and two times at ebb tide when the water depths were about 2, 3.5, and 5 m, respectively. Since towing a beam trawl net by boat could not be performed properly when the water depth decreased below 2 m, a small set net with a 10-m wing was also used to catch fishes.

Some sediment samples were collected to analyze the particle size by wet sieving and the distribution of possible prey for tonguefish. The digestive tract contents of tonguefish collected in the previous survey were examined to study prey animals.

RESULTS AND DISCUSSIONS

Occurrence, distribution, and growth of tonguefish at the northeastern part of the sound

Our previous survey on the distribution of tonguefish from 1990 through 1993 revealed that four species of Cynoglossidae juveniles, i.e., *Cynoglossus robustus*, *C. abbreviatus*, *C. joyneri*, and *C. interruptus*, occurred in water shallower than 25 m at the northeastern part of the sound. Within the intertidal zone, *C. abbreviatus* and *C. joyneri* were numerically dominant, so we focused our study on these two species. From the occurrence of juveniles less than 15 mm, we predicted that the periods for settlement of *C. abbreviatus* and *C. joyneri* were from March to May and from July to October, respectively. Older 0-group (0-yr-old) *C. abbreviatus* seemed to migrate offshore or into deeper parts of the sound, because the density of the juveniles in the shallow area decreased to nearly zero in winter (Fig. 2a). This seasonal migration was confirmed by the information obtained through a questionnaire on tonguefish occurrence sent out to fishermen (Ohsaka and Koshiishi 1995). Contrary to this, seasonal change in the density of *C. joyneri* was rather low in general. Though there was a certain depth migration, 0-group *C. joyneri* inhabited the area shallower than 10 m during their first year (Fig. 2b). Mean body length of 1-yr-old *C. abbreviatus* collected in the early settling season was about 150 mm and that of *C. joyneri* was 130 mm (Koshiishi et al. 1994).
Figure 2. Seasonal change in main distribution area of 0-group tonguefish in northeastern part of Ariake Sound. a: *Cynoglossus abbreviatus*, b: *Cynoglossus joyneri*. The dotted line indicates 5-m isodepth. Five sampling surveys were carried out from May 1991 through April 1992. Since the number of 0-group *C. abbreviatus* collected in February was few, no illustration was presented.

Distribution of tonguefish in the sand-covered area

The ground levels of the sand-covered area and the control (muddy) area were about 50 cm and 10 cm above the lowest low water level, respectively. More than half of the sediment on the sand-covered area consisted of medium and coarse sand, and about 70% of that in the control area consisted of particles less than 63 mm (Fig. 3). About 25 thousand fish of ca. 50 species were collected in our survey in 1994 and 1995 (Table 1). The fact that more than 90% of these fish were juveniles confirmed the importance of the tidal flat as a nursery habitat for fish, as pointed out previously by Uehida and Tsukahara (1955). Among these species, several gobiid species were numerically dominant. Cynoglossidae species were also collected in relatively large numbers.

Though the lines on the sand-covered area and the muddy control area were set closely, only 50 m apart, the majority of each demersal fish
Table 1. Fish species collected by small beam trawl net and set net in the sand-covered area and muddy control area in 1994 and 1995.

<table>
<thead>
<tr>
<th>Family</th>
<th>Species</th>
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<tbody>
<tr>
<td>Clupeidae</td>
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<td></td>
<td>Konosirus punctatus</td>
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<td>Ilisha elongata</td>
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<td>Engraulididae</td>
<td>Engraulis japonicus</td>
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<td>Plotosus lineatus</td>
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<td>Mugilidae</td>
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<td>Atherinidae</td>
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<td>Leiopterygidae</td>
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<td>Nibea albiflora</td>
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<td>Acanthogobius hasta</td>
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<td>Amblycepaenichthys hexanema</td>
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<td></td>
<td>Kareius bicoloratus</td>
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<td>Soleidae</td>
<td>Zebras zebra</td>
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<tr>
<td>Cynoglossidae</td>
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<td>Cynoglossus abbreviatu</td>
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<td>Tetraodontidae</td>
<td>Takifugu sanctoperus</td>
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<td>Takifugu rubripes</td>
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species was collected, throughout the survey period, in either the sand-covered area or control area (Fig. 4), indicating the strong effect of sediment condition on their distribution. As for Gobiidae species, almost all Favonigobius gymnauchen were collected in the sand-covered area while Acentrogobius pfaumii were collected in the control area. The tendency of one-sided catch in these species was recognized regardless of their size, or age. On the other hand, density ratios between the sand and control areas for juveniles of Acanthogobius hasta drastically increased with growth (Table 2). The juveniles collected in the sand-covered area were about 10% of those in the control area when less than 20 mm in body length, but became nearly 100% when they exceeded 60 mm.

As for Pleuronectiformes, almost all Japanese flounder Paralichthys olivaceus and stone flounder Kareius bicoloratus were collected in the sand-covered area (Fig. 4). Contrary to this, only a few C. joyneri juveniles were collected in the sand-covered area (Fig. 5). Though a few small juveniles were collected in the sand-covered area in August, the older 0-group fish were collected in the control area without exception. The juveniles of C. abbreviatu showed a similar distribution pattern to A. hasta. The percentage of juveniles collected in the sand-covered area increased with growth (Fig. 5, Table 2).

Figure 6 shows the body length frequency of two tonguefish species caught by the two sampling gears in 1994 and 1995. In June, the average body length of C. abbreviatu collected by beam trawl net in the sand-covered area was larger than that in the control area, and the differences were significant in both years. This is very interesting because no such results were obtained for C. joyneri. In August, the number of C. abbreviatu collected by beam trawl net decreased markedly, and the number collected by set net increased in turn. It is noteworthy that more than half of the C. abbreviatu collection by set net occurred when the water depth decreased to less than 1 m of ebb tide. These results suggested that C. abbreviatu juveniles expand their habitat from the muddy tidal flat to the sandy flat with growth. The increase in number of fish collected by set net in August may indicate that
Table 2. Mean density (N/100m²) of 0-group fish caught by beam trawl on the days of spring tide and respective mean body length.

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<tbody>
<tr>
<td>Acanthogobius hasta</td>
<td>1.6</td>
<td>1.2</td>
<td>0.3</td>
<td>10.2</td>
<td>13.6</td>
<td>1.1</td>
</tr>
<tr>
<td>Sand-covered area (S)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control (muddy) area (M)</td>
<td>15.2</td>
<td>5.8</td>
<td>0.3</td>
<td>157.2</td>
<td>26.7</td>
<td>1.4</td>
</tr>
<tr>
<td>S/M (%)</td>
<td>10</td>
<td>21</td>
<td>106</td>
<td>7</td>
<td>51</td>
<td>77</td>
</tr>
<tr>
<td>Mean body length (mm)</td>
<td>17.5</td>
<td>45.4</td>
<td>69.2</td>
<td>13.7</td>
<td>32.5</td>
<td>64.5</td>
</tr>
</tbody>
</table>

| Cynoglossus abbreviatus |          |          |          |          |          |          |
| Sand-covered area (S)   | 0.3      | 0.1      | 0.1      | 0.2      | 0.8      | 0.2      |
| Control (muddy) area (M)| 8.9     | 4.3      | 0.3      | 2.0      | 1.7      | 0.6      |
| S/M (%)                 | 4        | 2        | 15       | 8        | 45       | 36       |
| Mean body length (mm)   | 22.6     | 45.0     | 113.4    | 15.7     | 31.8     | 110.7    |

**Figure 4.** Cumulative catches of nine fish species by six serial samplings carried out in the sand-covered area (S) and nearby muddy control area (M). Average number per unit area of five to six tows in each sampling series was cumulated.
migration synchronized with the tidal cycle was not clear in May or June when the juveniles were still small. Compared with *C. abbreviatus*, the reverse pattern was true for *C. joyneri*. Few 0-group fish exceeding 100 mm in body length were caught in the sand-covered area, and the juveniles collected by net were the smaller ones.

Our laboratory experiment showed that the *C. abbreviatus* juveniles of about 40 mm in body length could burrow in fine sand, but could not when the bottom was coarse sand (Ohsaka et al. 1997). This experiment also showed that the range of particle size in which 0-group *C. abbreviatus* could burrow widened with growth. The juveniles of 70 mm were found to show high burrowing rates in coarse sand as well as in fine sand. Figure 7 shows the relative ratios of the densities of 0-group tonguefish in sandy and muddy areas which was calculated from the number of fish caught by beam trawl net in our previous survey in 1991 and 1992. Sediment was classified into two categories, i.e., sand and mud, along the lines of towing. The ratio of 0-group fish caught in sandy sediment tended to increase with growth in both *C. abbreviatus* and
**Figure 6.** Body length composition of 0-group tonguefish caught by beam trawl net and set net in daytime in the sand-covered area and the muddy control area.
Cynoglossus joyneri

<table>
<thead>
<tr>
<th>Month</th>
<th>BL (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>APR</td>
<td>71.4</td>
</tr>
<tr>
<td>FEB</td>
<td>64.7</td>
</tr>
<tr>
<td>OCT</td>
<td>35.4</td>
</tr>
<tr>
<td>AUG</td>
<td>30.6</td>
</tr>
</tbody>
</table>

Cynoglossus abbreviatus

<table>
<thead>
<tr>
<th>Month</th>
<th>BL (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FEB</td>
<td>161.2</td>
</tr>
<tr>
<td>OCT</td>
<td>139.6</td>
</tr>
<tr>
<td>AUG</td>
<td>95.9</td>
</tr>
<tr>
<td>MAY</td>
<td>26.6</td>
</tr>
</tbody>
</table>

Relative ratio of densities

Figure 7. Relative ratio of the densities of 0-group tonguefish caught by beam trawl net in our previous surveys in 1991 and 1992. Data from 25-35 samplings along lines distributed in northeastern part of Ariake Sound in each month were used.

C. joyneri. However the tendency was much clearer in C. abbreviatus than joyneri. These results coincided with the pattern of distribution of tonguefish juveniles in the sand-covered area.

Prey animals of the two tonguefish and their distribution

Prey animals of both C. abbreviatus and C. joyneri consisted of small crustaceans such as copepods, gammarids, and polychaetes (Fig. 8). Both species preyed mainly on copepods when their body lengths were smaller than 50 mm. C. abbreviatus preyed primarily on harpacticoid copepods compared to C. joyneri whose prey primarily consisted of calanoid copepods. The importance of copepods as prey had decreased in both species when their body lengths exceeded 50 mm. Gammarids and mysids became the main prey of C. abbreviatus. Contrary to C. abbreviatus, C. joyneri of over 50 mm preyed primarily on polychaetes.

We tried to compare the amount of food organisms distributed in the sand-covered area and control area. Using several samplers such as the core sampler, grab, and sled net, four series of sampling were carried out from May through July in 1995 and 1996. Unfortunately, no clear distribution pattern was found in gammarids, mysids, and cumaceas. However, a larger number of harpacticoid copepods was always found in the sand-covered area, and the reverse results were found for polychaetes.

Effects of sand-covering manipulation for tonguefish growth and survival

Our sampling survey revealed that C. abbreviatus inhabited the sand-covered area, and they passed by in tidal migration when their body
length exceeded 40 mm. In order to prove some beneficial effects of a sand-covering manipulation for the growth and survival of 0-group *C. abbreviatus*, the next two points must be elucidated: (1) the density of available prey in the sand-covered area is higher than the nearby muddy flat area; and (2) the 0-group fish in the sand-covered area actually preyed on food organisms inhabiting the area.

As for gammarid and mysid density, our data showed no consistent difference in densities between the sand-covered area and the control area. But this may be partly because the sampling size was not large enough and the particle size of the sand used for the short-neck clam project was too large for these crustaceans. Generally speaking, small benthic crustacean densities are higher in sandy sediments than muddy sediments (Horikoshi and Kikuchi 1976, Kikuchi 1985). We believe that the first point will be clarified if more samples are analyzed.

To illustrate the second point, *C. abbreviatus* juveniles collected by a 24-h serial sampling in June were analyzed for digestive tract contents (Table 3). All juveniles caught in the daytime and at night were analyzed together, since there was no clear diurnal change in the whole contents. Time interval of the sampling was changed from 1 to 4 h according to tidal periodicity. There was no difference in the digestive tract fullness index between the fish collected in the sand-covered area and the control area when fish
Table 3. Fullness index of digestive tract (dry content weight / dry body weight, %) of C. abbreviatus caught in the sand-covered area and the control area in June, 1995. The prey found as intact appearance was classified as undigested.

<table>
<thead>
<tr>
<th>Body length (mm)</th>
<th>Sand-covered area</th>
<th>Control (muddy) area</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No.</td>
<td>Whole</td>
</tr>
<tr>
<td>14.0 ~ 40.0</td>
<td>54</td>
<td>2.93</td>
</tr>
<tr>
<td>40.1 ~ 78.6</td>
<td>12</td>
<td>2.91</td>
</tr>
</tbody>
</table>

smaller than 40 mm were compared. However, for the larger juveniles, the amount of undigested contents of juveniles collected in the sand-covered area was clearly larger than that collected in the control area as shown in the fullness index of % dry weight of undigested content/dry body weight. Because the time interval was relatively short, we supposed that the amount of undigested prey in the digestive tract closely represented that of the prey ingested in the area where the juveniles were collected. Thus, the second point is partially explained.

Though our data is limited, we consider that covering the muddy flat with sand provided beneficial effects for the growth and survival of C. abbreviatus.

LITERATURE CITED


PROSPECTS IN STOCK ENHANCEMENT OF JAPANESE FLOUNDER

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ABSTRACT

According to fisheries statistics, there has been no significant increase in commercial catch of the Japanese flounder Paralichthys olivaceus during the past 40 yr even though releases of hatchery-reared juveniles started in 1977 and the numbers of juveniles released increased linearly to 22.6 million in total by 1995. The extensive studies conducted in many institutions to improve performance of the stock enhancement program indicate that: (1) the adaptability of reared juveniles to the natural environment is poor, (2) their mortality rate just after being released is extremely high due to cannibalism and predation from various animals, and (3) their growth depends on the availability of food organisms at the release site which may be limited and fluctuates annually. Recently, however, positive achievements have been obtained in some areas where larger-sized juveniles are released and strict management of the mixed stocks of released and wild is observed. On the other hand, mass releases of the hatchery-reared fishes are alleged to cause a variety of problems including: (1) spread of pathogens, (2) limited numbers of broodfish decrease genetic diversity, (3) genetic constitution and fitness of wild stocks are changed or diminished, and (4) impacts of mass releases on ecosystems are not well understood. In order to make stock enhancement not only economically but also scientifically sound, conservation of the biodiversity cannot be ignored. As a countermeasure to these issues, the Japanese government has initiated a new project to clarify genetic effects of stock enhancement on natural populations and interactions between the released and native populations.

INTRODUCTION

Faced with declining marine fish populations worldwide and an expanding world population, marine fish enhancement has been attracting global attention (Blankenship and Leber 1995). In Japan, stock enhancement programs were initiated by the government of Japan as a national project in the early 1960s in order to restore the stocks of commercially important marine species whose populations were declining due to overfishing, pollution, habitat degradation, or human influences. Technology developed in these projects has enabled us to produce large numbers of marine fish and shellfish larvae beyond vulnerable juvenile stages.

Mass releases of the hatchery-reared juveniles of Japanese flounder Paralichthys olivaceus widely distributed in coastal waters of Japan from Hokkaido to Kyushu began in 1977. Since then, numbers of juveniles released in all areas increased linearly to 22.6 million in total by 1995 as shown in Figure 1 (Fisheries Agency of Japan 1997). However, fisheries catch statistics (Ministry of Agriculture, Forestry and Fisheries 1997) show no significant change in commercial catch of this species during the past 40 yr.

In the case of stock enhancement of chum salmon Oncorhynchus ketae, more than half a century of hatchery releases in Hokkaido produced no evidence of an increased yield until the 1960s. But as the annual number of releases increased from 0.5 billion in the 1970s to 1 billion in 1982, the total numbers of catch started to increase gradually and reached up to 440% over the historic record of the pre-hatchery release period with the return rate of about 3% in 1990 (Kariyama 1994). Based on this achievement, some people believe the numbers of flounder released are not sufficient to expect a substantial increase in commercial catch.

In order to improve the performance of stock enhancement of flounder, extensive studies have been conducted in many national and
prefectural institutions, and universities. In this review paper, we examined the progress to date to clarify why stock enhancement of flounder has not shown clear-cut evidence for increased yields nationwide. Also, the future direction of this program is discussed including whether or not a large increase in numbers (up to billions) of juveniles released is feasible or has potential to obtain results similar to chum salmon.

PROGRESS TO DATE

As mentioned earlier, releases of over 20 million juveniles in waters along the entire Japan coast have shown no positive effect on commercial landings of this species. However, if the relationship between annual catch and number of juveniles released is examined by region (regions 1-8, Fig. 2), we can see a somewhat different picture. Annual catches show increasing trends in region 4, Southern Pacific Ocean, and region 8, Seto Inland Sea, as the numbers of juveniles released have increased (Figs. 3, 4). A common feature in these two regions is that the level of annual catches before the start of mass-releases was rather low compared with the remaining regions. To understand differences in results of juvenile flounder releases in regions 4 and 8 and other regions throughout Japan, it is instructive to examine progress made in the studies on biology and ecology of this species, and on fisheries management practices.

QUALITY AND FITNESS TO THE NATURAL ENVIRONMENT

Mass production of fry or juveniles is made possible by providing sufficient foods under intensive condition and by isolating them from predators. As a consequence, physically weak individuals which cannot survive in the wild and those having deformity and abnormal coloration of the body, etc. are produced. The most commonly observed problems in the production of flounder juveniles used to be albinism and ambicoloration (Seikai 1997). Also, it has been found that the juveniles reared with a formulated feed contain much higher levels of free non-essential amino acids in the muscle. Since free amino acids, especially non-essentials, stimulate the olfactory and gustatory senses of crustaceans, it is presumed that they are more vulnerable to predators. However, the composition of free amino acids can be changed within a week by feeding mysids instead of a formulated feed (Yoshinaga 1996). Likewise, quality of reared fish is improving due to progress in rearing techniques and improvements in feeds.
Figure 2. Coastal waters around Japan divided into 8 regions.

The life history of Japanese flounder has been well elucidated by exhaustive field and experimental studies (Minami 1997, Noichi 1997, Tanaka 1997). Generally speaking, the juveniles less than 70 mm in total length (TL) prey mainly on mysids and then become piscivorous depending on the availability of food organisms (Noichi 1997). According to changes in feeding behavior, they disperse from nursery grounds in coastal waters to offshore (Koshiishi et al. 1991). In addition, physiological and behavioral studies indicate that the released fish show poor swimming ability, peculiar feeding behavior, and lack of predator avoidance, which result in poor survival after release (Furuta 1996). Although the ecological mechanisms are not completely understood, it is reported that rearing fish under less intensive conditions or simulated natural conditions for a short period before release improves their fitness to the natural environment (Yamashita 1997).

ENVIRONMENTAL CONDITION OF RELEASE SITE

Growth of the released juveniles depends on the availability of food organisms such as mysids on the nursery ground, although mortality by starvation may be insignificant (Yamashita et al. 1994). Koshiishi et al. (unpublished data) have shown that abundance of mysids substantially varies annually and seasonally as shown in Figure 5. Also, it has been reported by Koshiishi et al. (1988) that density of mysids at the release site is drastically decreased within a day after mass releases of juveniles. Thus, it is apparent that the carrying
Figure 3. Annual catches of Japanese flounder and number of juveniles released in regions 1-4.

Figure 4. Annual catches of Japanese flounder and number of juveniles released in regions 5-8.
capacity of the nursery ground is limited and fluctuates annually. The availability of food organisms is a crucial factor to sustain good growth of juvenile flounder since they stay in particular nursery grounds until becoming piscivorous. This early marine-life behavior of Japanese flounder is different from chum salmon.

A major cause of the high mortality after the release of flounder is known to be predation by crustaceans and fishes including wild flounder (Yamashita et al. 1993), so that the presence of sandy ground providing a hiding place is also a critical element. To minimize predation problems, various measures are being practiced such as releasing small-sized juveniles (30-50 mm in TL) before wild flounder appear on the nursery ground, or raising juveniles to larger sizes (up to 100 mm in TL) which are less vulnerable to predation (Yamashita et al. 1993).

**FISHERY MANAGEMENT**

High survival and growth can be expected if large-sized juveniles are released according to the carrying capacity of a target nursery area having suitable habitat at a time when food organisms are abundant. Even though these factors are taken into consideration and the best methods are

![Figure 5. Annual and seasonal changes in the density of mysids.](image)

![Figure 6. Annual catch of Japanese flounder and number of juveniles released in Aomori Prefecture.](image)
employed in releasing juveniles, the results differ among regions. One of the reasons for the lack of success in many regions seems to be the bycatch of less valuable small-sized fish in commercial fishing.

As mentioned earlier, positive results for releasing juvenile flounder have been obtained in certain regions like the Seto Inland Sea. Additionally, positive relationships between the annual catches and numbers of animals being released in the other species such as red sea bream and crustaceans have been achieved in this region (Ogawa 1995). The Seto Inland Sea is a relatively closed area which limits migration of released animals out of this region. Also, self-imposed regulations by fishermen are well abided to not harvest animals less than certain sizes and to re-release them if captured.

So far, the most successful achievement has been attained in Aomori Prefecture. The annual catch of Japanese flounder in Aomori Prefecture used to be the highest in Japan (about 15% of the total catch in Japan) and it is designated as the prefecture's fish. However, the annual catch of over 1500 tons in 1976 dropped to 224 tons in 1989 (Fig. 6). In response to the drastic decline, the prefectural government implemented a guideline for fisheries management of this species with a consensus of the fishermen after laborious dialogues through the Fisheries Cooperative Associations. The guideline contains various regulations to protect the broodstock and juveniles of both native and released flounder, and designation of the important nursery grounds as a sanctuary. In accordance with implementation of this guideline, 2-4 million juveniles about 50 mm in TL have been produced using funds contributed by the fishermen (4% of income from flounder fishing) and have been released annually since 1990. The minimum size to be harvested was raised gradually from 25 cm in 1990 to 35 cm in 1995. As a result of these efforts, the annual catch of flounder has been linearly increasing and it surpassed the 1000-ton level (almost 5-fold increase in 7 yr) in 1996 (Aomori Prefecture 1997).

These results indicate that fisheries management is a key factor for successful stock enhancement activity. Also, the fact that positive results have been obtained in regions 4 and 8, where the annual catches before the start of stocking were relatively small or in Aomori Prefecture where the stock was depleted, indicate
the importance of the initial stock size for a successful stocking program, which in turn may indicate that the carrying capacity for juvenile flounder is limited and varies from region to region. Thus, unlike the chum salmon project, large increases in numbers of juvenile flounder for release in many regions may not be feasible. However, a substantial increase in size may be effective in certain areas if the production of larger juveniles becomes cost effective.

FUTURE DIRECTION

In Fukushima Prefecture, about 0.2-0.4 million juveniles having 70-100 mm in TL have been released annually since 1987 but so far have produced no evidence of an increased yield (Fig. 7). However, the detailed market survey along with field study indicate that the recapture rate of released flounder by year class in was in a range of 16-31% with average value of 24% for 4 yr (1987 through 1990) which is almost 8-fold higher than the return rate of chum salmon. The reasons for attaining a high recapture rate in Fukushima Prefecture are reported to be that the survival of released juveniles is high due to use of large-sized fish; mysids are abundant around the release sites; fishing effort for flounder is intensive; and the fishermen refrain from harvesting flounder less than 30 cm in TL (Fujita et al. 1993). They also made a cost-benefit analysis for the entire operation in Fukushima Prefecture, and found that the flounder stocking resulted in annual profits of $410-670 thousand assuming wholesale prices of flounder for 1-yr-old fish and for 2-yr-old fish were $21 and $33/kg, respectively, and the benefit was 2-3 times higher than the entire costs of juvenile production and release. This result agrees very well with that of a market survey conducted by the Japan Sea Farming Association which indicates that stock enhancement of flounder can pay off if the recapture rate exceeds 20% (Furumawa 1994). Fujita et al. (1993) suggested that much higher profits can be obtained if harvest restrictions of 0-yr-old flounder are more strictly observed by fishermen because its wholesale price is only about $4/kg.

These results suggest that in certain cases, stock enhancement can be economically feasible even if it does not result in increased yield. An economically beneficial effect may be found in other areas as well if a cost-benefit analysis is conducted. Thus, encouraging prospects do exist in a stock enhancement program for Japanese flounder, although fish stocking may not be a panacea to the problem of declining populations.

As fisheries resources management has developed and expanded, the use of and need for cultured fishes have increased (Schramm and Piper 1995). However, mass releases of cultured fish have been alleged to cause a variety of problems such as: spread of pathogens; limited numbers of the broodfish decreases genetic diversity; genetic constitution and fitness of wild stock are changed or diminished; and so forth (Edward and Nickum 1993). Also, conservation of the species and ecological diversities became an international issue after the Convention on Biological Diversity came into effect. Under these circumstances, many symposia or workshops related to these issues have been held worldwide.

For instance, the US-Japan Natural Resources (UJNR) Aquaculture Panel held the Symposium on Interaction between Cultured Species and Naturally Occurring Species in the Environment in Alaska in 1993, and the International Symposium and Workshop on the Uses and Effects of Cultured Fishes in Aquatic Ecosystems were held in New Mexico in 1994. In order to make a stock enhancement program not only economically but also scientifically sound, more academic information on the impact of mass releases of hatchery-reared fish is needed. The Agriculture, Forestry and Fisheries Research Council of Japan has just initiated a new project "Effect of Fish Stock Enhancement on Biodiversity." In this project, we plan to conduct studies on the genetic constitution and ecological effects of stock enhancement on the native populations of Japanese flounder, and to develop technology for stock enhancement minimizing adverse effects on biodiversity. Also, a joint project on flounder between Japan and the USA is now ongoing and significant scientific contributions from these projects are expected.

A put and take fishery which is supposed to have less impact on the genetic diversities of natural populations can be one of the future directions for stock enhancement programs. However, this practice will permanently depend on a stocking program like the chum salmon project.
CONCLUSIONS

- Unlike the chum salmon project, large increases in numbers of juvenile flounder for release may not be feasible because of the limited carrying capacity.

- If the stock enhancement program is carried out where the initial stock size is relatively small or the stock is depleted, clear-cut evidence for increased yield can be obtained even at the present level of releases.

- As far as a high valued fish like flounder is concerned, if the recapture rate exceeds 20%, mass-release is economically feasible even though no increase in the catch is obtained.

- In either case, stock management by fishermen is a must, especially in the restriction of harvesting undervalued small fish.

- In order to make stock enhancement a sustainable program, impacts of mass releases on the ecosystem must be scientifically elucidated.

LITERATURE CITED


