Flounder stock enhancement in Miyako Bay, Japan

Hiroyuki Okouchi
National Center for Stock Enhancement (formerly the Japan Sea-Farming Association)
Miyako Station, 4-9-1 Sakiyama, Miyako, Iwate, 027-0097 Japan

Shuichi Kitada
Tokyo University of Marine Science a d Technology (formerly Tokyo University of Fisheries), 4-5-7 Konan, Minato, Tokyo, 108-8477 Japan

Akio Iwamoto
National Center for Stock Enhancement (formerly the Japan Sea-Farming Association)
Yashima Station, 2-3-4 Yashima-higashimachi, Takamatsu, 761-0011 Japan

Tatsuhiro Fukunaga
Japan Sea-Farming Association (after 1 October 2003, Fisheries Research Agency – Stock Enhancement Division), 3-14-8 Uchikanda, Tokyo, 101-0047 Japan

ABSTRACT

This paper reviews the flounder stock enhancement programme around Miyako Bay, Japan, during the period from 1980 to 1995 focusing on the stocking effectiveness of the nine releases from 1987 to 1995 evaluated by the fish census at Miyako Fish Market. We analysed the data of all landed flounder for 132 months from June 1988 to May 1999. A total of 368 986 flounder were landed, of which 106 331 (28.8%) were hatchery-produced and 262 655 (71.2%) were naturally produced fish. Return rates ranged from 5.9 percent to 23.3 percent, with average of 12.2 percent. Estimates of economic efficiencies were between 0.46 and 2.53, and seven releases exceeded the break-even point of 1.0. Flounder release was found to be economically feasible when sound juveniles were released in August and early September. Release of large-sized juveniles proved advantageous for high return rates. The most efficient size at release was detected at total length (TL) of 90 mm. The stock enhancement programme was considered to augment fishery production without displacement of natural fish. The stocking programme raised awareness among the fishers of the need to conserve small fish, which enabled a regulation to be implemented that prohibited catching flounder of body length under TL 30 cm. The yield per release ranged from 15.7 to 75.5 g before this regulation was begun, and was raised to 89.8 g in 1995 after its implementation, showing that the regulation worked effectively both for hatchery and natural flounders and improved the yield per release/recruit. General lessons, strengths and weaknesses, future prospects and limitations to the programme are discussed.

INTRODUCTION

The stock enhancement programme of marine resources in Japan, supported by the Japanese Government, began in 1963 by targeting important commercial coastal fishery resources. The programme has been reviewed, focusing on its organization (Imamura, 1999) and stocking effectiveness (Kitada, 1999). Flounder is one of the main target species of the programme. The number of annually released juvenile flounder exceeded one million in 1980 and 30 million fish were released from 37 of 39 prefectures facing Japan's coastal waters (Anon., 2000a).

It is necessary to survey a wide area to estimate stocking effectiveness of finfish species such as flounder, which migrate widely and which are landed at many fish markets. A method for estimating stocking effectiveness based on two-stage sampling designs has thus been developed, and related parameters were first estimated with precision in a case study of flounder (Kitada, Taga and Kishino, 1992). Estimates of stocking effectiveness have also been reported for abalone (Kojima, 1995) and masu salmon (Miyakoshi *et al*., 2001) using the same method. However, there have been few case studies evaluating the stocking effectiveness with appropriate procedures, although this measure has been one of the most important issues in Japan's stock enhancement programmes.

Miyako Station of the Japan Sea Farming Association (JASFA) has been involved in developing juvenile production technologies for flounder and has been involved in evaluating stocking effectiveness around Miyako Bay since 1984 for the Fisheries Agency of Japan. Miyako Bay was considered to contain nursery grounds of juvenile flounder and was therefore a suitable release site. Released flounder are caught in an area 30 km north and 20 km south of the mouth of the bay, almost all being landed at Miyako Fish Market (MFM). We have therefore carried out a census of landed flounders at MFM since 1988 to give a precise estimate of stocking effectiveness rather than by introducing sample surveys. Released flounders landed have been distinguished from naturally produced fish by the characteristic pigmentation on the abocular side of hatchery-produced flounders. In addition, the brand marking and alizarin complexone (ALC) otolith marking have been used to determine the age composition of recaptured flounder.

The objective of this paper is to review the results of the flounder stock enhancement programme in Miyako Bay during the period from 1981 to 1998 and to discuss their implications for the programme. We analysed the nine releases from 1987 to 1995 and estimated the stocking effectiveness with an index of the economic efficiency based on the census data. Relationships between return rates and stocking variables such as size at release, release timing and quality of juveniles were examined. Effects of the body length regulation on the stocking effectiveness and the interaction between hatchery- and naturally produced stocks are discussed. Finally, we discuss general lessons and the strengths and weaknesses of the programme.

This report analyses the census data of flounder landed at Miyako fish market for eight years from June 1988 to May 1996 and evaluates stocking effectiveness, including the economic return rates of the flounder released in Miyako Bay. The size at release and fish market survey design is also examined.

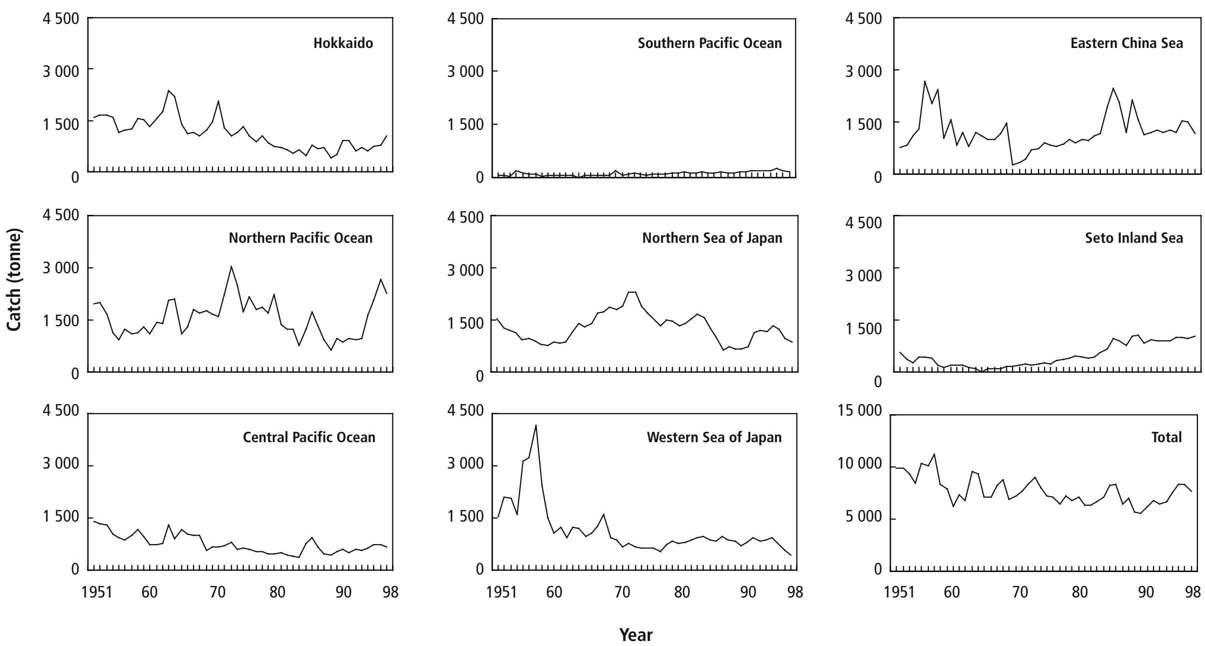
REVIEW OF FISHERY

Status of flounder catches in Japan

Flounder is one of the main target species of Japan's stock enhancement programme and is also important for coastal fisheries as well as for aquaculture. Based on the annual statistical report of fisheries and aquaculture production, the catch of Japan's coastal fish species in 1998 excluding pelagic fish was 1 161 374 tonnes (of a total catch of 5 314 826 tonnes), of which 0.66 percent was flounder (7 665 tonnes). Fishery production for the coastal area in 1998 amounted to 309 589 million yen; total production amounted to 1 337 903 million yen. Of the total coastal fish production, 5.19 percent (16 068 million yen) was from flounder. Aquaculture production of marine fish totalled 258 801 million yen, of which 5.88 percent (15 217 million yen) came from flounder production (Anon., 2000b).

The average total catch of flounder in Japan from 1951 to 1998 was 7 707 tonnes, with maximum a of 11 198 tonnes in 1957 and a minimum of 5 517 tonnes in 1990. Catches in Hokkaido, the northern Pacific Ocean and the central Pacific Ocean had decreased annually until the mid 1980s but there has been an upward trend since then. The Eastern China Sea, the Seto Inland Sea and the southern Pacific Ocean show the same upward trend from around the 1970s. By contrast, in both fishing areas in the Sea of Japan, catches of flounder have decreased and remained at low levels. Among all these areas, the northern Pacific Ocean has shown a remarkable increase, and this area includes Iwate Prefecture (Figure 1).

FIGURE 1. Changes in annual catch of flounder at the eight study areas in Japan

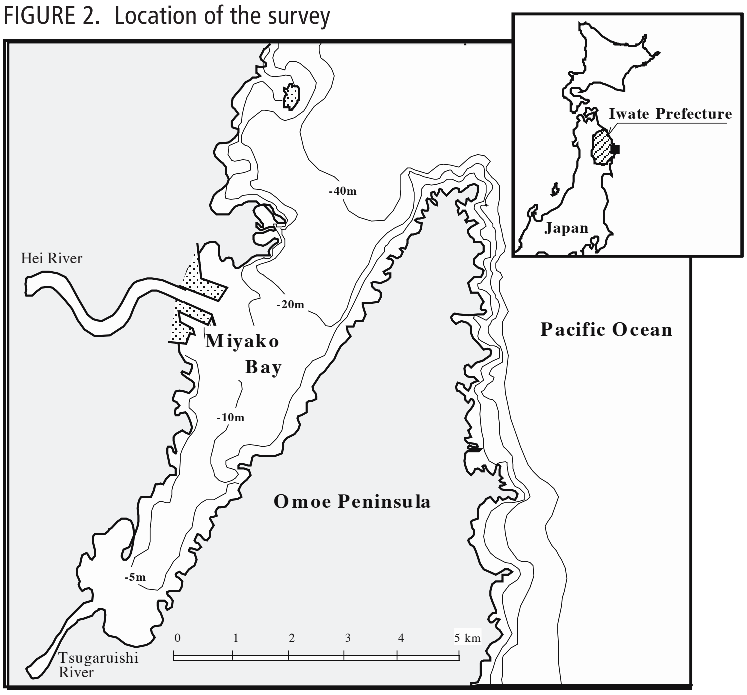


Status of flounder catches in Iwate Prefecture and Miyako Bay

Iwate Prefecture is located on the northern Pacific Ocean side of Honshu, the main island of Japan, and Miyako Bay is located mid way along the Iwate Prefecture coastline (Figure 2). The average catch of flounder in Iwate Prefecture from 1951 to 1998 was 89.9 tonnes, with a maximum of 158 tonnes in 1963 and a minimum of 30 tonnes in 1989. The trend in caught flounder showed a steep drop in 1989 but has began to increase and reached historical highest level of 155 and 156 tonnes in 1997 and 1988 (Figure 3).

Catch statistics are also available for MFM from 1956, which is the principal fish market in the area around Miyako Bay, and about 90 percent of the flounder catch in the area can be determined from the catch statistics of MFM. The average catch of flounder from 1956 to 1998 was 17.1 tonnes. The maximum catch was 38 tonnes in 1963 and minimum 5 tonnes in 1982. The flounder catch at MFM was on a decreasing trend from 1980 to 1990, but with large annual fluctuations. In the 1990s, the catch trend was upward and catches have recovered to a level of 20 tonnes in 1997 and 1988 (Figure 3).

FIGURE 2. Location of the survey



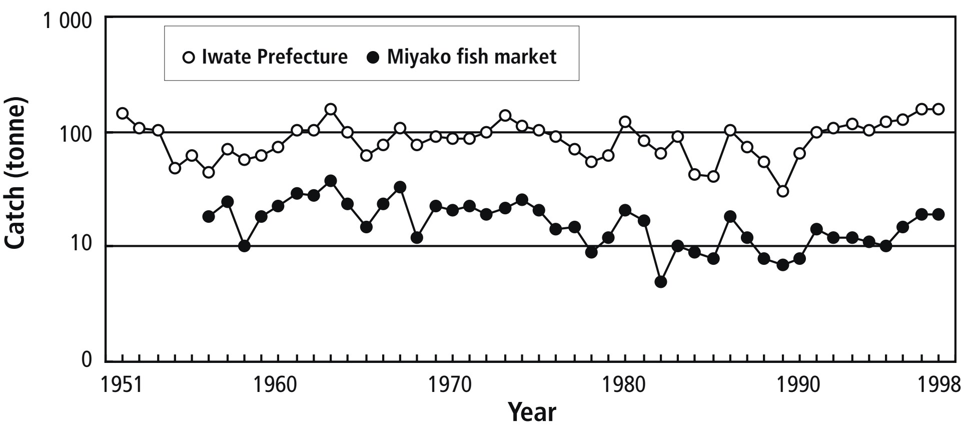
At MFM, landed flounder in 1998 was 19 tonnes (0.05 percent of the total landings) and 40 million yen (0.5 percent of the total catch value). The contribution of flounder to the total fishery production was thus small. However, flounder is traded at a high price (Table 1) and is caught by small-scale fishing operations (Figure 4). Flounder is an important resource for these small-scale fishing operations, to which many coastal fishers around Miyako Bay belong.

Unique features of the fishery around Miyako Bay

Setnet, small setnet, gillnet and longline fisheries are all operated off the coast around Miyako Bay. Trawl fisheries operate in the offshore area but small trawlers are not used in the coastal areas. The setnet fishing season lasts for ten months, from May to February, in the central part and mouth of Miyako Bay and along the coast facing the open sea. The small setnet fishing season lasts for six months, from March to August, largely at the central and inner parts of Miyako Bay. Trawlers fish for ten months from September to June, in waters 200 m deep around the central and northern parts of Iwate Prefecture, which includes the offshore area of Miyako Bay.

Fishers in this area mainly belong to one of three cooperative fishery associations, Miyako, Taro or Omoe. The number of regular members of the Miyako, Taro and Omoe cooperative associations is 1 205, 567 and 573, respectively. The gives a total for the three associations of 2 345, or about 3 800 if associate members are also included. The aggregate number of fishery units of the three associations is 18 for setnets, 55 for small setnets, 395 for gillnets and three for trawlers. It is difficult to determine the number of fishery units using longlines because this method is not licensed in the area. However, many fishers are engaged in longline fishing during the summer, when they can obtain live bait such as anchovies.

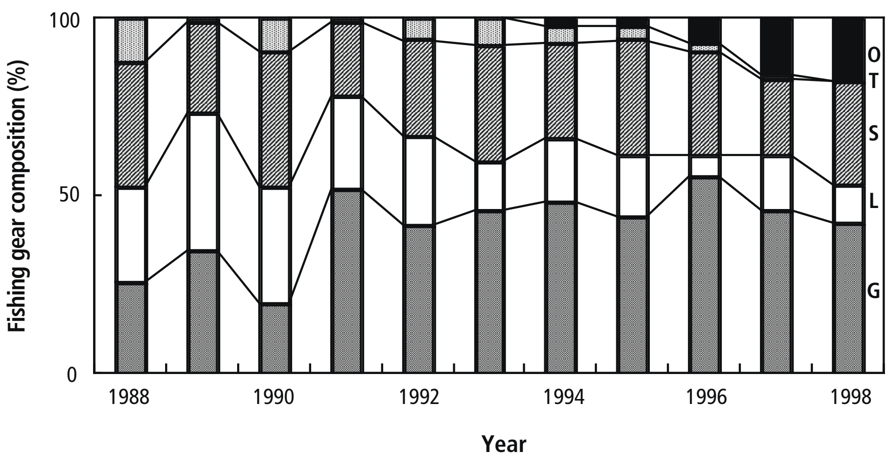
FIGURE 3. Changes in annual catch of flounder for whole Iwate Prefecture and the Miyako fish market



Judging from annual production, setnets seems to be the principal fishing method in this area. Also of importance are gillnets and longlines operated by individuals on a small scale. Many of these small-scale fishers are also engaged in aquaculture businesses harvesting scallops, oysters and seaweed or in fisheries harvesting abalone, sea-urchin and seaweed as an aside.

In the area around Miyako Bay, setnets, small setnets, gillnets and long lines are used to catch flounder (Figure 4). Setnets (including small setnets) and longlines were the dominant fishing methods from 1988 to 1990, and these fishing methods accounted for about 70 percent of the total numbers caught. However, catches by gillnets have increased since 1991 and this now accounts for about 50 percent of the total landings of flounder.

FIGURE 4. Change in fishing gear composition of flounder as a percentage of the number of fish landed at the Miyako fish market



From June 1995 to May 1996, 16 setnets, 16 small setnets, 107 gillnets, 17 long lines and three trawlers landed flounder at MFM; these were all members of the Miyako, Taro and Omoe fisheries cooperative associations. The ratio of fishery units that landed flounder at MFM to the total number of fishery units for each fishing method was 89 percent for setnets, 29 percent for small setnets, 27 percent for gillnets and 100 percent for trawlers. The ratios for small setnets and gillnets were low because the number of fishers actually operating was smaller than those permitted to operate. Most fishers operating in the area around Miyako Bay actually fish for flounder.

Principal problems with fishery around Miyako Bay

MFM is the only principal fish market in the area around Miyako Bay; total landings accounted for 38 319 tonnes and 9 043 million yen in 1998. Data for landings by fish species at MFM in 1998 showed that saury ranked first with 13 375 tonnes, or 34.9 percent of total weight, and salmon (chum salmon comprised 99 percent with the remainder being pink, coho and Chinook salmon) ranked second with 8 089 tonnes, or 21.1 percent of total weight. These two species accounted for 56 percent of the total landings by weight. Data based on value showed that saury ranked first at 3 410 million yen (37.7 percent of the total landings), and salmons ranked second at 3 044 million yen (33.7 percent of the total). These two species accounted for 71.4 percent of the total revenue of landings (Table 1).

TABLE 1. Ranking for landings by weight, value and unit price at the Miyako fish market (1998)

Landings in weight				Value				Unit price		
Rank	Species	Weight (tonnes)	%	Rank	Species	Value (×1000 yen)	%	Rank	Species	Price (yen/kg)
1	Saury	13 375	34.9	1	Saury	3 410 625	37.7	1	Sea urchin	6 933
2	Salmon[1]	8 089	21.1	2	Salmon[1]	3 044 438	33.7	2	Bluefin tuna	3 411
3	Pollock	3 727	9.7	3	Cod	544 500	6.0	3	Kichiji rockfish	2 257
4	Cod	3 630	9.5	4	Kichiji rockfish	291 153	3.2	4	Flounder	2 154
5	Octopus	617	1.6	5	Octopus	264 076	2.9	5	Red rockfish	1 982
6	Squid	565	1.5	6	Squid	172 325	1.9	6	Tuna[2]	1 711
7	Mackerels	394	1.0	7	Sea urchin	145 593	1.6	7	Sea cucumber	1 260
8	Soles	213	0.6	8	Soles	145 479	1.6	8	Bigeye tuna	957
9	Sardine	184	0.5	9	Pollock	145 353	1.6	14	Salmon[1]	376
10	Striped marlin	139	0.4	10	Swordfish	103 124	1.1	18	Saury	255
18	Flounder	19	0.05	11	Flounder	40 926	0.5	23	Cod	150
				12	Yellowtail	38 418	0.4			

[1] Chum salmon occupies over 99%. Others are pink, coho and chinook.

[2] Except for bluefin, longfin, bigeye and yellowfin tuna.

Saury is the most important fish for offshore fishing industries, and the main fishing area is offshore around Hokkaido. By contrast, landings of chum salmon from local coastal fisheries are substantial around Miyako Bay. Data from the hatchery-release programme show that the number of returned chum salmon increased after around 1975, with total landings reaching 10 000 tonnes in 1984, from a value that had been below 1 000 tonnes before 1974. However, the unit price of chum salmon fell remarkably after 1995, mainly as a result of the over production of local chum salmon and increased importation of salmon. The number of returned chum salmon then began to decrease from 1997, and this has had a serious influence on the fisheries community around Miyako Bay. The fisheries cooperative associations and the fishers need to have various fishery resources in order to stabilise production.

The Fisheries Agency of Japan began the stock enhancement programme of flounder in 1980 with concern over the decrease of flounder catches in northern Japan during the 1970s (Figure 1). Despite a strong demand for scientific evaluation of stocking effectiveness, there have been few case studies completed. The Fisheries Agency therefore entrusted the evaluation of flounder stocking programmes to the JASFA and Miyako Station initiated surveys at MFM in order to obtain precise estimates of stocking effectiveness.

Stock enhancement programmes have two roles: to augment fishery production by releasing hatchery-produced juveniles and to supplement reproduction. There are no natural spawning grounds in Miyako Bay and the source of natural larvae from outside the bay is unknown. The programme was therefore aimed at augmenting fishery production by releasing hatchery-produced juveniles. We set two goals for the programme: to detect suitable release sites and sizes at release, and to evaluate the stocking effectiveness quantitatively.

METHODOLOGY OF STOCK ENHANCEMENT

Broodstock selection and management

JASFA Miyako Station has developed juvenile production technologies since 1980. The broodstocks were a mix of wild fish caught in the area around Miyako Bay (two or three years of age) and progenies produced at Miyako Station (shown in Appendix 1).

The broodstock was reared in two circle-shaped concrete tanks 80 m^3 in volume. Ratios of males to females were adjusted to 0.5. Fertilized eggs obtained by natural spawning in these tanks were used for juvenile production. Natural spawning continued from late April to early June, but we used eggs spawned during early May as this was the high spawning season.

The broodstock used from 1988 to 1995 for juvenile production largely consisted of progenies produced from wild fish initially introduced to Miyako Station. The broodstock remained largely unchanged during in this period. However, these broodstocks were discarded in 1995 because a large number of juveniles died and viral diseases were suspected to have been introduced into the production process. In 1996 and for nine or ten years thereafter we used another broodstock reared from hatchery progeny, and began to collect wild matured flounders landed on MFM to prepare new broodstocks. In 1997, all broodstocks reared from hatchery progeny were disposed of and new broodstocks that comprised only wild fish were established. We carried out a blood test for all individuals of broodstock candidates after 1996. Fish with an antibody level that exceeded a threshold value were judged to be virally infected and were discarded.

Juvenile production

JASFA Miyako Station initiated juvenile production of flounder in 1980. Flounder juveniles are reared in 50 m^3 concrete tanks at a water temperature of 16 or 17 °C. Flounder larvae were fed with rotifers (3–30 days after hatching), *Artemia nauplius* (12–45 days after hatching) and an artificial diet (20 days and thereafter). We finished the larval rearing period when the hatched flounder larvae were up to 30 mm in total length (TL) at 50 days after hatching, and we then evaluated the results. Since 1988, the technology of juvenile production has given stable results regarding fish survival and health. The average survival rate during the larval rearing period from 0 to 50 days after hatching reached 80.9 percent (range, 56.1–88.7 percent). However, it remained difficult to prevent perfectly the appearance of black pigmentation on the abocular side of the fish.

Juveniles of TL 30 mm were moved to net cages set in another concrete tank 120 m^3 in size, and were reared up to the size at release of TL 80 mm in these net cages for 40–50 days. Because cannibalism was observed during this period as a result of the large size difference between individuals, we separated small juveniles of inferior growth from normal-sized juveniles when the average total length reached 35 mm, 45 mm and 60 mm. Juveniles of slow growth were moved to other cages and continued to be reared.

Genetic resource management

It have been a requirement that released fish do not affect the genetic diversity of wild stocks. The first approach with this in mind is to examine the genetic structure of the target species. It has been suggested that the flounder stock of the Sea of Japan can be separated into two groups of north and south based on the difference in the number of dorsal fin rays. By contrast, allele frequencies of mitochondrial DNA (mtDNA) of flounder have suggested a homogeneous population structure along the entire coast of Japan (Tanaka *et al*., 1997). There were no clear genetic differences among fish from sampling sites along the Pacific coast including Miyako Bay (Asahida *et al*., 1998).

The research team consisted of individuals from Kitasato University, Tohoku National Fisheries Research Institute and the JASFA, who examined the genetic diversity of hatchery-produced flounder juveniles through mtDNA analysis. Samples of juvenile flounder produced in five prefectural sea-farming centres (hatcheries), the JASFA Miyako Station and wild flounders landed in Ibaraki, Kanagawa, Tokushima, Kagoshima and Yamagata Prefecture were analysed. The results showed that juveniles produced from wild broodstock had similar genetic diversity to the wild stocks. By contrast, juveniles produced from hatchery-produced fish or from mixed broodstocks of wild and hatchery-produced fish had lower genetic diversity (data not shown). The results suggested the importance of using wild fish caught from local sea waters for the broodstocks to maintain the genetic diversity of the wild stocks, as pointed out by Bartley, Kent and Drawbridge (1995) and Harada, Yokota and Iizuka (1998).

Fish health management

A careful health management of broodstocks and juveniles has been continued at the JASFA Miyako Station by maintaining appropriate rearing density of fish, quantity of feed, exchange rate of rearing water and careful observation of fish. Among these operations, the most careful attention was given to disease management. To keep infections to a minimum, we sterilized the rearing tools, tanks and equipment, and the tools and those in charge were exclusive to each rearing tank.

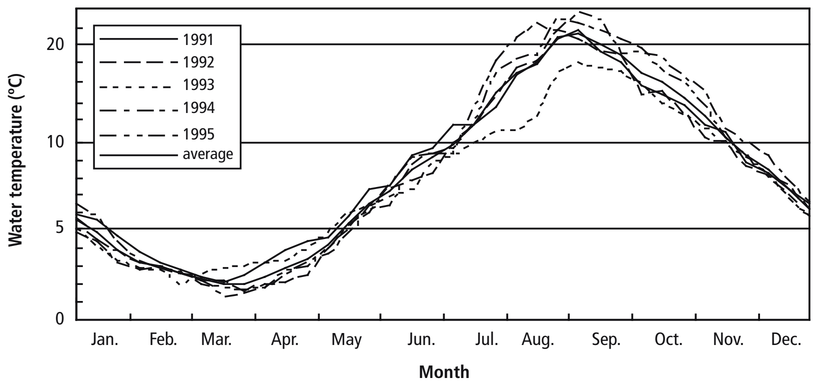
When symptoms of disease were observed, blood samples were taken and examined quickly. If a disease was diagnosed as bacterial, we improved the rearing conditions and used permitted medication. If there was a strong chance of the infection spreading to healthy fish, the diseased fish were disposed of and rearing tanks and equipment were sterilized. If the disease was judged to be viral, we disposed of all fish in the tanks immediately. At the same time, we examined fish reared in other tanks in parallel for virus infection and disposed of the fish if a positive result was obtained. In the JASFA Miyako Station, a bacterial disease occurred in 1984 and a viral disease occurred from 1996 to 1998; we therefore incinerated all juveniles produced in each of these years.

Release site selection

Flounder release experiments and follow-up surveys in the area around Miyako Bay have been carried out since 1980. At the early phase of the survey before 1984, juveniles with external tags were released at Miyako Bay and around Taro Bay and the Sakiyama coast (Appendix 2). Movement patterns of released fish were surveyed based on tag recoveries reported by fishers. The result showed that flounders released in Miyako Bay moved within a narrower range than the fish released at the other two sites. Miyako Bay was considered to have specific conditions that made flounder juveniles more likely to settle down.

Miyako Bay is a narrow bay 4 km wide at its mouth and extending inland for 10 km (Figure 2). The depth at the mouth is 40 m, which is the deepest part of the bay and it gradually becomes shallower as it extends inland. Two rivers flow into the bay: the Hei River into the central western part and the Tsugaruishi River into the inland part. The surface water temperature near the centre of the bay fluctuates within a range 6–22 °C. Lowest temperatures are observed in mid or late March when snowmelt flows in and highest temperatures in late August or early September (Figure 5). Tidal flats expand in to the inner part of Miyako Bay, which is strongly affected by river water. Mysid and goby juveniles are particularly dense there and they form the principal bait for flounder juveniles (Yamada *et al*., 1994, 1998). These results showed that the inner part of Miyako Bay was a suitable location as a nursery for flounder juveniles, and the release sites have been fixed in Miyako Bay since 1986.

FIGURE 5. Seasonal changes in surface water temperature in Miyako Bay

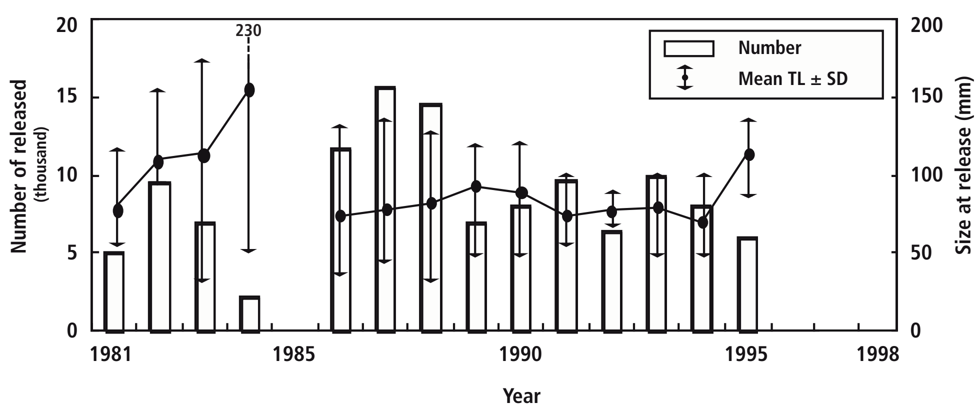


Release strategy

All or part of the released juveniles were marked except those released in 1980 and 1981. The total number of flounder juveniles released around Miyako Bay was 1 205 000 for the 16 years from 1980 to 1995, of which 1 038 000 fish were released actually in the Bay. The actual number each year ranged from 22 000 to 157 000 and the average TL at release ranged from 70 mm to 157 mm (Figure 6, Appendix 2).

Before 1988, the technology of juvenile flounder production was unstable and the numbers of released fish fluctuated widely. Since 1989, however, 60 000–100 000 juveniles have been released consistently every year. The size at release varies with the time at release and the type of tags or markers used, but the standard size has been kept at TL 80 mm since 1986. In addition, 245 000 small juveniles with an average TL of 25 mm were released in 1980 for a pre-survey, and 633 000 small juveniles with an average TL of 21.0–32.0 mm were released in 1989 and 1990 to examine the feasibility for releasing small-sized juveniles. No release was carried out in 1985 because production ended in failure as a result of a bacterial disease outbreak. The juvenile release experiments after 1982 can be divided into three periods, namely Phase I (1982– 1984), Phase II (1986–1988) and Phase III (1989–1995) according to the objectives of the releases (Appendix 2).

FIGURE 6. Changes in annual number of released flounder and average size at release of juvenile flounder at Miyako Bay



Phase I (1982–1984)

The objective of the survey in this period was to understand movement and dispersal patterns of released flounders and to detect suitable release sites. External tags such as anchor and disk tags were mainly used in order to obtain recapture reports from fishermen. Juveniles were reared to the size at release of TL 100 mm or larger because anchor and disk tags heavily burdened small fish. As the rearing period was extended to include larger juveniles, the time at release occurred later in October or early November. Different coloured and shaped tags were attached to each group to identify fish groups released at different sites and years.

Phase II (1986–1988)

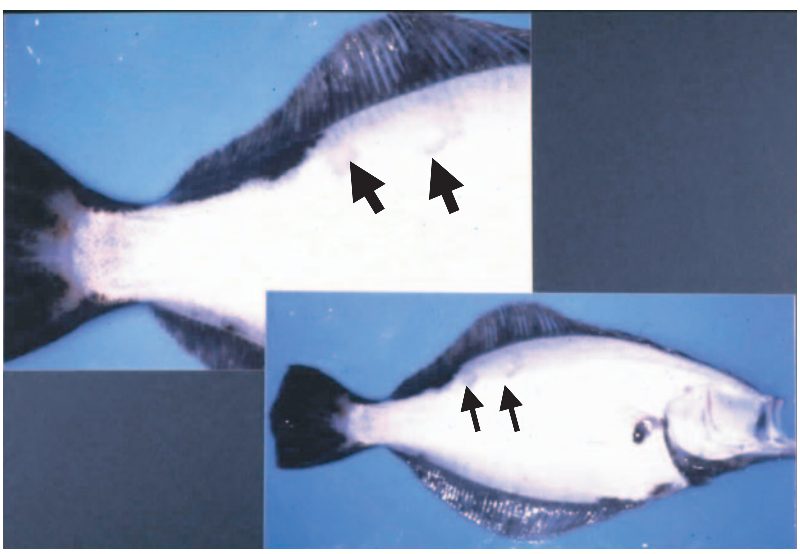
The objective of the survey was to estimate stocking effectiveness. The survey procedure was changed from recapture reporting to sample surveys at MFM. The survey of landings at MFM started in 1986 and was initially conducted only for the high fishing season of flounder between June and August. An inspector was stationed at the fish market in 1988 and all flounder landed were checked on about 280 days in the year when the market was open.

Using non-shedding marks was important rather than using visible external tags because the inspectors examined marked fish in the catches at the fish market, and mark–recapture reports from fishers were not expected. We therefore used as a natural mark the black pigmentation that appears on the abocular side in almost 100 percent of hatchery-released fish. However, it was not possible to distinguish the year of releases using this pigmentation. Ratex marking was then used to identify the year of release and the release groups with different sizes at release within the same year. Rubber-like ratex of different colours was injected hypodermically to the abocular side of the juveniles, which could be easily detected externally. However, the use of ratex marking was abandoned in 1988 because a food hygiene problem was discovered. All releases were completed in September or in early October before the water temperature dropped.

Phase III (1989–1995)

In this phase, we carried out an extensive fish census to evaluate stocking effectiveness precisely. We continuously used the pigmentation as a natural mark and marked 100 percent of released juveniles by using brand and ALC marking. Brand marking was carried out on dorsal and caudal fins on alternate years to distinguish the year of release. Brand marks refer to scars made by penetrating the basal part of the dorsal fin or caudal fin of a flounder juvenile from the abocular side with a heated soldering iron, which could then be observed as a round and transparent mark on the abocular side of landed released flounder (Figure 7). Brand marking could be used on juveniles larger than TL 70 mm, so the size at release was fixed at TL 80–90 mm.

FIGURE 7. Released flounder landed at Miyako fish market. The age was identified by the brand marks (arrows; TL 32.0 cm, age 2+)



ALC otolith marking (Kuwada and Tsukamoto, 1987) was simultaneously introduced to distinguish between groups released in the same year with different sizes at release so as to compare the effect of the size on stocking effectiveness. ALC marks could be observed as a fluorescent circle on the otolith of landed hatchery-reared fish. We used a single circle marked at TL 30 mm and double circles marked at TL 30 mm and 50 mm to distinguish the release groups. ALC otolith markings were also used to examine the feasibility of releasing juveniles smaller than TL 20–30 mm.

We attempted to bring forward the time at release and completed the release in early August at the earliest and in mid September at the latest. From 1996 to 1998, no release of flounder juveniles was conducted in Miyako Bay because of the viral disease problem in juvenile production detailed earlier.

MONITORING AND EVALUATION PROGRAMME

Fish census at the market

As mentioned above, all flounder in the landings have been checked on all landing days at MFM since 1988, and we have termed this the fish market census. Most of the flounder landed at the market are stocked alive in small tanks. The inspector was allowed to examine live fish. The following four items were recorded at the fish market for every flounder: (1) pigmentation on the abocular side, (2) total length, (3) external marking and (4) fishing method.

Flounder with pigmentation were judged as released and those without pigmentation as natural. For fish with ratex or brand marks, we recorded the type of marks, the colour and body length measurements, which allowed us to determine the year of release. Because the labels attached on the tanks in which landed flounders were stocked gave the name of the fishers and the fishing vessels, we were also able to identify the fishing method for individual flounder.

Age determination of landed flounder

The census of all the flounder landed at MFM enabled us to distinguish whole landings of released and natural flounder caught around Miyako Bay. However, in order to estimate return rates, we had to estimate the age composition of released flounders landed. The spawning period of flounder in the coastal waters of the northern Pacific Ocean around Japan was estimated to occur in June or July and larvae of natural flounder settled in the shallow water were observed after late June in Miyako Bay. We therefore assumed that 1 June was the date of birth and the period from June to May of the following year referred to the same cohort.

Because 100 percent of the flounder juveniles released from 1989 to 1995 were marked by brand and ALC marking (Appendix 2), the age of recaptured flounder could be determined. As very many flounder with marks were recaptured, we were able to estimate the mean TL and standard deviation (SD) by month with high accuracy. We converted length frequencies to age compositions of released flounders with brand marks. We estimated age compositions of released fish with no brand marks or marks that had disappeared by using TLs and SDs of brand-marked fish landed (Okouchi, Kitada and Iwamoto, 1998; Appendix 3). No difference in the growth of brand-marked and unmarked flounders was confirmed in the rearing experiment for 13 months after marking. Landed flounders were divided into three cohorts of age 1+, age 2+ and age 3+. Most of flounders landed at MFM were age 1+ and 2+, and thus we treated the remaining fish as age 3+ because age 0+ fish were never caught around Miyako Bay. Most flounders for the cohort of age 3+ were actually age 3+ and older fish were rare.

Measures of success

We estimated the number of landings of flounder for hatchery- and naturally produced fish by age classes for the nine releases from 1987 to 1995. Contribution rates of released fish to the annual fishery production were calculated for number, weight and the monetary value. Return rates were determined by dividing the number of landings of released fish by the total number of released fish. Economic efficiency were evaluated as the ratio of the total value of landings of released fish to the release costs.

TABLE 2. Results of the flounder census (weight, kg; value, 1000 yen) at the Miyako fish market from 1988 to 1998

Survey year	Landings	Total	Hatchery-released fish			Natural fish	Total	Contribution of hatchery fish (%)
			1+	2+	3+			
1988	Number	4 394	3448	905	41	21 659	26 053	16.9
	Weight	810	533	245	32	9087	9897	8.2
	Value	887	475	285	126	22 613	23 500	3.8
1989	Number	8 926	2751	5143	1032	8020	16 946	52.7
	Weight	2 059	385	1288	386	3568	5627	36.6
	Value	2 621	331	1553	737	8782	11 403	23.0
1990	Number	15 311	9004	5605	702	38 109	53 420	28.7
	Weight	4 642	1976	2023	643	11 122	15 759	29.5
	Value	7 591	1890	3393	2313	18 257	25 849	29.4
1991	Number	14 923	7214	5994	1715	21 854	36 777	40.6
	Weight	5 078	1511	2349	1218	9646	14 727	34.5
	Value	9 185	1434	4273	3478	21 585	30 770	29.9
1992	Number	19 415	13 495	4808	1112	20 626	40 041	48.5
	Weight	6 366	3456	2027	882	10 359	16 725	38.1
	Value	10 218	3328	4052	2841	27 163	37 381	27.3
1993	Number	12 437	5064	6645	728	23 396	35 833	34.7
	Weight	4 705	1176	2864	665	10 265	14 970	31.4
	Value	8 672	1070	5366	2236	21 966	30 638	28.3
1994	Number	10 051	5982	3426	643	20 474	30 525	32.9
	Weight	3 682	1576	1417	689	10 270	13 952	26.4
	Value	6 936	1666	2656	2613	24 630	31 566	22.0
1995	Number	4 699	2052	2403	244	23 844	28 543	16.5
	Weight	2 498	832	1361	305	13 423	15 921	15.7
	Value	6 179	1230	3517	1 432	33 210	39 389	15.7
1996	Number	3 718	530	2445	743	21 162	24 880	14.9
	Weight	2 468	204	1292	972	13 347	15 815	15.6
	Value	6 844	285	2878	3681	35 386	42 230	16.2
1997	Number	10 678	0	8365	2313	37 501	48 179	22.2
	Weight	5 840	0	3969	1871	22 662	28 502	20.5
	Value	14 703	0	8693	6010	63 077	77 780	18.9
1998	Number	1 779	58	461	1260	26 010	27 789	6.4
	Weight	1 487	18	254	1215	16 106	17 593	8.5
	Value	5 316	16	682	4618	51 302	56 618	9.4
Total	Number	106 331	49 598	46 200	10 533	262 655	368 986	28.8
	Weight	39 634	11 668	19 088	8877	129 856	169 488	23.4
	Value	79 152	11 726	37 348	30 085	327 971	407 124	19.4

Based on the length measurement data, we estimated the individual weight by length class based on the length–weight relationship of natural flounder in the Northern Pacific coast of Japan including Miyako Bay ($W = 0.000003117 \times L^{3.125}$; Kitagawa *et al*., 1994). We then estimated the weight of landings of both released and natural flounder by month and age by multiplying the number of individuals for each length class by the estimated individual body weight of the length class obtained from above length–weight relationship. Total value of landings were estimated by using the unit price of flounders derived from the statistics of the fish market.

The release costs per flounder juvenile was estimated at 3.9 yen for TL 15 mm, 8.2 yen for 30 mm, 33.5 yen for 50 mm and 74.5 yen for 100 mm based on the data from 1985 to 1987 at the JASFA Miyako Station; this took into account direct production costs such as water, electricity, fuel and feed, together with facility depreciation and personal expenses (Anon., 1990). These costs were expected to be the lowest at the present level of juvenile production technologies. Based on these actual release costs, we determined the unit release costs per juvenile at 35 yen for TL 50 mm, 45 yen for 60 mm, 50 yen for 70 mm, 60 yen for 80 mm, 70 yen for 90 mm, 80 yen for 100 mm and 90 yen for 110 mm. We calculated the release costs by multiplying these unit costs by the number of released juveniles.

In 1989 and 1990, TL 20–30 mm groups were released to evaluate the feasibility of releasing small-sized juveniles, but later analysis (described in section **Biological interaction with natural stocks**) revealed that post-release survival rates before recruitment for these releases were quite low, which meant that evaluation of stocking effectiveness including the small-sized groups would be biased. Therefore, we excluded these two small-sized releases from the evaluation.

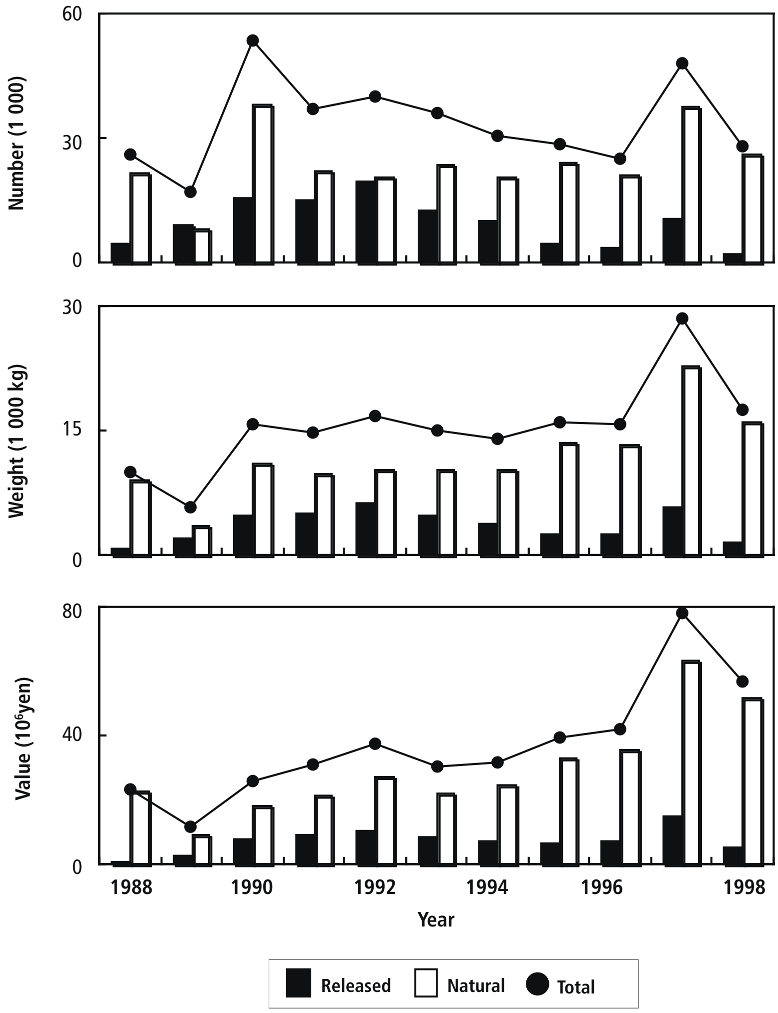
Contribution of hatchery fish to fishery

We analysed the fish census data of all landed flounder from June 1988 to May 1999. A total of 368 986 flounder were landed at MFM during this period, of which 106 331 were released and 262 655 were natural. Annual landings of released flounder ranged from 1 779 to 19 415 in number, from 810 kg to 6 366 kg in weight, and from 887 000 to 14 703 000 yen in monetary value. The annual number of landings of natural flounder ranged from 8 020 to 38 109 (Table 2).

The annual number of landings of released flounder increased from 1988 to 1992 but then decreased in 1993. This decrease was considered to be the result of the low survival rates until age 1+ for 1993 and 1994 (Table 3), and introduction of the body length regulation for 1995 and 1996. However, landings of released flounder increased again in 1997 regardless of the discontinuity of releases after 1996. By contrast, landings of natural flounder were relatively stable and ranged from 20 474 to 26 010 except in 1989, 1990 and 1997 (Figure 8, Table 2).

Monthly changes in length frequencies of released flounder landed were determined by age classes based on the mark–recapture information for the high fishing season in Miyako Bay from June to November. The length frequencies of released flounders landed from 1988 to 1995 corresponded to fluctuations in the recruitment months (Figure 9). Age compositions of released flounder landed were estimated from the length frequency data for 132 months from June 1988 to May 1999 (Figure 10). The average composition was 54.4 percent for age 1+, 38.7 percent for 2+ and 6.9 percent for 3+ between 1988 and 1995. The regulation to prohibit catching flounder smaller than TL 30 cm began in July 1995. In 1996, age 2+ and age 3+ fish increased remarkably. Total weight and total value had been increasing since 1995 (Figures 8 and 10). The body length regulation therefore

FIGURE 8. Annual changes in estimates of landings in number, weight and value for released and natural flounder landed at the Miyako fish market



worked effectively to increase the landings, particularly for weight and value, showing that management of the yield per recruitment is economically efficient.

That there was no age 1+ released flounder in the landings in 1997 was because we had stopped releasing flounder juveniles in 1996. However, we detected age 1+ and 2+ released flounders in the landing (Figure 10, Table 2) in 1998, showing that landings at MFM included hatchery-reared flounders released from other sites, considered to be the southern area of Iwate Prefecture or its northern boundary with Aomori Prefecture. Taking account of these flounders released outside the bay, the number of returned fish was overestimated. However, the number of age 1+ released flounder was negligible, only 58, and that of age 2+ was 461 in 1998. In addition, we excluded from the analysis flounders landed at other fish markets that had been released in Miyako Bay. The numbers of returned flounder were thus not overestimated.

Released flounder were landed with smaller size than TL 30 cm in 1988 and 1989; however, the average total length of released flounder landed became large and stable in the range 31–33 cm between 1990 and 1994. By contrast, that for natural flounder was stable in the range TL 34–36 cm between 1988 and 1994 except 1990. After 1995, the sizes of released and natural flounder landed both increased (TL > 36 cm) as a result of the body length regulation. In 1998, the mean total length of released flounder was 41 cm, larger than that of natural fish, because the age exceeded 3+, which could be judged from the fact that juvenile release was halted in 1996 and 1997.

The contribution rate for the number of landings was the real value (not estimate) based on the census of all landed flounder at MFM. The average contribution rate for the period of 11 years between 1988 and 1998 was 28.8 percent for the number, 23.4 percent for the weight and 19.4 percent for the monetary value. Released flounder contributed relatively highly to the total landings in each category (Figure 12, Table 2).

The contribution rate ranged from 6.4 percent to 52.7 percent for number, from 8.2 percent to 38.1 percent for weight and from 3.8 percent to 29.9 percent for amount, varying with the survey year. Values rose sharply in 1989 and maintained high levels until decreasing again in 1995 (Figure 12). The rise in 1989 was caused directly by a decrease in landings of natural flounder. The decreased contribution rates in 1995 and 1996 were thought to be caused by the decreased catch of small-sized fish (which made up the majority of the released flounder) as a result of the body length regulation. In 1997, the contribution rates rose again owing to an increase of landings for age 2+ flounders released in 1995 (Figure 9). The contribution rates in 1998 decreased because of the halts to releases in 1996, 1997 and 1998.

FIGURE 9. Monthly changes in age composition of released flounder landed at the Miyako fish market from 1988 to 1995. Length frequencies were divided into three age classes of age 1+, age 2+ and age 3+ or older

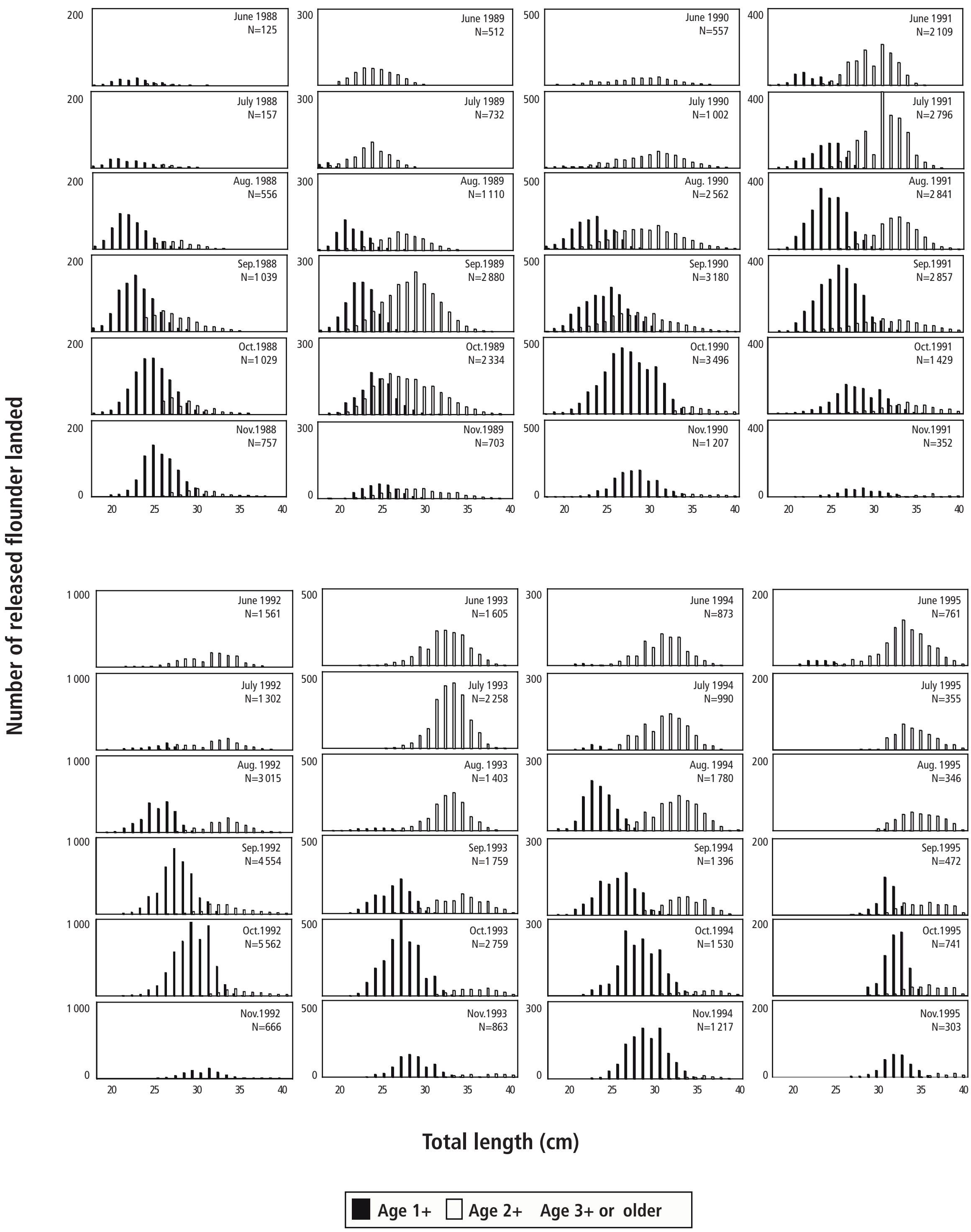


TABLE 3. Estimated numbers of returned released flounder in Miyako Bay

Year of release	No. released	No. returned			Total returned	Return rate (%)
		1+	2+	3+		
1987	157 000	3 448	5 143	702	9 293	5.9
1988	145 000	2 751	5 605	1715	10 071	6.9
1989	69 000	9 004	5 994	1112	16 110	23.3
1990	80 000	7 214	4 808	728	12 750	15.9
1991	96 000	13 495	6 645	643	20 783	21.6
1992	64 000	5 064	3 426	244	8 734	13.6
1993	100 000	5 982	2 403	743	9 128	9.1
1994	80 000	2 052	2 445	2 313	6 810	8.5
1995	60 000	530	8 365	1 260	10 155	16.9
Total	851 000	49 540	44 834	9 460	103 834	(12.2)

TABLE 4. Estimated returns in weight of released flounder in Miyako Bay

Year of release	Weight returned (kg)			Total returned (kg)	Yield/release (g)
	1+	2+	3+		
1987	533	1 288	643	2 464	15.7
1988	385	2 023	1 218	3 626	25.0
1989	1 976	2 349	882	5 207	75.5
1990	1 511	2 027	665	4 203	52.5
1991	3 456	2 864	689	7 009	73.0
1992	1 176	1 417	305	2 898	45.3
1993	1 576	1 361	972	3 909	39.1
1994	832	1 292	1 871	3 995	49.9
1995	204	3 969	1 215	5 388	89.8
Total	11 649	18 590	8 460	38 699	45.5

FIGURE 10. Change in age composition of released flounder landed at the Miyako fish market

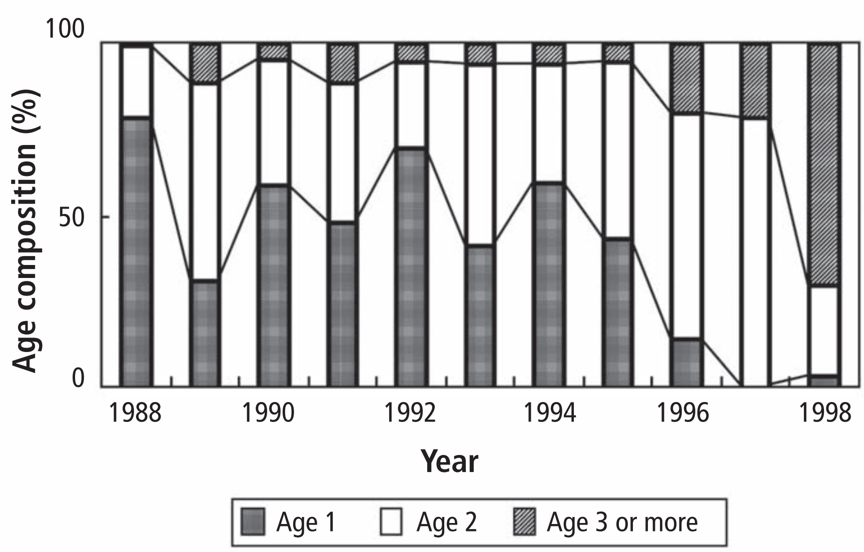
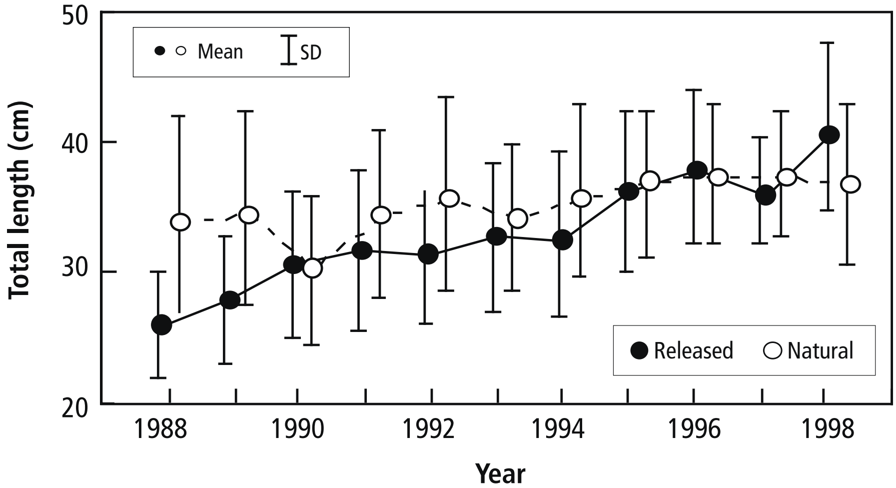


FIGURE 11. Annual changes in the average size at landing for released and natural flounder



Return rates and economic efficiency

We estimated the return rate, the weight of landings of released fish, and the economic efficiency for the nine annual releases from 1987 to 1995 (Table 3 and 4).

Return rates for the 1987 and 1988 releases were 5.9 percent and 6.9 percent, respectively. Those for the four releases from 1989 to 1992 improved and ranged from 13.6 percent to 23.3 percent. The average return rate of the latter four releases was 18.9 percent, which was about three times as large as the average of 6.4 percent for the former two releases. Return rates for the 1993 and 1994 releases were stable but relatively low. However, the return rate for the 1995 release improved again as a result of the increase of age 2+ fish (Table 3).

The weight of landings obtained from each release group ranged from 2 464 kg to 7 009 kg. The yield per release ranged from 15.7 to 89.8 g with the average of 45.5 g. The body length regulation had a dramatic effect on the 1995 release, resulting in the highest yield per release at 89.8 g (Table 4).

FIGURE 12. Changes in contribution rate of released flounder to total landings by number, weight and value

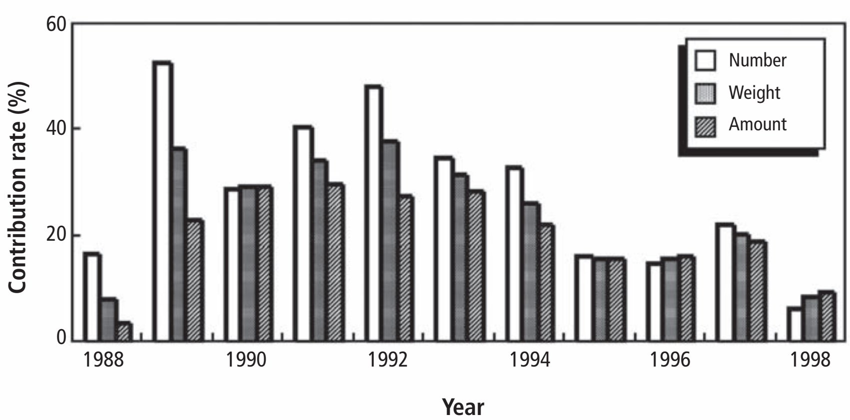
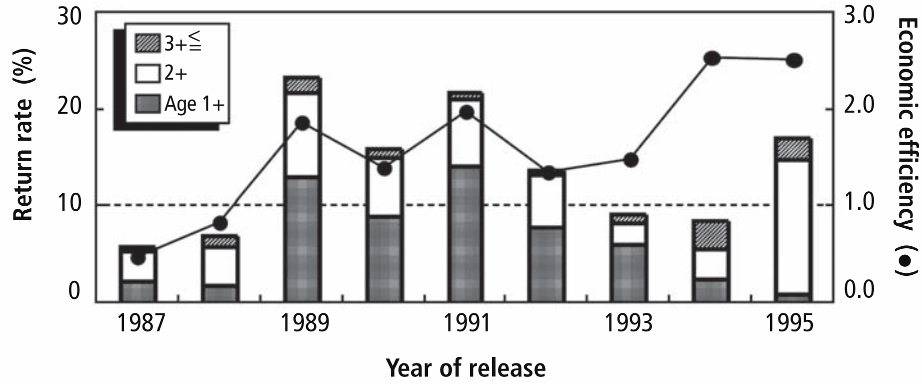


FIGURE 13. Changes in estimated return rate by age class and the economic efficiency for the nine releases from 1987 to 1995



The estimated value of landings for each release ranged from 4 341 000 to 13 596 000 yen. For the 1987 and 1988 releases, with low return rates, the economic efficiency fell below the break-even point. By contrast, for the five release groups from 1989 to 1993 with an improved return rate, the value of the returns exceeded the release costs and the economic efficiency ranged from 1.34 to 1.96. Furthermore, the economic efficiency for the two releases of 1994 and 1995 reached 2.53 and 2.52, respectively, owing to the increase of age 2+ and age 3+ fish in the landings as a result of the size limitation (Table 5, Figure 13).

The relationship between estimated return rates and economic efficiencies for the seven releases from 1988 to 1993 revealed a positive correlation ($R^2 = 0.79$). Economic efficiency thus generally depended on the return rate. Economic efficiencies for the 1994 and 1995 releases were stable at the higher level regardless of the return rate, showing that the body length regulation increased economic efficiency (Figure 14).

TABLE 5. Release cost, estimates of landing value (1000 yen) from released flounder and economic efficiency in Miyako Bay

Year	Release cost	Landing value			Total value	Ecomonic efficiency
	(A)	1+	2+	3+	(B)	(B/A)
1987	9 420	475	1 553	2 313	4 341	0.46
1988	8 700	331	3 393	3 478	7 202	0.83
1989	4 830	1 890	4 273	2 841	9 004	1.86
1990	5 600	1 434	4 052	2 236	7 722	1.38
1991	5 760	3 328	5 366	2 613	11 307	1.96
1992	3 840	1 070	2 656	1 432	5 158	1.34
1993	6 000	1 666	3 517	3 681	8 864	1.48
1994	4 000	1 230	2 878	6 010	10 118	2.53
1995	5 400	285	8 693	4 618	13 596	2.52
Total	53 550	11 709	36 381	29 222	77 312	(1.44)