DISCUSSION

Stocking variables affected the return rates

Scatter plots for the average size at release and return rates showed no linear relationship, suggesting that causes other than size at release affected the return rates (Figure 15).

Quality of juveniles

In the juvenile production process, the JASFA Miyako Station selected juveniles of delayed growth to make their length uniform and to prevent cannibalism. Selected juveniles of delayed growth were reared in separate tanks. Only juveniles of normal growth were released from 1989 to 1992, whereas many juveniles of delayed growth were released in 1987 and 1988. The distribution of sound juveniles to Members of the JASFA took first priority and juveniles of normal growth were distributed to several Prefectures in 1987 and 1988. The size at release for 1987 and 1988 were almost the same as for releases from 1989 to 1992; however, time at release became later because the rearing period was extended as a result of the delayed growth (Figure 6, Appendix 2).

We observed clear seasonal growth changes of released flounder, with a period of growth between June and December and a period of no growth from January to May. The releases of 1987 and 1988 were evidently inferior in terms of growth to other groups. By contrast, the releases from 1989 to 1992 showed growth patterns almost equivalent to that of natural flounder populations (Kitagawa *et al.*, 1994; Figure 16). This result showed that flounder juveniles of TL 80 mm released in Miyako Bay in late August or early September could grow to TL 26–27 cm one year after release, 32–37 cm after two years and 40–45 cm after three years. We considered the quality of juveniles caused the difference in return rate of releases from 1987 to 1992. The juveniles of delayed growth released in 1987 and 1988 might have problems related to an inability to survive and lack of physical strength that could directly affect the return rate. Therefore, we concluded that the juveniles of

FIGURE 14. Relationship between return rate and economic efficiency for seven releases from 1987 to 1993. Two releases (1994 and 1995) were outwith the linear relationship with high economic returns because of contributions from fishery management. The numbers against the symbols are the year of release

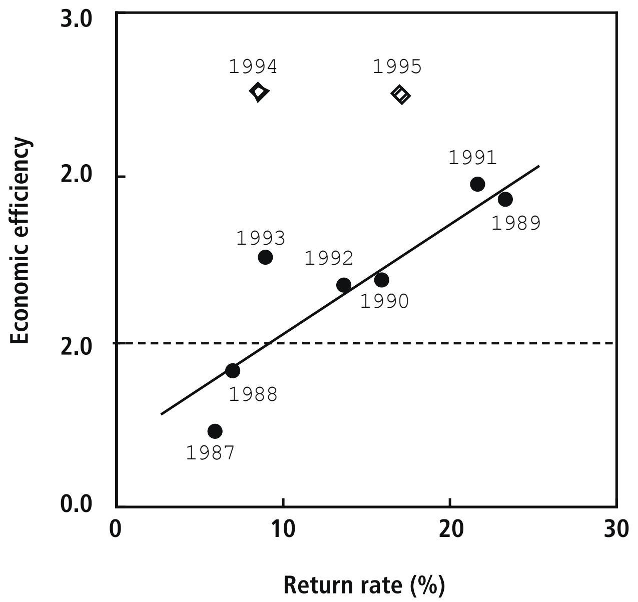


FIGURE 15. Relationship between sizes at release and return rates for nine releases from 1987 to 1995. The numbers against the symbols are the year of release

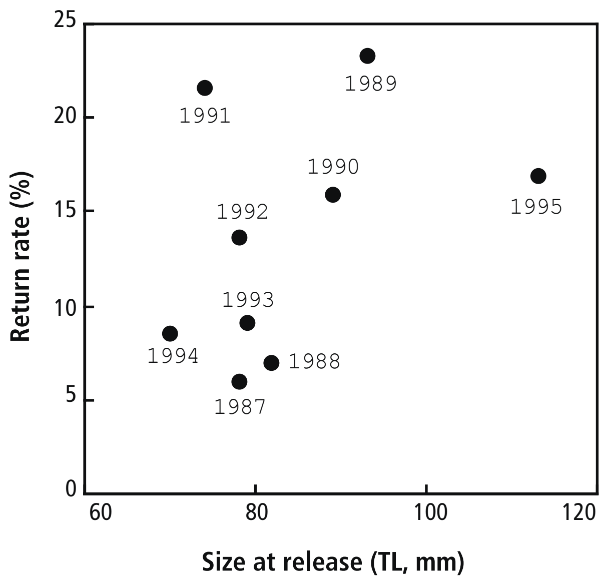
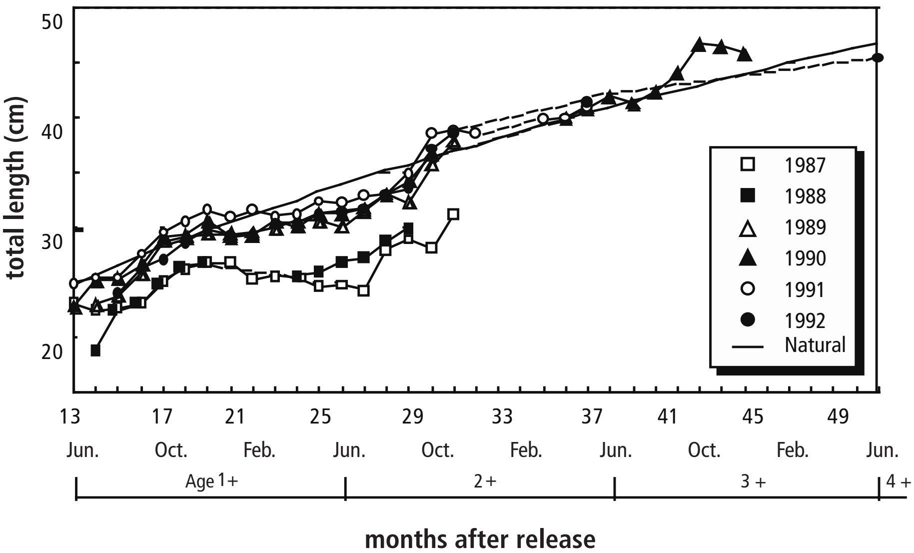


FIGURE 16. Growth patterns of released flounder for six releases from 1987 to 1992. The mean total length of released flounder estimated from marked fish was plotted along with the growth curve of natural flounder, which was the average of females and males calculated by using the growth curves of Kitagawa *et al.* (1994)



delayed growth in the larval rearing process were inferior in terms of survival and growth rates after release. Judging from the relatively high return rates and similar growth curves to natural flounder, the four releases from 1989 to 1992 were concluded to be of good quality.

Time at release

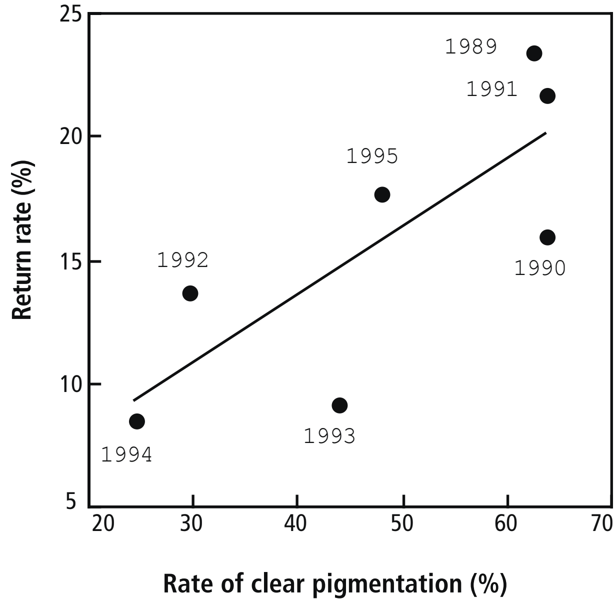
Fujita, Mizuno and Nemoto (1993) pointed out through their surveys in Fukushima Prefecture that delayed releases in a period of lower water temperature slowed growth and lowered the return rate of the released flounder. A comparison of time at release in each group at Miyako Bay showed a difference of two weeks between the releases of 1990– 1992 (high return rate) and those of 1987 and 1988 (low return rate). However, there was no distinct difference in the time at release between the 1989 release (high return rate) and those of 1987 and 1988 (low return rate). There was no difference between releases from 1989–1992 and 1995 (high return rate) and those of 1993 and 1994 (low return rate).

Disappearance of black pigmentation

The low return rates for releases of 1993 and 1994 could not be explained by the above analysis. The environmental conditions of the released area could have changed but we have no data to discuss this further. We examined the possibility of the disappearance of the pigmentation on the abocular side. We classified the level of pigmentation of hatchery-produced juveniles using five grades (G1–G5) as follows: G1, an individual with no pigmentation that was impossible to distinguish from natural fish, and that had not been observed in the juvenile production process at Miyako station; G2, an individual with extremely slight pigmentation that could be distinguished from natural fish by careful observation; G3, an individual with a mid level of pigmentation that covered less than 50 percent of the abocular side; G4, an individual with a distinct level of pigmentation that covered more than 50 percent of the abocular side; and G5, an individual with pigmentation covering the entire abocular side.

The relationship between the estimated return rate of juveniles for G3, G4 and G5 and the sample size was examined for the releases from 1989 to 1995 for normal growth juveniles. A positive correlation was detected, suggesting that the pigmentation may disappear with time ($R^2 = 0.63$, Figure 17). The inspector carrying out this inspection was well trained and had a long experience, so no oversights were expected. The low return rates for the 1993 and 1994 releases were considered to underestimates resulting from a slight disappearance of the pigmentation.

FIGURE 17. Relationship between rate of juveniles with heavier pigmentation than G3 and return rate for seven releases from 1989 to 1995. The numbers against the symbols are the years of release



Post-release survival rate

Because the number of setnets and fishers who operated gillnets and longlines in this area had not varied largely during the period of the survey, the catch pressure on each release was assumed to be constant. The dispersal pattern of each release was stable because few released flounder moved out of the fishing ground around Miyako Bay. The natural mortality rate of each release was considered to be constant after the recruitment when the released fish grew to TL 20 cm. The difference in return rates among releases was considered heavily dependent on the post-release survival rates before recruitment when we neglected the pigmentation problem mentioned above. The quality of juveniles, the time at release and the size at release could all affect the post-release survival rates.

Size at release

We compared the return rates for releases of 1989, 1991, 1992 and 1993 with different sizes at release as distinguished by the ALC or brand marking in order to clarify the relationship between the size at release and the return rate (Appendix 2). We compared the return rates at age 1+ for each release group because it appeared difficult to distinguish release groups for three years after release as a result of shedding of brand marks. In addition, we found a positive correlation ($R^2 = 0.91$) between the return rate at age 1+ and that for the total landings from age 1+ to age 3+ for the releases from 1989 to 1992. We used the releases from 1989 to 1992 for a trial calculation because these releases were not affected by the body length regulation without regard to the underestimation of the return rate caused by disappearance of the pigmentation.

We sampled age 1+ released flounder landed at MFM for six months from June to November and estimated the returns of each release group with a different size at release by identifying their ALC and brand marks. We sampled flounder smaller than TL 30 cm to sample age 1+ fish with certainty and calculated the rate of number of landings for each release group against the sample size. The total number of age 1+ fish returned from the specific release group was estimated by multiplying the rate of each release group by the previous estimates of the total number of landings of age 1+ flounder.

TABLE 6. Estimated return rates at age 1+ for different sizes at release. Release groups were identified by brand and ALC marking

Year of release	Size at release (TL)		No. released (×1000)	No. of returns at age 1+	Return rate at age 1+ (%)
	Class (mm)	(Actual mean) (mm)			
1989	25	23.9	439.0	392	0.1
	60	69.0	25.0	1 879	7.5
	110	107.0	44.0	6 733	15.3
Total			508.0	9 004	
1991	60	62.0	44.0	4 060	9.2
	80	84.1	52.0	9 435	18.1
Total			96.0	13 495	
1992	60	60.0	24.0	875	3.7
	90	88.0	40.0	4 189	10.5
Total			64.0	5 064	
1993	60	60.1	50.0	2 343	4.7
	100	98.7	50.0	3 639	7.3
Total			100.0	5 982	

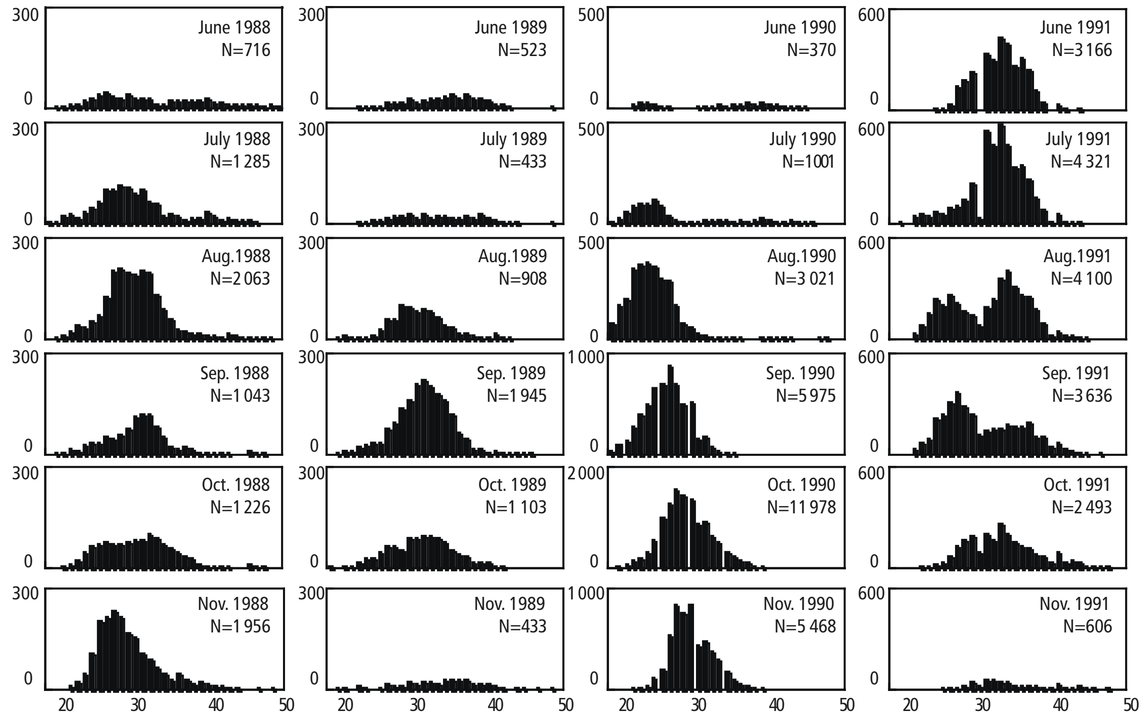
The release size classes in each year were TL 25, 60 and 110 mm in 1989, TL 60 and 80 mm in 1991, TL 60 and 90 mm in 1992, and TL 60 and 100 mm in 1993. In this experiment, we treated TL 60 mm as a standard size. The difference between actual sizes at release and the size classes ranged from –3.0 to +9.0 mm.

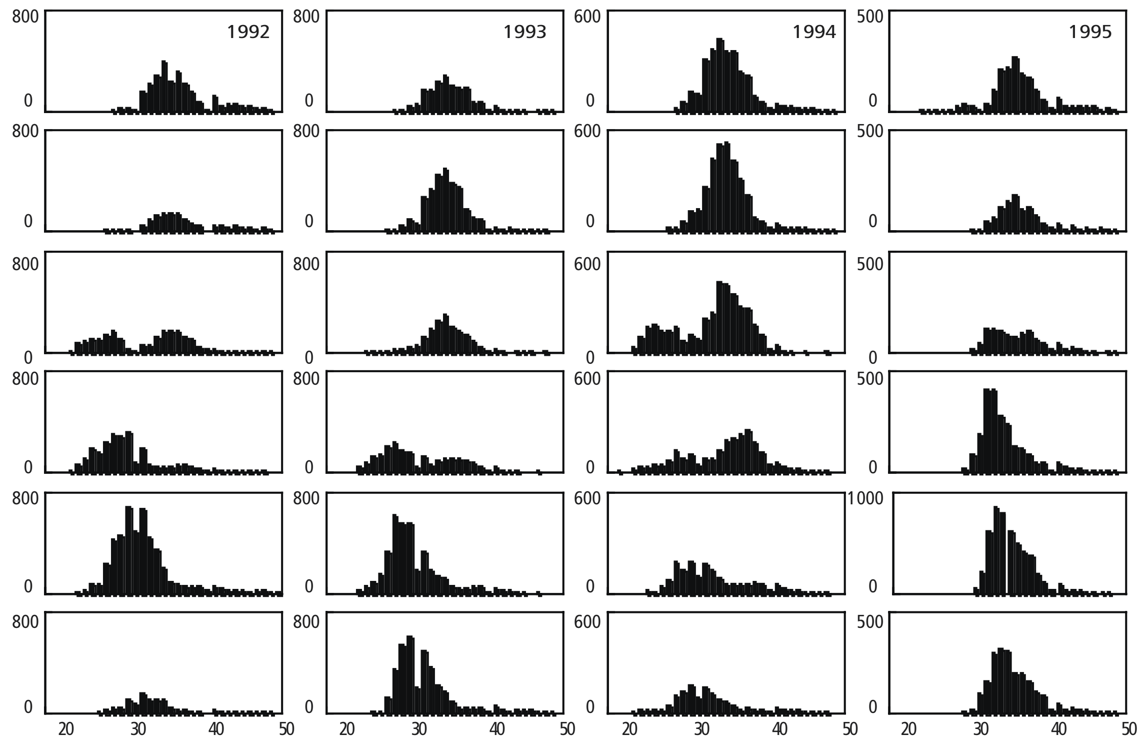
Estimates of the return rate at age 1+ from different sizes at release ranged from 0.1 to 18.1 percent. The return rate became higher with larger release size (Table 6). We calculated the ratio of the return rate for each group to that of the TL 60 mm group in each year. The return rate of the TL 80 mm release was 1.96 times larger than that of the TL 60 mm group, 2.87 times for TL 90 mm, 1.55 times for TL 100 mm and 2.03 times for TL 110 mm (Table 7). The largest ratio was 2.87 for the TL 90 mm group and the ratio decreased when the size at release exceeded TL 100 mm. By contrast, the ratio of the return rate of the TL 25 mm group to that of the TL 60 mm group was about 0.01. We concluded that the most efficient size at release was TL 90 mm. This was in agreement with the result of the otolith marking study, which showed that the survival rate

TABLE 7. Ratio of the return rate for six release groups with different sizes at release to the return rate of the 60-mm size group for each year. The percentage in parentheses shows the return rate at age 1+ for each group given in Table 6

Year of release	Size class at release (TL)					
	25 mm	60 mm	80 mm	90 mm	100 mm	110 mm
1989	0.01	1.00				2.03
	(0.1%)	(7.5%)				(15.3%)
1991		1.00	1.96			
		(9.2%)	(18.1%)			
1992		1.00		2.87		
		(3.7%)		(10.5%)		
1993		1.00			1.55	
		(4.7%)			(7.3%)	

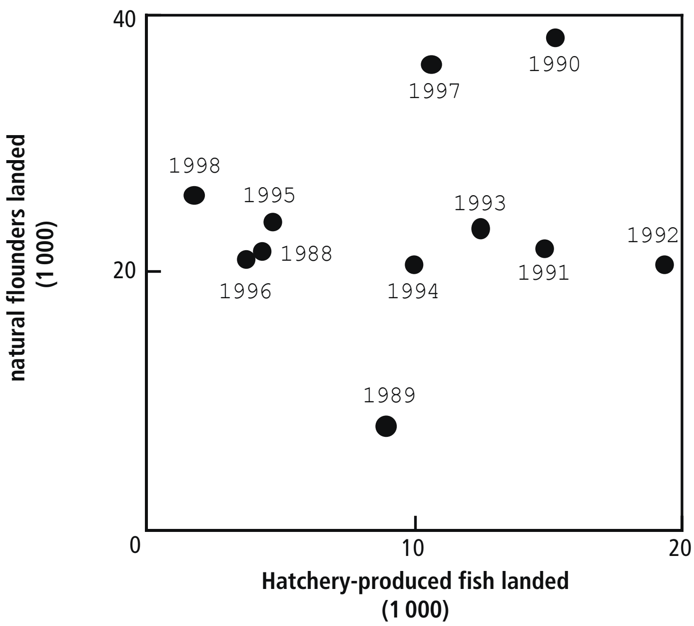
FIGURE 18. Monthly changes in body length frequencies of natural flounder landed at the Miyako fish market from 1988 to 1995





Length composition of natural flounder

FIGURE 19. Relationship between annual numbers of hatchery-produced and natural flounders landed at the Miyako fish market. The numbers against the symbols are the survey year



of flounder juveniles larger than TL 90 mm at release was relatively high and they were successfully recruited to commercial fisheries (Yamashita *et al.*, 1994).

Biological interaction with natural stocks

The average body length of natural flounder was small in 1990 when landings of natural flounder increased remarkably (Figure 11). No age determination of the natural flounders was carried out, and their age composition was unknown. Body length frequencies of natural flounder, however, showed that age 1+ fish was dominant in the landings (Figure 18). In addition, the distributions of the frequencies for August and September in 1990 suggested shorter body lengths of age 1+ fish than other years. The small average body weight in 1990 was considered to be the result of the large number of age 1+ fish, and the smaller body length to suggest a density effect. However, displacement of natural fish by hatchery fish may not have occurred as judged from the largest number of landings (Table 2).

No positive correlation was observed between the number of hatchery-produced fish and that of naturally produced fish in the landings (Figure 19). This showed that the number of landings of natural flounder was stable except for 1989, 1990 and 1997, regardless of the release numbers (Figure 8). The outstanding landings of natural flounder in 1990 and 1997 might be the result of unusually advantageous environmental conditions such as the high abundance of mysids in 1989 and 1996 when recruited flounders grew in the bay. The decrease in the landings of natural flounder in 1989 was caused by poorer environmental conditions in 1986, 1987 and 1988. The numbers of released fish were 116 800 in 1986, 157 000 in 1987 and 145 000 in 1988, these being the three highest numbers during the survey period (Appendix 2). The numbers of age 1+ fish returned were 3 448 from the release in 1987 and 2 751 from the release in 1988 (Table 3), showing the low survival rates of the released fish, although these values were heavily dependent upon the quality of juveniles as mentioned in section **Stocking variables affected the return rates**. There remained the possibility of the displacement of natural fish by the large numbers of releases from 1986 to 1988. Other releases however, were considered not to have displaced natural fish and to have augmented fishery production. It was considered appropriate to limit the number of released fish below 100 000, although this capacity might vary among years depending upon environmental conditions.

CONCLUSIONS

General lessons

We confirmed the return rates for the nine releases of flounder juveniles between 1987 and 1995 in Miyako Bay, which ranged from 5.9 to 23.3 percent (average 12.2 percent). The yield per release ranged from 15.7 to 75.5 g but was raised to 89.8 g in 1995 by introducing a body size regulation. The economic efficiency was also verified, and ranged from 0.46 to 2.53. We found that the flounder release was economically feasible when we released sound juveniles in August and early September.

The success of stock enhancement essentially depended upon the post-release survival rate, which was considered to have seriously affected the return rate. Quality of juveniles and the carrying capacity were also considered essential for success. Large-sized juveniles were advantageous in obtaining high return rates. The most efficient size at release was detected at TL 90 mm. The release of delayed-growth juveniles in rearing tanks resulted in lower return rates, suggesting that the size selection procedure in the juvenile production process to obtain high survival rates was not the most efficient method. Cost reduction for juvenile production was still required to improve economic efficiency, although production costs have been reduced extensively at the JASFA Miyako Station.

The stocking programme has raised the awareness among fishers for conservation of small fish, and this enabled successful implementation of a body length regulation prohibiting catching flounder below TL 30 cm. The fishing regulation worked effectively both for hatchery and natural flounder and improved the yield per release/recruit efficiently.

The juvenile releases of flounder augmented the fishery production. The augmentation was restricted by the carrying capacity of the release site and habitat.

Strength and weakness of the programme

The strength of the programme was that it allowed us to verify the stocking effectiveness scientifically by introducing the fish census at the fish market. Appropriate stocking variables such as release sites, release timings and sizes at release were also considered. The intrageneration effectiveness of stocking was thus evaluated; however, it was unclear whether released fish supplemented the reproduction of the wild stock. Flounder juveniles had been released over all of the fishing grounds in Iwate Prefecture, but we could not compare catch trends of flounder between areas with and without releases. The recent landings of naturally produced flounder in Miyako Bay increased in 1997 and 1998 (Figure 8) and the annual catch of flounder for whole of the Iwate Prefecture reached an historical high in 1997 (Figure 3). A remarkable increase in annual catch has been observed since 1996 in the northern Pacific Ocean where 20 percent of the annual number of flounder released in Japan are concentrated. This increasing trend was also shown elsewhere, except in two areas of the Sea of Japan (Figure 1).

Genetic effects on wild stocks have not been investigated. The only possible precautionary measure would be to develop the technology capable of producing fish genetically close to those of wild stocks. Broodstocks were replaced by natural flounders both in 1997 and in 2000. Tests of genetic similarity between wild and hatchery-produced juveniles and longitudinal monitoring of the genetic structure of the wild stocks will be required (Kitada, Hayashi and Kishino, 2000).

Future prospects and limitation

The JASFA began releasing flounder again in 1999 to examine the rate of disappearance of the pigmentation on the abocular side in the natural environment. The numbers of flounder released were 40 000 in 1999 and 2000, and a release of 100 000 juveniles was scheduled for 2001. All flounders were marked on otoliths with ALC. The fish census at MFM has been continued.

Annual landings of released flounder at MFM were not large, ranging from 810 to 6 366 kg in weight and 887 to 14 703 thousand yen in monetary value. By contrast, landings of natural flounder at MFM were large, ranging from 3 568 to 22 662 kg in weight and 8 782 to 63 077 thousand yen in value, and these numbers had increased and stayed at a high level despite the unexpected discontinuation of releases since 1996 as a result of disease problems. It may not be possible to increase the landings of hatchery flounder beyond the present level because of the ceiling of the carrying capacity in the bay. Stopping releases and monitoring the number of landings and the age composition were considered appropriate. When the landings decrease, stocking could be considered as an option of the adaptive management procedure, in which technologies for juvenile production should be maintained during the moratorium.

The goal of stock enhancement has been to obtain high yield per release, which should be changed to maintain fishery production while conserving wild stocks. Of most importance is to reconsider the necessity of stocking programmes by taking the status of stocks and fisheries into account. Rationality for stock enhancement is demanded.

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Appendix 1

CAPTIVE BROODSTOCKS OF FLOUNDER AT JASFA MIYAKO STATION

Year	Number		Mean TL (range) cm		Mean BW (range) kg		Age	
1987	–	167	48.0	(31.4–66.5)	2.1	(0.4–3.9)	Natural	3–9
							Hatchery	4–7
1988	_	18	60.0	(54.2–70.7)	3.5	(2.5–5.0)	Natural	3–10
	_	67	46.1	(35.2–67.0)	1.3	(0.6–3.8)	Hatchery	5–8
	–	83	45.5	(31.5–62.2)	1.3	(0.4–3.9)		
Total or mean		168	47.3	(31.5–70.7)	1.5	(0.4–5.0)		
1989	_	42	59.0	(44.5–74.0)	2.9	(1.2–5.3)	Natural	4–11
	_	133	50.2	(39.0–72.0)	1.6	(0.8–3.8)	Hatchery	6–9
Total or mean		175	52.3	(39.0–74.0)	1.9	(0.8–5.3)		
1990	_	33	61.7	(47.0–73.0)	3.7	(1.5–5.9)	Natural	5–12
	_	61	53.5	(41.5–72.0)	2.2	(1.2–4.4)	Hatchery	3–10
	–	18	56.8	(49.0–65.5)	2.9	(2.0–4.4)		
Total or mean		112	56.5	(41.5–73.0)	2.7	(1.2–5.9)		
1991	_	39	–		–		Natural	6–13
	_	69	–		–		Hatchery	4–11
Total or mean		108	60.3	(45.0–77.0)	3.2	(1.4–6.6)		
1992	_	37	–		–		Natural	7–14
	_	68	–		–		Hatchery	5–12
Total or mean		105	60.7	(48.0–77.0)	3.3	(1.4–6.6)		
1993	_	36	75.6	(70.0–82.0)	6.4	(4.6–8.3)	Natural	8–15
	_	67	55.6	(49.0–61.0)	2.2	(1.3–2.9)	Hatchery	6–13
Total or mean		103	62.6	(49.0–82.0)	3.7	(1.3–8.3)		
1994	_	43	–		–		Natural	9–16
	_	67	–		–		Hatchery	7–14
Total or mean		110	63.2	(48.0–85.0)	4.2	(1.2–8.6)		
1995	_	43	82.7	(75.0–95.0)	8.2	(5.3–10.0)	Natural	10–17
	_	110	58.3	(51.0–83.0)	2.5	(1.4–2.8)	Hatchery	8–15
Total or mean		153	67.8	(51.0–95.0)	4.8	(1.4–10.0)		
1996	_	78	64.5	(59.0–75.0)	2.8	(2.2–3.8)	Natural	2,3
	_	79	48.9	(43.0–54.0)	1.3	(0.9–1.6)	Hatchery	9,10
Total or mean		157	56.7	(43.0–75.0)	2.0	(0.9–3.8)		
1997	_	21	43.5	(36.0–56.0)	0.9	(0.3–2.0)	Natural	2–4
	_	7	38.2	(32.0–52.0)	0.6	(0.4–0.9)		
Total or mean		28	42.2	(32.0–56.0)	0.8	(0.3–2.0)		
1998	_	14	47.5	(37.0–60.0)	1.8	(0.5–3.2)	Natural	5–6
	_	15	41.7	(35.0–48.0)	0.9	(0.5–1.3)		
Total or mean		29	44.5	(35.0–60.0)	1.3	(0.5–3.2)		

Appendix 2

JUVENILE RELEASES OF FLOUNDER BY JASFA MIYAKO STATION

Year	Release site	Normal size [TL40 mm and over]					Small size [TL40mm under]		
		Number (×1000)	Mean TL range) mm		Month	Marking method (Marking rate, %)	Number (×1000)	Mean TL (range) mm	Marking method (Marking rate, %)
1980	Miyako Bay						245.0	25 (13–30)	–
Total or mean		–	–		–	–	245.0	25 (13–30)	0.0
1981	Taro Bay	13.0	71	(55– 88)	Sep.	–			
		11.0	76	(62– 93)		–			
		15.0	77	(58– 95)		–			
		11.0	94	(72–120)	Oct.	–			
		50.0	79	(55–120)		(0.0)	–	–	–
1982	Miyako Bay	20.0	130	(100–150)	Oct.	Disk tag			
		50.0	100	(95–120)		–			
	Taro Bay	10.0	130	(100–150)		Disk tag			
		13.0	100	(95–120)		–			
	Sakiyama	2.0	140	(100–160)		Anchor tag			
Total or mean		95	110	(95–160)		(33.7)	–	–	–
1983	Taro Bay	25.0	144	(90–174)	Oct.	Disk tag			
		1.0	120	(90–150)		Fin clipping			
		4.0	131	(90–150)		–			
		4.8	180	(120–220)		Disk tag			
	Sakiyama	18.0	120	(90–150)		–			
		13.0	40	(30– 55)		Laser			
		3.7	190	(170–220)	Nov.	Anchor tag			
Total or mean		69.5	114	(30–174)		(68.3)	–	–	–
1984	Taro Bay	7.0	165	(130–220)	Oct.	Disk & Laser			
		5.0	150	(120–220)		Disk tag			
		5.0	188	(150–230)		Ribbon & Laser			
	Sakiyama	2.9	162	(100–220)	Nov.	Anchor, Disk			
		2.0	70	(50– 90)		–			
Total or mean		21.9	157	(50–230)		(23.0)	–	–	–
1985	–	–	–		–	–	–	–	–
1986	Miyako Bay	46.0	52	(36– 64)	Sep.	Ratex			
		3.0	51	(44– 63)	Oct.	–			
		37.8	81	(42–136)		Ratex			
		30.0	98	(74–126)		Ratex & Laser			
Total or mean		116.8	73	(36–136)		(97.4)	–	–	–
1987	Miyako Bay	74.0	84	(62–111)	Sep.	Ratex			
		64.0	62	(42– 79)		–			
		19.0	107	(90–141)		Ratex			
Total or mean		157.0	78	(42–141)		(59.2)	–	–	–

Year	Release site	Normal size [TL40 mm and over]					Small size [TL40mm under]		
		Number (×1000)	Mean TL (range) mm		Month	Marking method (Marking rate, %)	Number (×1000)	Mean TL (range) mm	Marking method (Marking rate, %)
1988	Miyako Bay	126.0	82	(41–107)	Aug.	Ratex			
		9.0	43	(29– 78)		–			
		10.0	120	(108–134)	Oct.	Disk tag			
Total or mean		145.0	82	(29–134)		(93.8)	–	–	–
1989	Miyako Bay	25.0	69	(45– 82)	Aug.	Brand	323.0	21 (16–30)	ALC
		44.0	107	(91–123)	Sep.		116.0	32 (26–37)	
Total or mean		69.0	93	(45–123)		(100.0)	439.0	24 (16–37)	(100.0)
1990	Miyako Bay	54.0	81	(56–100)	Aug.	Brand	194.0	25 (24–33)	ALC
		26.0	107	(95–121)					
Total or mean		80.0	89	(45–123)		(100.0)	194.0	25 (24–33)	(100.0)
1991	Miyako Bay	44.0	62	(56– 72)	Aug.	ALC			
		15.0	82	(66– 93)					
		37.0	85	(76–104)		Brand			
Total or mean		96.0	74	(56–104)		(100.0)	–	–	–
1992	Miyako Bay	24.0	60	(40– 75)	Aug.	ALC			
		20.0	89	(74–109)					
		20.0	87	(76–107)		Brand			
Total or mean		64.0	78	(66– 93)		(100.0)	–	–	–
1993	Miyako Bay	50.0	60	(49– 76)	Aug.	ALC			
		50.0	99	(85–112)	Sep.	Brand			
Total or mean		100.0	79	(49–112)		(100.0)	–	–	–
1994	Miyako Bay	40.0	58	(47– 74)	Aug.	ALC			
		40.0	83	(65–102)	Sep.	Brand			
Total or mean		80.0	70	(47–102)		(100.0)	–	–	–
1995	Miyako Bay	30.0	110	(86–125)	Sep.	ALC			
		30.0	117	(85–138)		Brand			
Total or mean		60.0	113	(85–138)		(100.0)	–	–	–
1996	No releases								
1997	No releases								
1998	No releases								

Appendix 3

ESTIMATION OF AGE COMPOSITION OF RELEASED FLOUNDER WITHOUT MARKS

Most flounders landed on the Miyako fish market were age 1+ and age 2+ fish. We treated the remainder as age 3+ including older fish because age 0+ fish were not landed.

Suppose a monthly body length frequency of untagged hatchery fish with unknown age composition and the total number of individuals in the frequency is known as N. Let the observed number of fish of length class x_j be n_j (j = 1, 2, ... , J) and the total number of each age class be Ni (i = 1, 2, 3). We then hold the relationship as

(1)
$$N = \sum_{j=1}^{J} n_j = \sum_{i=1}^{3} N_i \, .$$

We estimate Ni (i = 1, 2, 3) assuming normal distributions for the length frequencies of age 1+ and age 2+ with means of μ_1 and μ_2 and variances of σ_1^2 and σ_2^2. The probability for age i+ fish in the jth length class is given by

(2)
$$p_{ij} = \frac{\Delta x}{\sqrt{2\pi\sigma_i^2}} \exp\left\{ \frac{-(x_j - \mu_i)^2}{2\sigma_i^2} \right\},$$

where Δ_x is the length class interval. The probability p_{ij} is estimated by substituting the means and variances of age 1+ and age 2+ hatchery fish landed into the Equation (2). A smaller Δ_x provides better accuracy. For length classes larger than mean length of age 2+, length frequencies of age 2+ and 3+ may be highly overlapped. Hence, we first estimate the number of age1+ (N_1) and 2+ (N_2) fish in the total number of individuals in the frequency (N) by minimizing the sum of squares

(3)
$$SS = \sum_{j=1}^{\mu_2} \left(n_j - \sum_{i=1}^{2} N_i \hat{p}_{ij} \right).$$

The number of individuals of age 3+ fish can be calculated by subtracting the estimates of the total number of individuals of age 1+ and 2+ from the total number of individuals in the frequency.

To estimate the weight of the landings by using a length–weight relationship, the number of age i+ fish in the jth length class ($=n_{ij}$) is required, which is estimated by using the estimate of N_i for the length classes of μ_2 and smaller as

(4)
$$\hat{n}_{ij} = \frac{\hat{N}_i \hat{p}_{ij}}{\sum_{i=1}^{2} \hat{N}_i \hat{p}_{ij}} \times n_j \, .$$

For length classes larger than μ_2, n_{ij} of age 1+ and 2+ is estimated by

(5)
$$\hat{n}_{ij} = \hat{N}_i \hat{p}_{ij} \, .$$

If $(n_{1j} + n_{2j}) > n_j$, n_{ij} is estimated by Equation (4) judging age 3+ fish are not included in the jth class. The number of age 3+ fish is estimated by subtracting the number of age 1+ and 2+ fish from the observed number in each class as

(6)
$$\hat{n}_{3j} = n_j - \sum_{i=1}^{2} \hat{n}_{ij}$$