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Community-Based Stock Enhancement and Fisheries Management of the Japanese Flounder in Fukushima, Japan

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In Fukushima Prefecture, one million hatchery-reared juvenile Japanese flounder Paralichthys olivaceus *have been released annually in the stock enhancement program since 1996. A community-based management system is used for this flounder fishery, where fishers pay 5% of their annual landings to operate the stock enhancement program. Also, since 1993, fishers have consented not to catch flounder <30 cm total length to maximize economic gains from the investment in stock enhancement. Our fish market surveys revealed that released flounder annually contributed an additional 30–90 tons to the catch. However, the economic efficiency of stocking has reduced since 1996, which has been largely attributed to a decline in fish price and recapture rate. Another problem is that the population dynamics of wild flounder have never been considered during implementation of the stock enhancement program. The occurrence of a dominant year-class of wild flounder causes a dramatic increase in landings and removes the need to release hatchery-reared juveniles. However, the program cannot be easily terminated because it plays important roles in having fishers recognize the importance of fishery management. It is a difficult but important realistic problem concerning how to make the stock enhancement program more flexible and effective.*

Keywords community-based system, dominant year-class, Japanese flounder, stocking effectiveness, wild population dynamics

INTRODUCTION

Stocking commercially important fishes and invertebrates has been widely carried out in Japan (Masuda and Tsukamoto, 1998; Kitada, 1999). The Japanese flounder *Paralichthys olivaceus* is one of the principal target species for stock enhancement in Japan, and >25 million hatchery-reared juveniles have been released every year along almost the entire coast of Japan (36 prefectures) since 1998. To make release programs more effective, fishery management, which limits the catch of fish less than 30 or 35 cm total length (TL), has been implemented with the fishers' consensus in >20 prefectures (Kitada, 1999).

Fukushima Prefecture, located in northern Japan, had confirmed the high stocking effectiveness of Japanese flounder until 1996. In Fukushima, Japanese flounder are caught mostly by trawls (161 tons annually and 44% of the total catch of flounder in 2000–2005) and gill nets (200 tons and 54%), and have accounted for a large part of the landing value of these coastal fisheries (6% in trawls and 35% in gill nets in 2000–2005). Because the stock level of flounder had been low in the 1980's, >200,000 flounder fingerlings produced by Fukushima Prefectural Sea-Farming Association were experimentally released on an annual basis between 1987 and 1995. High recapture rates of 8–31% and high economic efficiencies (the value of landings from released fish compared to the cost of juvenile production and release) of 1.7–3.8 by these releases were confirmed through fish market surveys (Kitada et al., 1992; Fujita et al., 1993; Fujita, 1996). As a result, a stock enhancement program was started in 1996 with the consensus of fishery communities, the prefectural government, and the cooperative association (Fujita, 1996). In this program, one million 10 cm TL juvenile flounder, which was suggested as a cost-effective size for post-release survival (Yamashita et al., 1994), are released annually along 160 km of the coast in Fukushima (Figure 1). A community-based

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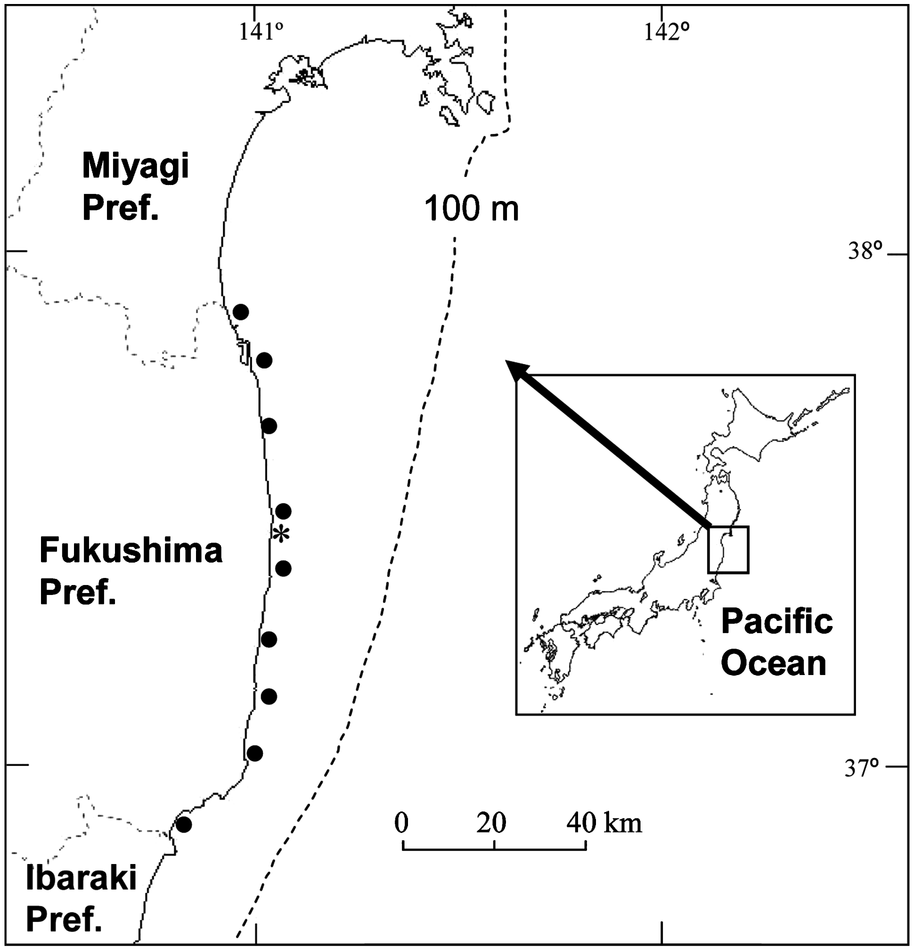

Figure 1 Map of the study area. Closed circles indicate the location of release points of hatchery-reared juvenile Japanese flounder. An asterisk shows the main site of collection of wild flounder juveniles.

management system is used for the flounder fishery, in which fishers pay 5% of their annual landings to operate the stock enhancement program (approximately 30% of juvenile production cost). Also, since 1993, fishers consented to protect small flounder by only retaining flounder ≥30 cm TL. The implementation of such commercial size limitation for fish in Fukushima was the first case in Japan (Kitada, 1999). As a result of these efforts, catches of flounder successfully increased from 1995 (Figure 2).

However, the economic efficiency of stock enhancement in Fukushima in 1996–2000 was far lower than that recorded from 1987 to 1995 (Tomiyama et al., 2004). This is largely attributed to a reduction in the recapture rate and a decline in the market price of fish due to the economic depression in the 1990's; the average market price of Japanese flounder dramatically decreased from 1993 to 1995 and remained low thereafter (Figure 2). Decreases in the market price of fish directly reduce the economic efficiency of stocking. An emergent issue is how to achieve high effectiveness of the stock enhancement program.

There is also an important issue in the stock enhancement program of Japanese flounder in Fukushima. The annual one million releases are invariable, and population dynamics of wild flounder have never been considered. On the other hand, dominant year-classes of wild Japanese flounder occurred in 1984 (Fujita and Mizuno, 1990), 1994, and 1995 (Watanabe and Fujita, 2000), and resulted in a dramatic increase in catch and landings from the next year (Figure 2). Releases of hatchery-reared juveniles in such situations should be unnecessary.

This article aims to (1) evaluate the effectiveness of the stock enhancement program in recent years, (2) predict the effects of increases in wild stock on stocking effectiveness, and (3) consider how to make the stock enhancement program more effective, especially how to take the population dynamics of wild flounder into account.

MATERIALS AND METHODS

Fish Market Surveys

To evaluate the economic effectiveness of the stock enhancement program, we carried out surveys 2–4 times per month per market from September 1994 to August 2006. We chose the 8 principal fish markets out of 11 fish markets available for survey;

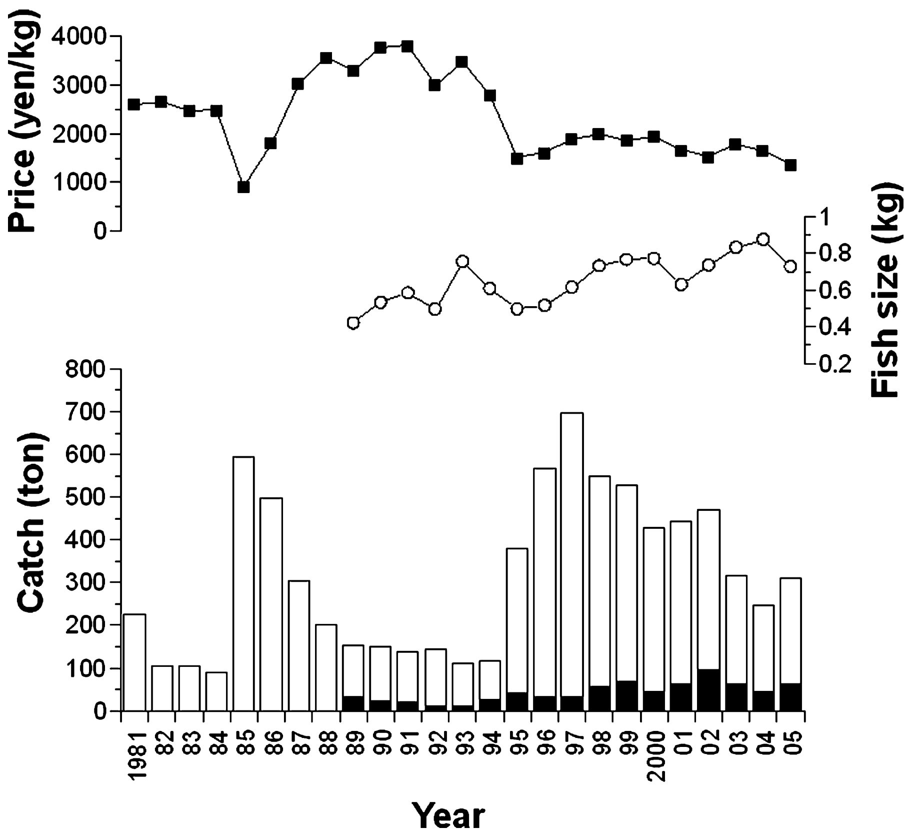

Figure 2 Average market price, average body weight, and total weight of landed Japanese founder in Fukushima Prefecture. Solid and open bars denote released and wild fish, respectively.

most fishery-caught Japanese flounder in Fukushima are landed in those 8 markets (e.g., 94.5% in 2005). Landed flounder were identified as wild or released on the basis of body color anomalies in released fish: hatchery-reared flounder generally have black pigmentation on the blind side. Total length (TL), body weight (BW), and market price (yen/kg) were recorded for both wild and released fish.

Collection of Wild Juveniles

Fishers annually collect shrimp and prawns, as angling baits, using small trawl nets of 5 m mouth opening, 26 m length, and 4-cm mesh in the cod end, in the sandy-bottom grounds <15 m deep off Fukushima (Figure 1). As wild juvenile flounder >5 cm TL are incidentally caught by these trawl nets mainly from August to September, we collected those juveniles annually from 1994 to 2005. The number of juveniles per 30-min tow (CPUE) was determined for each collection day and averaged from August to September. The data prior to the day when juvenile flounder were first collected in each year were eliminated. Average CPUE was used as an index of year-class strength.

Analysis

We estimated stocking effectiveness for each year-class using ratio estimation (Kitada, 2001) rather than a two-stage sampling estimation (Kitada et al., 1992) because our market surveys were not carried out randomly either on days or markets. The landed weight and surveyed weight were important in our estimation method. The landed number and weight of each year-class of wild and released fish in Fukushima Prefecture were determined as follows:

$$N_i = \sum_j \left[\left(SW\ total_j \times \sum_k SW_{jk}^{-1} \right) \times \sum_k \left(n_{ijk} \times w_{jk}^{-1} \times SW_{jk} \right) \right]$$

$$W_i = \sum_j \left[\left(SW\ total_j \times \sum_k SW_{jk}^{-1} \right) \times \sum_k \left(w_{ijk} \times w_{jk}^{-1} \times SW_{jk} \right) \right]$$

where N_i (W_i) = total landed number (weight) of fish of group i, $SW\ total_j$ = statistical landed weight of fish in Fukushima Prefecture (total 11 markets) in the jth month, SW_{jk} = statistical landed weight of fish at market k in the jth month, n_{ijk} (w_{ijk}) = total landed number (weight) of fish of group i surveyed at market k in the jth month, and w_{jk} = landed weight of fish surveyed at market k in the jth month. Statistical landed weight of each market is recorded by fishery communities. Prior to the above estimation, we determined ages of surveyed flounder from their body sizes (TL or BW). Although the Japanese flounder has a lifespan >10 years (Minami, 1997), fish >3 years old were relatively few and therefore were pooled to simplify the analysis. There were 8 survey markets and 48 survey months (0-, 1-, 2-, and 3-year-olds) in this study. There were 8 groups (4 year-classes of wild/released) in each month.

Because the market price of Japanese flounder differed largely between trawls and gill nets (Tomiyama et al., 2004), the landed value of each year-class of wild and released fish was determined as follows:

$$V_i = \sum_j \left[\left(SV total_j \times \sum_m SV_{jm}^{-1} \right) \times \sum_m (p_{ijm} \times W_{ijm}) \right]$$

where V_i = total landed value of fish of group i, $SVtotal_j$ = statistical landed value of fish in Fukushima Prefecture in the jth month, V_{jm} = statistical landed value of fish caught by method m in the jth month, p_{ijm} = market price of fish of group i caught by method m in the jth month, and W_{ijm} = landed weight of fish of group i caught by method m in the jth month. We used m for the two survey methods of trawls and gill nets, although there were some other methods of catching Japanese flounder, e.g., angling. W_{ijm} was determined by dividing the W_{jm}, statistical landed weight of fish caught by method m in the jth month, into the 8 groups, with reference to the landed weight of fish of each group in some markets in which the landed flounder are usually caught by method m. The price of each group was established on the assumption,

$$V_{jm} = \sum_i \left(p_{ijm} \times W_{ijm}\right).$$

Recapture rates in number (%), landed weight (tons), and landed value (yen) of released fish were determined for each year-class. Landed value divided by the cost of juvenile production was used as the economic efficiency; production cost was calculated on the basis of 100 yen per one juvenile of 10 cm TL.

To show that a high level of occurrence of age-0 fish leads to increases in landings, relationships between year-class strength of wild juveniles and the landed number or weight of Japanese flounder after reaching commercial size were examined. To confirm that released fish contribute to increase in catch without replacement of wild fish production caused by releases, we examined (1) the relationship between catches of wild and released fish, which is negative when replacement exists (Kitada and Kishino, 2006), and (2) the relationship between the number of fish released and recruitment success of wild fish, which is also negative when replacement exists. As an indicator of recruitment success, we used the ratio between catch in number of a wild year-class and the year-class strength as juveniles.

To test if the landings of flounder affect market price, we examined relationships between the price and possible controlling factors, landed fish size and landed weight, using a multiple regression model. The average price (landed value divided by landed weight, yen/kg), landed weight (tons), and average landed size of individual fish (kg) were calculated for each year from 1989 to 2005. The price also would be affected by economic trends, so a ratio (the data of each year/the data 1 year before) was used for all variables (price, fish size, and landed weight).

To test whether or not the abundance level of wild flounder affects their growth, growth was compared among 1984–2002 year-classes. As the index of occurrence level of each year-class, the number of age-1 commercial landings in Fukushima was used, because there were no data available for CPUE of wild juveniles before 1994. As the index of growth of each year-class, we used the most frequent body size in landings at Soma-Haragama fish market in November at age-1. We chose the data in November, because wild Japanese flounder typically reach commercial size (30 cm TL) in August and September at age 1, because they grow rapidly from August to October (Yoneda et al., 2007), and because the landings of Japanese flounder were high around November. We chose Soma-Haragama fish market because of an existing sufficient dataset of fish market surveys from 1984–2006 and because it had the highest number of landings of Japanese flounder in Fukushima Prefecture (49.2% of total landings in weight from 2001–2005).

RESULTS

Stocking Effectiveness of Hatchery-Reared Juveniles

Catch of released flounder reached 30–90 tons and comprised 4.6–20.1% of the landed weight and 3.5–14.8% of landed value from 1996 to 2005 (Figures 2 and 3). Replacement of wild fish caused by released fish was not detected; the relationship between catches of released and wild fishes was not significant ($n = 17, r = 0.44, p = 0.07$); nor was the relationship between number of released flounder and recruitment success ($n = 9$, $r = 0.19$, $p = 0.62$).

Recapture rates of released fish in number were 7.2–17.0% in 1996–2002 year-classes (Table 1). Economic efficiency

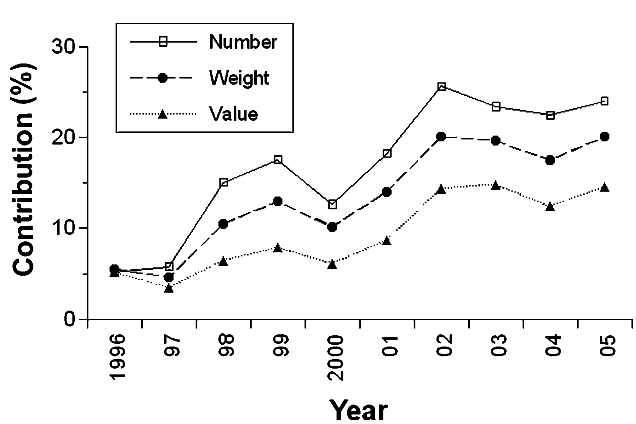

Figure 3 Annual contribution rates of released Japanese flounder to the total landed number, weight, and value in Fukushima Prefecture.

Table 1 Stocking effectiveness of Japanese flounder released along the coast of Fukushima from 1994 to 2002

Release Year	Number of Fish Released (×1000)	Recapture Rate (%)	Catch (Tons)	Landing (Million Yen)	Economic Efficiency*
1994	387	21.3	44.4	64.5	1.67
1995	438	13.0	29.3	39.1	0.89
1996	1006	8.0	42.3	56.7	0.56
1997	1100	10.3	60.7	74.5	0.68
1998	1204	9.4	71.8	80.5	0.67
1999	1015	7.9	51.3	62.8	0.62
2000	1050	14.4	85.0	95.2	0.91
2001	1030	17.0	101.0	116.7	1.13
2002	1030	7.2	49.0	54.1	0.53

*Landed value divided by the cost of seed production (see text).

exceeded 1.0 only in the 2001 year-class; release investment between 1996 and 2002 was higher than the value of landings from released fish, except in 2001 (Table 1). There was a significant relationship between recapture rates in number (*RR*) and economic efficiency (*EE*): $RR = 12.8 \ln EE + 15.0$ ($n = 9, r = 0.99, p < 0.001$). Using this equation, a 15.0% recapture rate is needed for economic efficiency to exceed 1.0.

Wild Population Dynamics

Wild Japanese flounder juveniles were collected by small trawl nets from 1994 to 2005 except in 2003, a year when settlement of wild juveniles was markedly delayed (Uehara et al., 2005). The number collected varied largely among years. Many juveniles were collected in 2005 as well as in 1995, which were dominant year-classes (Figure 4).

Significant positive relationships were detected between occurrence level of wild juveniles and landed number or landed weight of wild flounder of the same year-class:

$$N_t = 56.1C_t + 430.0\ (n = 9, r = 0.74,\ p < 0.05)$$

$$W_t = 27.3C_t + 343.9(n = 9, r = 0.72,\ p < 0.05)$$

where N_t = total landed number (thousands of individuals) of flounder of year-class t from 0 to 3 years of age, N_t (W_t) = total landed weight (tons) of fish of year-class t, and C_t = collected number of wild juveniles by small trawl nets per 30 min towing in year t. No significant relationship was detected between occurrence level of wild juveniles and recapture rate of released fish ($n = 9, r = 0.04, p = 0.91$).

On a long-term basis, the market price of Japanese flounder tended to decline with increasing catch level (Figure 5). However, this inverse relationship was not significant in 1993–2005 (Spearman rank correlation, $n = 13, r_s = -0.13, p = 0.66$) but was significant in 1969–1992 ($n = 24, r_s = -0.81, p < 0.001$). On a short-term basis, market price of Japanese flounder will decrease when the size of landed fish decreases or landed weight

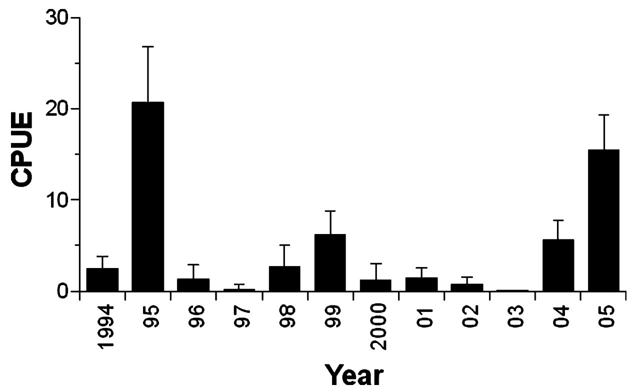

Figure 4 Number of wild juvenile Japanese flounder collected per 30 min towing by small trawlers (CPUE). Vertical bars denote standard errors.

increases. This is because the ratio of market price compared to the price 1 year before (y) was significantly accounted for by size of landed fish (x_1) and by landed weight (x_2): $y = 0.55\,x_1 - 0.12\,x_2 + 0.52$ (multiple regression analysis, x_1: $t = 4.22$, $p < 0.01$; x_2: $t = -2.76$, $p < 0.05$; constant: $t = 3.16$, $p < 0.01$; $R^2 = 0.77$, $R_a^2 = 0.73$, $F_{2,15} = 21.5$, $p < 0.001$).

Growth of the dominant year-classes in 1984 and 1995 were both slower than that of other year-classes (Figure 6); most of the wild fish in those year-classes took a few more months than usual to reach commercial size, 30 cm TL.

DISCUSSION

Stocking Effectiveness of Hatchery-Reared Juveniles

Catches of released flounder were estimated to be around 60 tons from 1996 to 2005. These catches should be in addition to the catch of wild fish, because replacement of wild fish caused by releases was not observed. This result indicates that releases of hatchery-reared juveniles can contribute to increased landings of Japanese flounder.

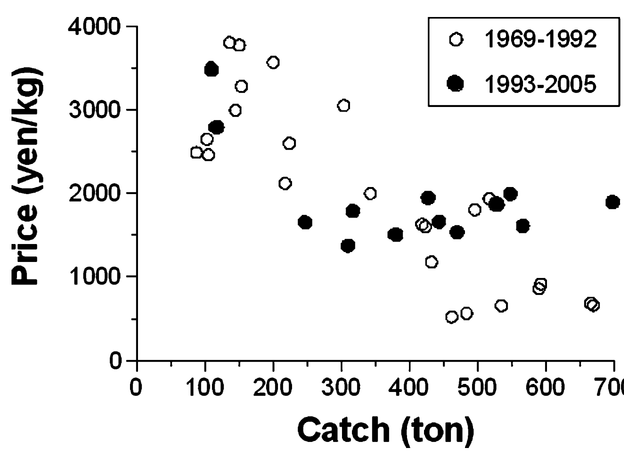

Figure 5 Relationships between annual catch and average market price of Japanese flounder in Fukushima before and after 1993, when fishery regulation on flounder <30 cm TL was introduced.

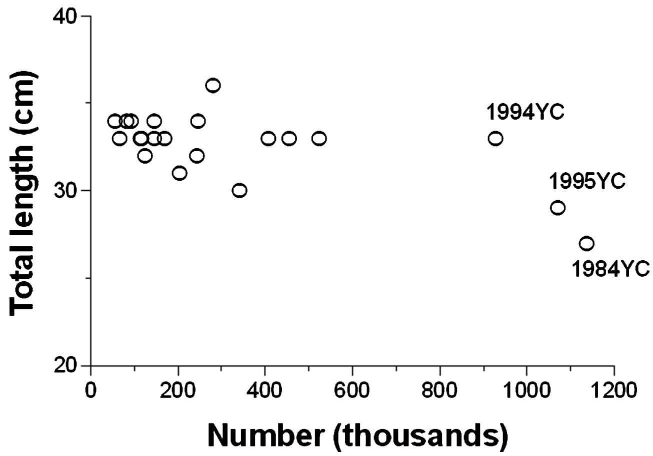

Figure 6 Relationship between the catch of 1-year-old Japanese flounder in number and the mode of total length distribution in November at 1 year of age for each year-class (YC). Dominant year-classes occurred in 1984, 1994, and 1995.

Recapture rates of fish released in 1996–2002 were lower than those released in 1987–1995 (7.8–30.6%; Fujita, 1996), a period in which <0.5 million juveniles were released (Table 1). However, recapture rates of about 10% are still very high for stock enhancement programs with Japanese flounder, considering the large scale of this program; such high recapture rates have been observed in Japan only around Fukushima. This is possibly attributed to a high abundance and productivity of prey (mysids and fish), large areas of nurseries, and high pressure from fisheries (Fujita et al., 1993).

Economic effectiveness of stocking can be evaluated from two aspects. One aspect is economic efficiency, which is >1 when the benefit from released fish exceeds the cost of juvenile production and release. The other is the contribution of released fish to total landings; economic effectiveness is reached when the landing value of released fish exceeds the fishers' investment in the stock enhancement program. For the former aspect, it is very difficult to achieve the target recapture rate of 15% needed to obtain economic efficiency >1. If juvenile production cost could be decreased, this target recapture rate also could be decreased. Considering the latter aspect, the contribution of released fish to the total value of Japanese flounder was mostly over 5%, except for 3.5% in 1997 (Figure 3), indicating that fishers have profited from the release program because they invest 5% of their landing values of Japanese flounder for the program. However, during years when wild stock yields are disproportionately high, as observed in 1997 (Figure 2), the landed value of released fish may become insufficient to cover the investment made by fishers in stock enhancement.

Contribution levels of released fish to total landings were higher in number than in either weight or value (Figure 3), which was also observed in Miyako Bay, Japan, by Okouchi et al. (1999). This pattern strongly indicates that the released fish landed in the fishery were smaller than wild fish, and that released fish were traded at lower prices in the market than wild fish. Indeed, the market price of released flounder was far lower than the price of wild fish (approximately 20–40% less than wild fish) because of their irregular body color. Thus, an increase in the body size of landed fish or prevention of the body color anomaly would increase the economic efficiency of stocking.

Stocking may induce secondary effects on fishery landings. Howell and Yamashita (2005) stated that stable landings of Japanese flounder in Japan over the last 20 years may indicate that the contribution of releases to commercial fisheries and reproduction of stocked fish may play an important role in stabilizing fishery landings. Although successful reproduction of released flounder was actually observed by Fujii et al. (2006), a quantitative evaluation of the reproductive contribution by released fish to the flounder stock has never been conducted.

Issues Concerning Stocking and Wild Population Dynamics

The stocking program should consider carefully the population dynamics of flounder. Dominant year-classes resulted in a dramatic increase in catch and landings in the past decade (Figure 2); the occurrence of a dominant year-class in 2005 will possibly induce an increase in catch and landings of Japanese flounder from 2006 to 2007.

The occurrence of dominant year-classes affects the economic and ecological aspects of flounder stock enhancement. Increases of catch and landings will likely cause decreases in the market price of the fish (Figure 5). Increased landings and the subsequent decline of market price will decrease the economic efficiency of releasing juveniles when the stock has been dramatically enhanced.

Furthermore, growth of dominant year-classes was slower than those of other year-classes, indicating that carrying capacity of Japanese flounder in this region is limited and is approached when a dominant year-class occurs. This hypothesis might be applicable to the 2005 year-class because growth reduction was also observed (Tomiyama, unpublished data, 2006). However, growth of other strong year-classes such as the 1999 and 2004 year-classes (Figure 4) was not decreased, possibly because food was generally abundant and carrying capacity was seldom reached (van der Veer et al., 2000). Available carrying capacity is a necessary condition for successful stocking (Støttrup, 2004). Excessive releases (overstocking) will inhibit growth of wild flounder (Yamashita et al., 2006) and thus result in the reduction of wild fish production, a form of lost production caused by releases. Additionally, excessive releases would cause impacts on other species (Bell, 2004).

How Can We Make the Release Program More Effective?

Releases of hatchery-reared juveniles are evidently unnecessary, from economic and ecological bases, in the short term after occurrence of a dominant year-class of wild fish. The stocking program would become unprofitable for fishers and program staff. However, it is difficult to terminate the stocking program because of the following social reasons:

1. The stock enhancement program has the support of the fishing community and cooperative associations, especially Fukushima Prefectural Sea-farming Association, which annually produces hatchery-reared juveniles for releases. To prepare for an unexpected decrease in wild flounder stock, the maintenance of rearing facilities, parental flounder, and staff are all needed. To obtain salaries for staff of the Fukushima Prefectural Sea-farming Association, funding for hatchery-reared juvenile production is necessary.
2. The aspect of the release program where fishers invest 5% of their annual landings and then release juveniles themselves has played an important role in having fishers recognize the importance of protection of small fish and efficient use of the stock. If the release program is terminated, this community-based system of stock enhancement and fishery management will collapse.
3. Prediction of occurrence levels of wild fish is impossible because juvenile production in the hatchery begins before field surveys of wild recruitment patterns. At the moment we recognize the occurrence of a dominant year-class, production of hatchery-reared juveniles has already progressed well beyond the starting point.

It might be effective for the stock enhancement program to reduce the amount of releases in the year following a dominant year-class because the market price of fish will be decreased when the wild stock is enhanced. Additionally, the slow-growing wild fish of the 2005 year-class might compete for food with hatchery-reared fish released in 2006 because of the small body sizes of the former. Consensus of the fishing community is necessary to keep the 5% investment by fishers to maintain the sea-farming association even when the number of juveniles needed for release is reduced.

Because the program is organized around a community-based system, these kinds of considerations about stocking plans need to be discussed by fishers, the prefectural government, and cooperative associations to decide how to continue this program and how to make it flexible and more effective. Construction of such a release program is strongly encouraged.

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