Capture-based aquaculture of yellowtail

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SUMMARY

The 2004 production of cultured yellowtail (*Seriola* spp.) in Japan from 1 288 enterprises was 150 028 tonnes valued at ¥111.2 billion (US$1.334 billion). Yellowtail mariculture has developed remarkably due to the abundant supply and low price of wild-caught juveniles (*Mojako*) and sardines used as the main fish feed of fishmeal component. Hatchery produced yellowtail seed are far more expensive. Other critical elements that supported the growth of yellowtail farming include the existence of abundant suitable culture sites along the Japanese coast and innovative technical developments.

The history of yellowtail culture in Japan began over 70 years ago. Before that, fishers cultured undersized fish in ponds and sold them when they reached marketable size. This utilization of bycatch (undersized fish) was accepted by the public, particularly as unmarketable fish were often used as fertilizer or livestock feed. Currently aquaculture production for many species exceeds that landed from capture fisheries.

Some commercial culture trials on amberjack have been undertaken in Taiwan Province of China, Mexico and Vietnam, but no successes have been achieved with raising yellowtail. The main constraints include diseases and low production costs in tropical areas. In contrast, the culture of *Seriola* spp. is promising due to their strong vitality and rapid growth, and may well expand at the global level through hatchery-produced juveniles.

DESCRIPTION OF THE SPECIES AND ITS USE IN AQUACULTURE

Life cycle and geographical distribution

The genus *Seriola* or yellowtail, a highly active fish belonging to the Carangidae family, is found in the Atlantic, Indian and Pacific oceans, with most species occurring in tropical and subtropical waters. A few species have global distribution (such as the amberjack, *Seriola dummerili*, and the Pacific yellowtail, *Seriola revoliana*) while others, such as the Japanese yellowtail, *Seriola quinqueradiata*, have a more limited regional distribution. Currently approximately 12 species of *Seriola* that have been described.

These fish are typically streamlined, elongated and laterally compressed. Larger members of the genus which are commonly cultured (i.e. the gold-striped amberjack, *Seriola lalandi*, and *Seriola dummerili*) may reach 200 cm in length and weigh up to 50–60 kilograms. *Seriola* spp. typically inhabit deep open waters often adjacent to

TABLE 1
***Seriola* species cultured in Japan**

English name	Yellowtail	Amberjack or great amberjack	Gold-striped amberjack or yellowtail
Japanese name	Buri, Hamachi, Mojako	Kanpachi, Akahara	Hiramasa
Scientific name	*Seriola quinqueradiata*	*Seriola dumerili*	*Seriola lalandi* or *Seriola aureovittata*
Market size	up to 6 kg for fillet 3.5–4.5 kg for sashimi	3.5–5.5 kg for sashimi	up to 4 kg for fillet and sashimi
Price (¥/kg)	600–900 to producer 1 200–2 500 to consumer	800–1 300 to producer 1 500–3 000 to consumer	700–1 200 to producer 1 500–3 000 to consumer
Maximum size	up to 15 kg	up to 70 kg	up to 50 kg
Juvenile cultured (as of 1997)	53 303 × 10^3	17 200 × 10^3	2 500 × 10^3
Geographical distribution	Japan, Korea, China	Asia-Pacific and Mediterranean Sea	Japan, China, Mexico
Seed supply	Wild, Artificial propagation	Wild (also imported from China and Viet Nam)	Wild juveniles of about 700 g caught around the Goto Islands

Source: Nisshin Feed Co. Ltd.

offshore islands or coastal areas where they may also be present in shallower areas. Their prey includes a variety of fish, squid and a number of crustacean species.

In Japan, yellowtail spawn offshore from southern Kyushu to Chugoku off the Sea of Japan and then migrate north to Hokkaido where they reach sexual maturity in 3–5 years. Following this they migrate south again to spawn (Abe and Homma, 1997). Throughout the season, various sizes of yellowtail can be caught in different parts of Japan where special names are given to fish of different size (Suehiro and Abe, 1994). Migratory populations are differentiated by their growth rate and nutritional status (Abe, 1987). All juveniles weighing less than 50 g are called *Mojako*. Cultured yellowtail weighing <5 kg are called *Hamachi*, and those heavier than 5 kilograms are called known as *cultured-Buri* which are distinguished from the *wild-Buri* (Abe, 1986). All cultured Carangidae in Japan have different characteristics and require different culture methods as shown in Table 1.

Amberjack aquaculture has developed rapidly and the species rivals yellowtail in popularity. The amberjack meat maintains its brilliant colour and firm texture longer than that of the yellowtail and, due to its superior quality, it usually attains a much higher market price compared to cultured red seabream (*Pagrus major*), which is a highly valued fish species in Japan. Amberjack is distributed throughout the world and is a popular game fish in Hawaii (United States of America), Australia and in the Mediterranean Sea. This species grows faster and has a better feed efficiency than yellowtail at water temperatures higher than 17 ºC.

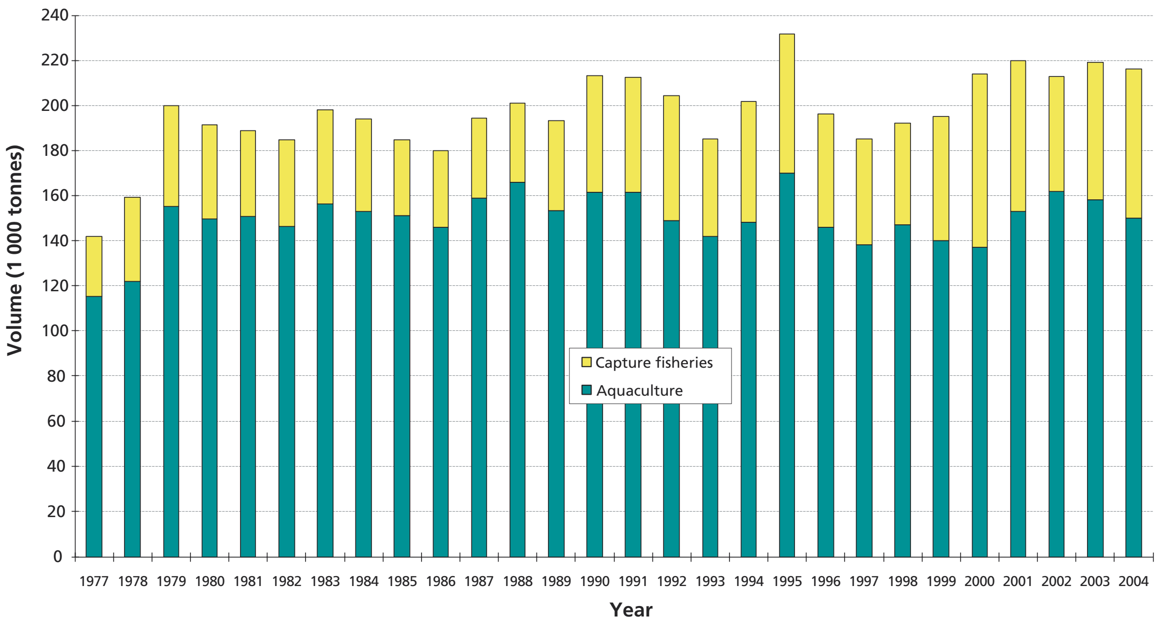
Capture fishery

Yellowtails of various sizes are harvested from many fishery grounds along the Japanese coast using several kinds of fishing techniques. In 1995, capture fisheries of yellowtail yielded around 61 666 tonnes, and aquaculture production yielded 170 312 tonnes, totalling 231 978 tonnes (Figure 1). In 2004, capture fishery landed 66 345 tonnes using different fishing gear including set nets (21 786 tonnes), round haul nets (18 876 tonnes), purse seines (11 581 tonnes), gillnets (6 006 tonnes) and other fishing techniques (8 096 tonnes). At present, wild yellowtail capture fishery remains stable whilst yellowtail aquaculture continues to increase.

Collection and culture of wild seed

After the wild *Mojako* juveniles are harvested, measured and the numbers recorded by the cooperatives, they are weaned on artificial feed and weak specimens discarded. As young yellowtail and related species are sensitive to food deprivation, cannibalism

FIGURE 1
Production of wild and farmed yellowtail



Source: Statistics and Information Dept., Ministry of Agriculture, Forestry and Fisheries, Japan.

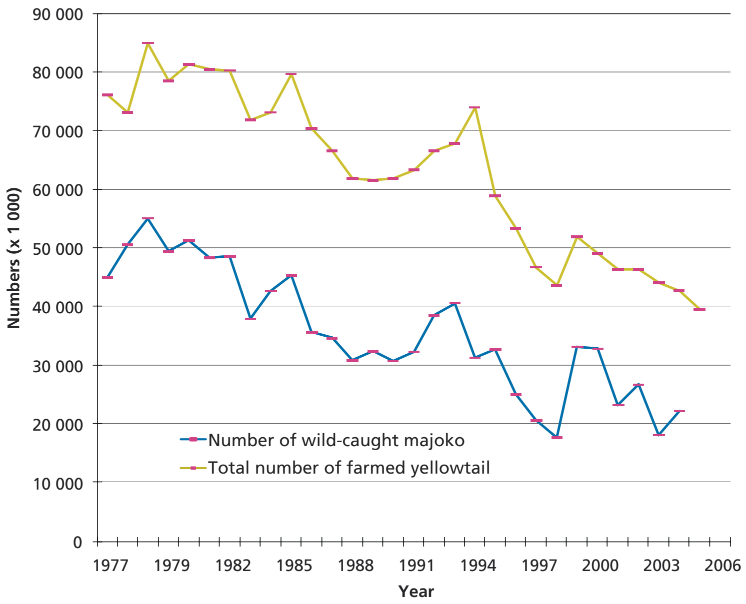
may occur, particularly if the fish are kept in the holding tanks for long periods. Furthermore, if the young fish are not fed for more than three days they will usually fail to adapt to the artificial feeds.

In 1998, the Fisheries Agency of Japan imposed regulations limiting the number of *Mojako* that can be caught annually for use in aquaculture to approximately 25 million in order to ensure the sustainability of the fishery and to protect the resource. The Marine Aquaculture Association of Japan determines the fishing allocations made to each prefecture, while each prefecture decides on the fishing season and distribution of the fishing permits to the local Federation of Fisheries Cooperatives. In 1970, the number of *Mojako* caught was over 100 million individuals, however, over the past 30 years the harvest has fluctuated between 30 to 100 million, and dropped to 25 million in 1997 (Figure 2). Fish farmers were, however, able to maintain a total production level of about 150 000 tonnes despite the decrease. The highest production level was achieved in 1995 with 170 000 tonnes produced. More recently the domestic supply of *Mojako* showed a significant decrease, and a few million were imported from the Republic of Korea. Juvenile amberjack (*Seriola dummerili*) are usually caught with *Mojako* and at one time the two species were cultured together. However, due to the parasitic worm, *Benedinia*, often present on the amberjack, farmers prefer to raise the two species separately.

The current price of amberjack juveniles ranges from ¥500–1 500 (US$4.8–14.3) for fish weighing between 50–600 g. The high price facilitated the commercial production of hatchery-reared juveniles. Japan has imported wild-caught juveniles from China and Viet Nam via China Hong Kong Special Administrative Region (SAR) since 1986.

Farmers prefer to use wild-caught seed over hatchery-produced seed as the latter are generally more expensive and are usually too small for successful rearing. In 2003, the Fisheries Agency of Japan succeeded in spawning and producing yellowtail seed larger than wild *Mojako* by controlling the water temperature and the photoperiod cycle of the broodstock. Unfortunately, however, the hatchery-produced seed had a high percentage of body deformity and mass seed production has not achieved mainly due to the difficulty in securing healthy broodstock.

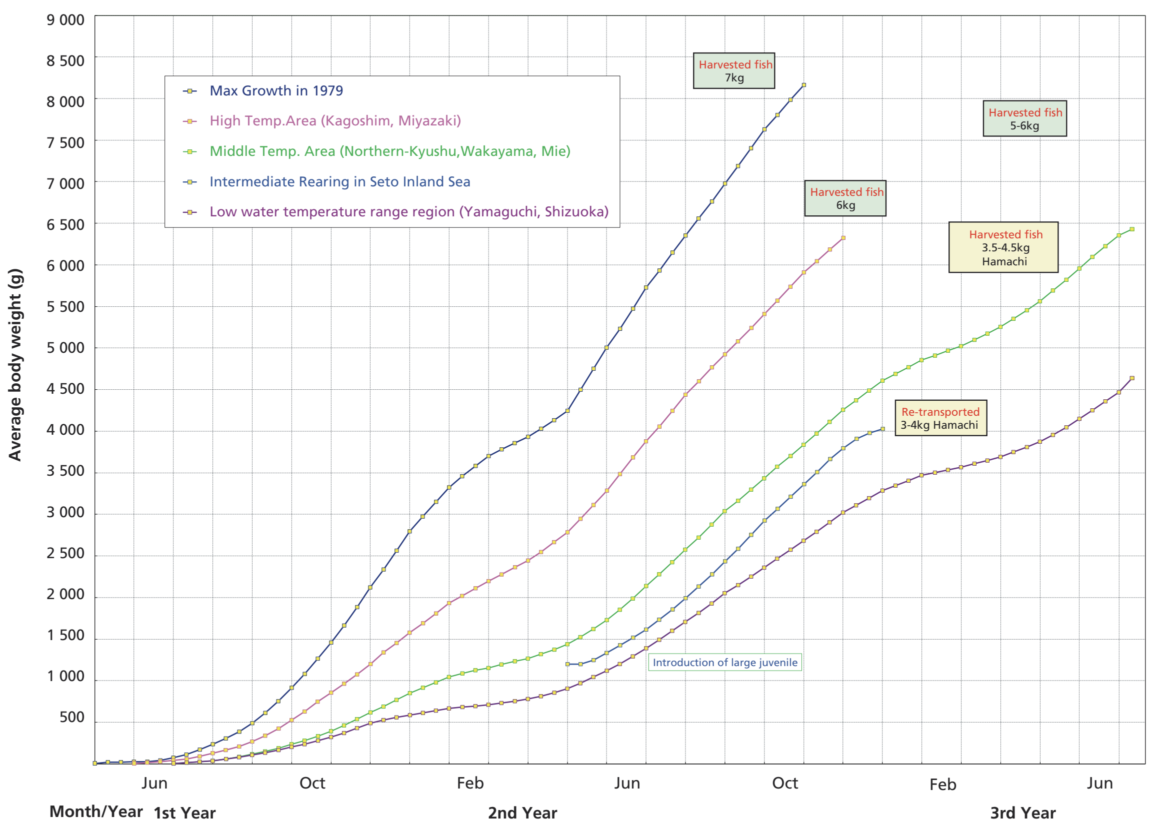
FIGURE 2
Temporal changes in numbers of wild-caught and farm-raised yellowtail juveniles, 1977–2006



Source: Marine Aquaculture Association of Japan.

The typical growth performance of yellowtail in four different sea areas in Japan is shown in Figure 3. Depending on water temperature, *Mojako* can usually be stocked from April through to July. In sub-tropical regions, such as Okinawa and Kagoshima, the average water temperature ranges from 20–24 °C. This optimal temperature range for farming yellowtail is stable for >75 percent of the year and it is possible to obtain >6 kilogram yellowtail within two years. In the Kyushu area, which includes Kumamoto and Nagasaki, the average annual water temperature ranges from 17–19 °C. This temperature is optimal for yellowtail culture for about 50 percent of the year and, due to the shorter culture

FIGURE 3
Typical growth performance of yellowtail in four different sea areas of Japan



Source: Nisshin Feed Co. Ltd.

period when the temperature is optimal, over 70 percent of the yellowtail reared in this region are three years old at harvest. In the Honshu area, which includes Shizuoka and Yamaguchi, yellowtail can be farmed but the temperatures are not as favourable compared to the regions further south. The average annual water temperature is around 18–19 °C, and more than three years are required to produce 6 kilogram fish. A specific feature of this region is its short autumn, which provides the fish with insufficient time to prepare for winter. If the fish are pushed to grow rapidly during autumn, high mortalities may occur in winter and early spring, therefore, fish weighing from 3.5 to 4.5 kilograms are produced for the sashimi market.

In the Seto Inland Sea, the average annual water temperature is lower than 17 °C, with less than 50 percent of the year being conducive to yellowtail growth. The temperature falls below 10 °C during the last two months of winter, at which time yellowtail may experience mass mortalities. To avoid the mortality problem, the fish are transferred to warmer areas such as Kochi and Miyazaki for over-wintering. In spring, when the water temperature rises again the fish may be returned to the Seto Inland Sea and reared to the size appropriate for use in sashimi. Another widely used approach is to stock large juveniles from other districts in the spring. It is then possible to produce fish suitable for sashimi within a growing season.

Farming techniques

In 2004, yellowtail farming comprised 13 570 net cages and only 44 net enclosures. Most cage farms use fresh fish (524 670 tonnes) or artificial pellets (357 311 tonnes) as feed. An optimum density and proper feeding rate are essentials for an economic production of yellowtails. The optimum stocking density and feeding rate for maximum growth and feed efficiency, relative to season and fish size, can be ascertained from rearing records collected at a particular site for at least a 3-year period.

The health status of the farmed fish is regularly checked by observing swimming behaviour and using underwater visual equipment to observe feeding. Observations on the swimming speed of individual fish while feeding, the swimming activity of the fish shoal as a whole, and the colour of the fish are all important parameters to determine the health status of the cultured fish.

Culture mortality

Mortality in cultured yellowtail can be caused by four main factors: 1) physical damage arising from inappropriate handling and transportation, and contact with the cage netting during storms and strong tides; 2) turbid water and high levels of pollutants; 3) feeding of deteriorated fresh fish and nutritionally inadequate feeds; and 4) diseases. The survival rates and mortality causes in four growth stages of juvenile yellowtail are shown in Table 2.

TABLE 2
Survival rates and mortality causes in four growth stages of juvenile yellowtail from capture and the start of the farming operation

Growth stage	Weight (g)	Survival (%)	Mortality causes
Mojako (first introduction and domestication)	0.2–50	90–95	Stress Starvation
Hamachi	50–2 000	95–98	Diseases Rough handling Poor water quality
Hamachi (over-wintering)		90–95	Low temperatures Diseases
Hamachi and *Buri*	1 000–7 000	95–98	Diseases Transportation accidents
Overall survival		70–80 %	

The damage to cultured fish from water pollution is increasing, as there are no sound measures in place to prevent environmental pollution around coastal/nearshore mariculture sites. To rectify this, investigations into restoring water quality by removing contaminants from urban and agricultural drainage and from aquaculture are underway. One promising technology for maintaining a clean environment that should be considered is the development and introduction of an auto-feeding system. A further solution could be the culture of yellowtail in offshore or in land-based closed systems. However although these approaches have produced high quality flesh and low pollution, they are not economically viable.

Disease is usually not a problem during the initial phases of rearing a particular aquaculture species, however, as the number of yellowtail farms increase around Japan, disease outbreaks have become frequent. High density stocking and overfeeding make the fish more susceptible to diseases, which then can spread rapidly among the fish. The importation of wild fry, fingerlings and juvenile fish, especially from tropical waters, is also a source of disease. Environmental deterioration and nutritionally deficient feeds may aggravate the situation.

Initially, diseases were easily controlled by reducing or stopping feed, or by administering antibiotics. However more comprehensive approaches are now required particularly as a crucial step for disease management is to remove the cause. In order to identify the causes and prevent disease outbreaks, detailed records should be kept, especially when mass mortality occurs. Removal of sick and dead fish from the net pens is a first step in the prevention of further spread of disease. Furthermore, the amount of feed consumed in net pens where disease has occurred should be documented as sick fish will not feed as well as healthy fish. It is usually necessary to reduce feeding to 60–70 percent of the normal rate.

The most common disease in yellowtail is caused by the bacteria, *Enterococcus seriolicida*, which is diagnosed by simply identifying gram-positive bacteria using STAN agar. Other significant problems with producing yellowtail and related species in warm waters include muscle parasites and ciguatoxin (a toxin in fish tissues that derives from dinoflagellates, and which causes poisoning in human). In the waters south of Kagoshima, aquaculture of these species is not feasible because of parasitism with the spore-forming myxosporean parasite *Kudoa,* which is found in the muscles and the internal organs. Among viral diseases, iridovirus is noteworthy. This virus was introduced with wild juveniles imported from tropical areas, and resulted in mortalities of juvenile yellowtail and amberjack in Japan.

DESCRIPTION OF THE FISHING ACTIVITY

Yellowtail spawning areas and seasons have been described by the Japan National Sea Fisheries Research Institute of the Fisheries Research Agency (Figure 4). In the southern parts of the East China Sea, the fish spawn from early February until April. Following spawning the young *Mojako* drift to the Pacific Ocean in association with floating seaweed. Off the west coast of Kyusyu, spawning occurs mainly from March to June and most of the *Mojako* drift through the Tsusima warm current to the Sea of Japan. Spawning areas and seasons move north to the 20 to 22 °C water temperature off Sizuoka from May to June, and to Toyama from July to August.

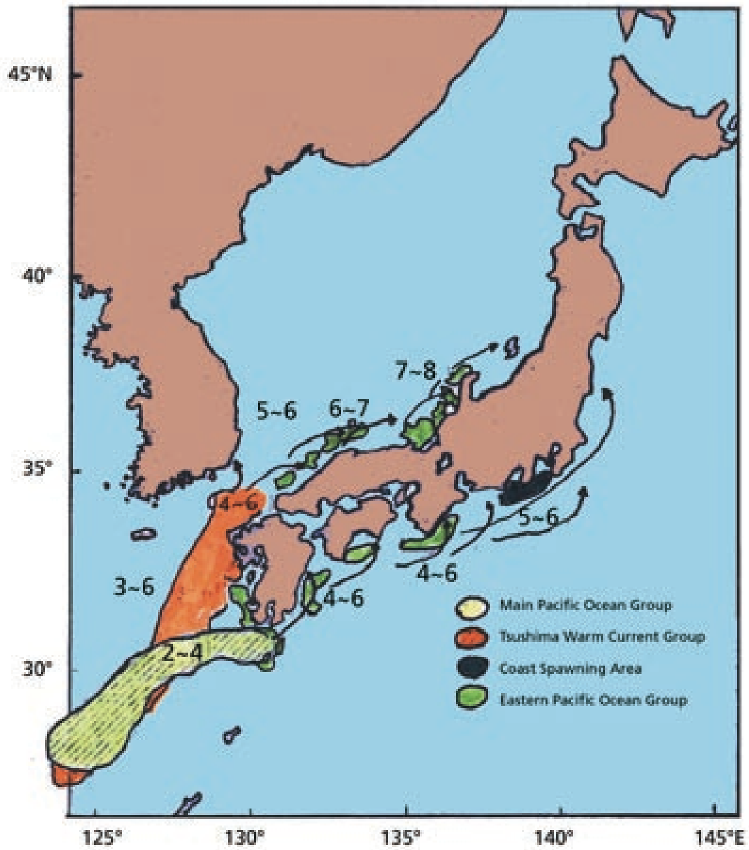
Fry of yellowtail and related species seek protection in seaweeds that break off the bottom of the sea, and feed on micro-organisms and small fishes while drifting north with the current. Small *Mojako* (4–5 cm long) usually stay under or inside the floating seaweed, while larger fish swim 0.5–2 m below the surface. *Mojako* feed actively at sunrise and sunset when swarms of zooplankton can be detected; during the day they feed on small fish (Sakakura and Tsukamoto, 1996; Anraku and Azeta, 1967). After reaching 10–14 cm in length, the *Mojako* leave the floating seaweed and swim towards the shore, where they are targeted by the set nets (Ikehara, 1984).

Wild *Mojako* juveniles for aquaculture are harvested from the floating seaweeds, by experienced crew using specifically designed fishing vessels (Figure 5). In contrast, wild yellowtail for human consumption are caught using set nets, tow nets and round haul nets from the shore.

Statistics and trends in the amount and sizes of juveniles caught

The number and size of *Mojako* captured by the prefectural fisheries organizations have changed in recent years, largely due to changes in the amount of drifting seaweed in the South Seas (Table 3). Furthermore, the size of captured *Mojako* differs by area and month, influenced by water temperature and nutrients in the sea.

FIGURE 4
Yellowtail spawning areas and seasonal changes

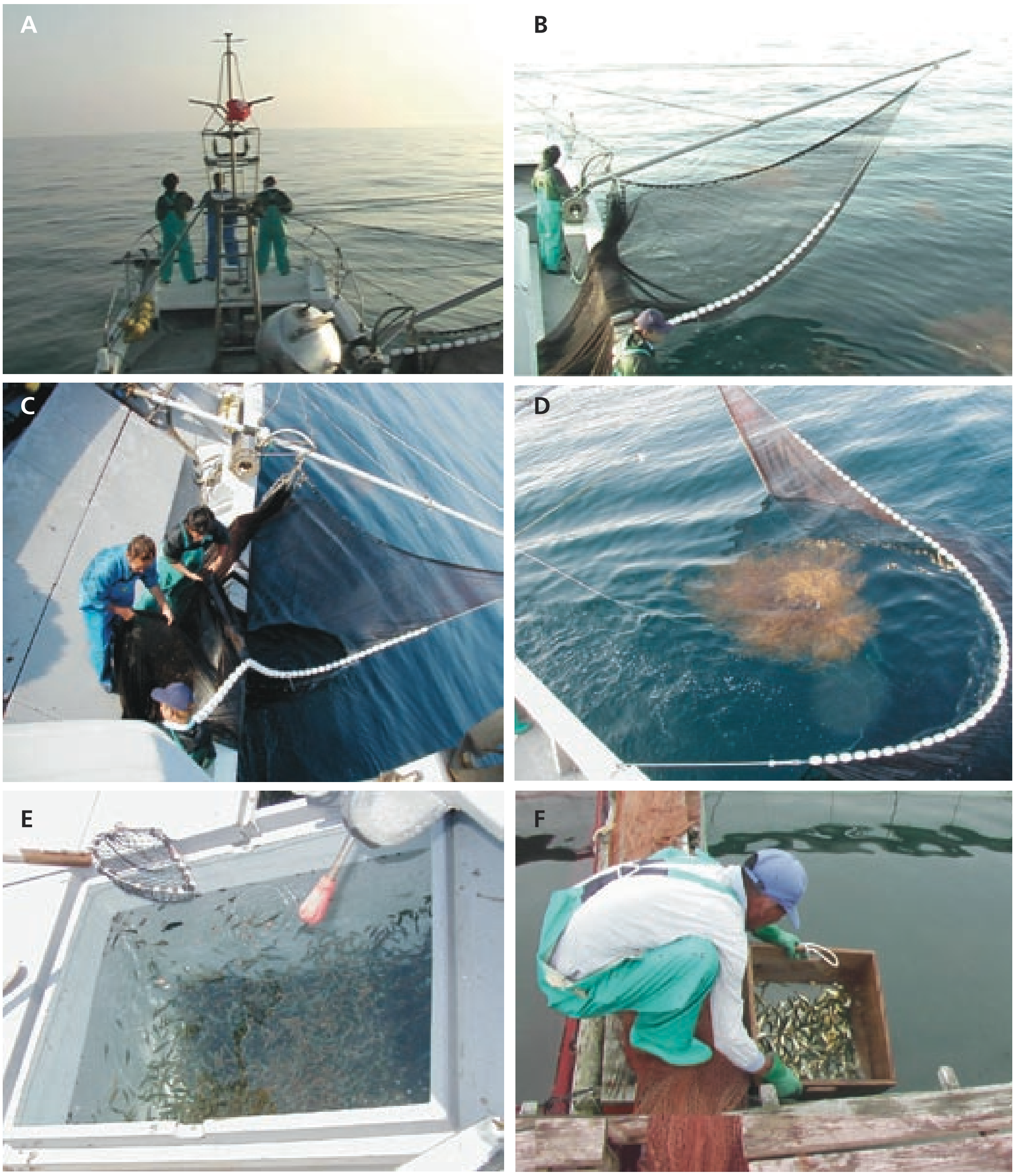


Source: Japan National Sea Fisheries Research Institute.

TABLE 3
Number of enterprises and number of juvenile yellowtail stocked in pens in 20 prefectures on 1 September 1997 (Unit: 1 000 fishes). Data not available for Saga Prefecture

Prefecture	Enterprise	1st year	2nd year	3rd year	Total
Chiba	5	35	43	0	78
Ehime	281	6 480	5 170	8	11 658
Fukui	1	0	7	0	7
Fukuoka	6	5	0	0	5
Hiroshima	10	0	270	150	420
Hyogo	12	129	95	0	224
Ishikawa	0	0	0	0	0
Kagawa	0	0	0	0	0
Kagoshima	285	4 405	1 872	30	6 307
Kouchi	78	1 984	417	0	2 401
Kumamoto	60	850	650	0	1 500
Kyouto	4	0	25	0	25
Mie	58	785	121	0	906
Miyazaki	26	558	359	112	1 029
Nagasaki	146	2 908	2 486	441	5 835
Ohoita	71	1 519	1 373	150	3 042
Shimane	4	63	222	4	289
Sizuoka	32	275	222	13	510
Tokushima	17	714	146	0	860
Yamaguchi	21	107	93	4	204
Total 1997	1 123	21 045	13 679	914	35 638
Total 1996	1 369	24 996	27 389	918	53 303
'97 as % of '96	82.0	84.2	49.9	99.6	66.0

FIGURE 5
A – Fishing vessels move to the fishing grounds in the early hours of the morning;
B – Locating floating seaweeds harbouring juvenile *Mojako*;
C – Scooping the seaweeds along with the fish;
D – Separating the seaweeds, *Mojako* and other aquatic organisms;
E – Sorting *Mojako* by size and discard of bycatch; and
F – Release of the *Mojako* into the nursery pens for acclimation



COURTESY OF JAPAN MARINE AQUACULTURE ASSOCIATION

Seasonality of fishing activities

From early March, the early juveniles (*Mojako*) are collected from drifting seaweed and then raised until they reach 2 000 g, which is achieved by the end of the year. The harvest season and size are regulated by the fisheries station in each prefecture. Usually the *Mojako* season opens in May at Kagoshima Prefecture, and in June at Mie Prefecture.

Participants in the fishery and their roles

Mojako fishing is dangerous work in rough seas, and workers need experience, special knowledge and intuition. After harvest, the juvenile fish are put into small net cages (5 x 5 x 5 m), and older workers feed them with minced raw feed fish or granulated feed more than 5 times per day. The former feed type is problematic, because it quickly pollutes the water, the *Mojako* lose their appetite and may develop gill problems. The granulated feed is preferred, and is given as soon as possible, even while the juvenile *Mojako* are in the holding tanks on the fishing boats. Granulated feed for marine juvenile fish results in a high survival and growth rate, and *Mojako* as small as 0.2 g easily domesticate and grow well.

Larger yellowtail *Mojako* are fed extruded pellets weighing 5 g or more, twice daily. As the fish grow, they are graded and transferred into 7 x 7 x 7 to 10 x 10 x 10 metre net cages. When the fish become 200 g or more (called *Hamachi*), they are fed moist pellets, which are prepared by the younger workers on the boats and distributed via mechanical feeders.

Seed handling procedures at sea

If the fishing areas for *Mojako* are very far from port, there is a long period when the fish are held on board, during which time the juveniles may prey on each other whilst in the holding tanks. To reduce cannibalism, they are fed minced fish which often causes the water to deteriorate rapidly due to food wastes and faeces. Newly developed granulated feeds have been fed successfully to the juveniles during transport to the net cages. These feeds have a high palatability, do not pollute the holding water and are easily taken by fish as small as 0.2 g. Wild *Mojako* weaned on granulated feed tend to perform well during subsequent culturing.

AQUACULTURE DEPENDENCY ON WILD SEED

In the 1980s, the wild catch of *Mojako* started to decline. In order to protect this natural resource the Japan Fisheries Agency required the Marine Aquaculture Association of Japan to regulate both the catch season and numbers (Figure 2) and since 2003 the Prefectural Fisheries Cooperatives are allowed to regulate this fishery and allocate quotas to each prefecture (Inagaki, 1990). However, when the number of *Mojako* caught has been insufficient, yellowtail fingerlings have been imported mainly from the Republic of Korea. Amberjack juveniles have been imported from China and Viet Nam, including some 20 million imported in 2000 which were cultured from wild amberjack seed. These are acclimated and reared to 50 to 300 g. Several viral and parasitic diseases have entered Japan with the imported juveniles. In 2005, the nematode worm *Anisakis,* which was introduced with juvenile amberjack from China. Because *Anisakis* larvae in fish can be transmitted to humans, the Japanese Ministry of Health, Labour and Welfare prohibited sales of the infected farmed fish for raw meat consumption. Concerns over the health of imported juveniles have persuaded some fishing cooperatives to send workers to China to conduct quality control on the health of the amberjack juveniles. Furthermore, all imported amberjack juveniles are also checked by custom officials as they are often fed with high levels of antibiotics prior to shipping.

A further and important seed source is aquaculture itself. The Marine Aquaculture Association of Japan and several prefectural experimental stations have established techniques for the artificial production of about 60 marine fish species. Significant quantities of yellowtail, amberjack, gold-striped amberjack and striped jack juveniles have been produced by aquaculturists (Kawabe *et al.*, 1996; Arakawa *et al.*, 1987; Tachihara, Ebisu, and Tukasima, 1993; Kawanabe *et al.*, 1997). Viable eggs are obtained from both wild spawners and cultured broodstock fed high quality formulated feeds, with maturation being stimulated by hormone injections in many instances (Mushiake *et al.*, 1993; Nagasaki Prefectural Fisheries Experimental Station, 1998). Healthy fry are fed on mass-produced food organisms such as rotifers and brine shrimp nauplii fortified with n-3 highly unsaturated fatty acids (HUFA) as well as formulated feeds (Verakunpiriya *et al.*, 1997a; Verakunpiriya *et al.*, 1997b; Fukuhara, Nakagawa and Fukunaga, 1986). Farm-raised juveniles have been released into the wild and used as seed for aquaculture.

Production benefits from aquaculture

For more than 30 years, the annual yellowtail capture fisheries harvest in Japan has been around 50 000 tonnes, while 160 000 tonnes are produced from aquaculture. The fishery is carried out using different fishing techniques and takes place in numerous fishing grounds along the extended coast of Japan. At present, the fisheries stations in the prefectures, along with the Japan Fisheries Agency monitor the wild resources and make recommendations to prevent excessive harvest of *Mojako*, juveniles and adults.

If wild *Mojako* harvesting was limited to what is needed for aquaculture, wild yellowtail fisheries could increase to more than 100 000 tonnes, however the wild yellowtail might then consume more than 1 000 000 tonnes of prey fish, which could otherwise be harvested for human food. It is suggested that wild *Mojako* and small jacks should be fully utilized as a resource for aquaculture, as they have very high natural mortality rate in the early life stages. Farm feeds could include artificial granulated feed, moist pellets, and extruded pellets made from trash fish and vegetable matter as well as human food left overs.

FISH FEED

Reliance on wild-caught food

In the early years of yellowtail culture in Japan, there was a high dependence on locally available trash fish for feed. However, as yellowtail culture techniques were disseminated, the demand for trash fish exceeded production, and different resources had to be used that included commercially available small pelagic fish such as sardines which were abundant and cheap. The government supported the installation of large-scale freezing plants along the coast and frozen sardines further supported the development of yellowtail aquaculture. Minced frozen sardines were widely used; however feeding efficiency was poor and water quality deteriorated rapidly due to accumulation of uneaten fish and faeces. However, after determining that feeding frozen fish was safe, and was better than feeding thawed fish, frozen sardines were fed cut into pieces or whole (Miyazaki, 1986). Two of the major advantages with the use of frozen fish were reduced deterioration of the feed and reduced environmental pollution.

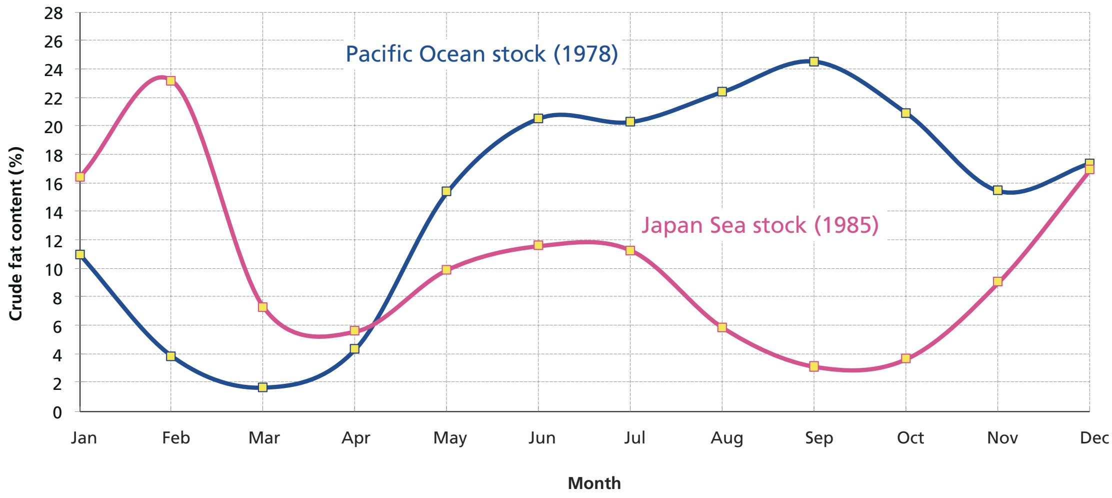
However, the use of sardines alone as the sole feed for yellowtail led to nutritional disorders, because of unsuitable calorie/protein levels. Furthermore, the crude fat content of sardines changed markedly with harvest areas and seasons (Table 4), and between the stocks in the Pacific Ocean and Japanese Sea (Figure 6). While a good system for distributing sardines to fish farmers was developed, there was no control over their fat content. There is a strong, negative correlation between the water and fat content of sardines landed at Kyushu, Sanin and Kushiro.

TABLE 4
Difference in crude fat content of sardines according to harvest area

Harvest area	Fat content – range (%)	Fat content – mean (%)
East Hokkaido	19.9–39.9	26.8
Boso: Joban	8.8–22.5	14.4
Sanin	1.4–22.3	13.0
Kyushu	4.0–13.6	8.6

Sources: Japan Marine Oil Association.

FIGURE 6
Monthly changes in crude fat content of Pacific Ocean and Japanese Sea sardines



Source: Japanese Marine Oil Association.

More recently, the catch of wild fish as feed has markedly declined. For example, the harvest of sardines between 1980 and 1990 was more than four million tonnes. These were used to feed farmed fish such as yellowtail, red seabream, and silver salmon as well as being transformed into fishmeal. However, after 2003 only 50 000 tonnes of sardines were locally fished. Fresh fish feed for yellowtail farming decreased over the years from 1.7 million tonnes to 0.88 million tonnes (including mainly sardines, horse mackerel, mackerel and sand lance). At the same time the total production of cultured yellowtail has been maintained at around 150 000 tonnes due to the development of artificial feeds such as moist and extruded pellets (Table 5).

TABLE 5
Temporal changes in quantities of fish and artificial feeds used in yellowtail aquaculture (tonnes), 1994–2006

Year	Feed fish (tonnes)	Artificial feeds			
		Powder	Dry pellets	Total	Dry pellet as % of total
1994	1 159 724	71 747	28 684	100 425	28.6
1995	1 748 843	86 449	54 282	140 731	38.6
1996	1 105 152	59 273	48 977	108 250	45.2
1997	1 197 292	60 889	60 063	120 952	49.7
1998	1 258 991	61 527	65 207	126 734	51.5
1999	1 060 763	50 891	67 894	118 785	57.2
2000	983 836	56 211	97 260	153 471	63.4
2001	929 691	59 483	138 908	198 391	70.0
2002	1 048 747	54 223	138 378	192 601	71.8
2003	965 701	49 521	153 241	202 762	75.6
2004	881 981	49 173	147 518	196 690	75.0
2005	NA	44 327	148 400	192 727	77.0
2006	NA	47 580	157 505	205 085	76.8

Source: Japanese Fish Feed Association.

TABLE 6
Feed intake efficiency (Feed Conversion Rates) and feed cost (¥/kg)

Type of feed	Yellowtail life stage	Feed intake efficiency (%)	Feed conversion rate (Dry weight)	Feed price (Yen/kg)	Feed cost [1] (Yen/kg)
Minced raw fish	Mojako	25	17.5 (6.1)	100	1 750
Minced raw fish	Hamachi	25	12.5 (4.4)	80	1 000
Granulated feed	Mojako	55	4.5	400	1 800
MRF + binder	Hamachi	45	8.5 (3.2)	60	510
Round raw fish	Hamachi	50	10 (3.5)	45	450
Round raw fish	Buri	50	7.5 (2.6)	45	338
Moist Pellet 0	Hamachi & Buri	50	11 (3.9)	55	605
Moist Pellet 30		60	6.5 (4.0)	92.5	600
Moist Pellet 50		70	5.0 (3.3)	117	585
Moist Pellet 100		80	4	140	560
High Fat Dry Pellet	Mojako	70	3.7	150	555
High Fat Dry Pellet	Hamachi	75	5	140	700
Extrude Pellet	Mojako	85	0.9	325	300
Extrude Pellet	Hamachi	75	1.4	250	350
Extrude Pellet	Buri	65	2.4	175	400

[1] Cost of feed to produce a kg of fish.

Extruded pellets containing more than 20 percent fat are efficiently utilized by yellowtail, and farmers have achieved feed conversion ratios of 1.2 during the production of 1-year old fish. Using the same type of feed, satisfactory growth has also been achieved during the second year, providing that water temperatures are optimal. For yellowtail larger than 3 kilograms, raw fish is preferred to extruded pellets, and it is difficult to attain daily feeding rates of 2 percent of the body weight on extruded pellets, especially during the winter. Development of an extruded pellet, containing >25 percent fat and weighing more than 30 g, will be required for the economical production of yellowtail larger than 3 kilograms, particularly during the winter months.

Artificial feed availability and problems

Artificial feeds support improved growth and survival rates when compared to fresh fish diets. When raw fish were used as the primary feed material for yellowtail, it was difficult to predict fish growth precisely because the nutritional composition of the feed varied significantly. As information on the protein and vitamin requirements of yellowtail was acquired (Takeuchi *et al.*, 1992), the production of various types of moist pellets and formulated feeds became possible. Currently the production cost for yellowtail moist pellets or formulated feed is less than that of raw fish, prompting numerous feed manufacturers to produce such feeds.

Although the quantity of formulated feed used for yellowtail culture has increased almost linearly over the last decade (see Table 5), more research is needed to develop dry pelleted feed, appropriate feeding techniques and identification of inexpensive feed materials (Nakada, 1997a; Shimeno, Masaya and Ukawa, 1997; Nakayama, 1997). The development of high quality formulated fish feeds is now being undertaken by the Fisheries Agency of Japan, the Fish Feed Association of Japan, university researchers and fisheries experimental stations (Matsumoto, 1997). The development of artificial feeds such as Umisachi and Otohime has contributed to the increased production and high survival of *Mojako*. By using such feeds it is now possible to raise healthy *Mojako* starting from initial sizes of >2 g; when raw minced fish was used as feed, high survival rates were not possible.

The Fish Feed Association of Japan supported the development of economical moist pellets, extruded pellets and granulated feeds for yellowtails that successfully lowered production costs and improved product quality. In addition, pharmaceutical companies developed vitamin mixtures and functional ingredients for the prevention and treatment of disease and improvements of fish quality.

Another advance in artificial feed came in 1979 when the Japanese Fisheries Agency started to develop a moist pellet diet for yellowtail culture in order to prevent pollution. However, during the 1980s the abundant and extremely cheap domestic spot-lined sardines continued to be used as the principal feed for yellowtail. It was not until the early 1990s that fish farmers finally became aware of the severe damage to the environment around their aquaculture grounds caused by feeding fish, and this prompted acceptance of the artificial feeds

Modification to the feed can include the addition of binding agents, which, when added to minced raw fish, improve the feed efficiency by almost twofold. The daily feeding rate can then be reduced by 20 to 30 percent, resulting in a better feed conversion rate and reduced water pollution. The use of the right feed in the appropriate amount is a very important factor for efficient and sustainable production, which can in turn improve cultured fish quality (Table 6).

Various substitutes for fishmeal have been successfully used to halve the amount of fishmeal and fish oil in yellowtail feeds without adverse effects (Watanabe, 1996; Shimeno, 1997; Shimeno, Takii and Ono, 1993). If defatted and dried fishmeal is used in aquaculture, fish feeds have insufficient lipid content in the absence of added fat (Nakada, 1992).

During the 1980s it was common practice to provide supplemental oil in feed for freshwater fishes, however, these oils could not be used for marine species due to their difference in fatty acid requirements. Feed oils suitable for marine species were developed and tested in commercial production trials with yellowtail, and produced fish similar in lipid composition to wild fish. However, the quality of oil containing high levels of highly unsaturated fatty acid (HUFA) varies, so the Society of Aquaculture Feed Oil Research has set standards for feed oils recommended for aquaculture feeds. Since world production of fishmeal and fish oil has fluctuated dramatically, further improvements in fish feeds, including use of alternative protein sources, has been undertaken. In the future, soybean meal, poultry meal and a certain amount of fish oil, along with soybean oil and/or coconut oil, will likely be used in place of the current fishmeal which is currently the major protein source in formulated feeds.

Sustainability of wild-caught feed

Under strict regulations from the Japan Fishery Ministry, the sardine resources are stable at low harvest levels. According to the 2004 statistics of the Japan Fishery Agency, feed fish production for yellowtails was 525 000 tonnes, and artificial feed production for yellowtails was 357 000 tonnes. As the sardine stocks are not increasing, sardines should not be harvested at levels greater than the previous year, and yellowtail culture will need to switch to artificial feeds.

ENVIRONMENTAL IMPACT OF JUVENILES FISHERIES

The annual *Mojako* stocks are estimated to be greater than 100 million specimens and current regulations limit harvest to 25 million. In order to enhance this natural resource and reduce impacts on the wild stocks, a number of actions have been taken over the years which included the establishment of suitable algal grounds to encourage yellowtail reproduction, release of artificial drifting seaweeds and artificial propagation. During the fishing of *Mojako,* non-targeted species bycatch is reported to the designated Prefectural Fisheries Station. Some valuable bycatch species are handled with care and may be retained, while other species are released back to the sea along with the drifting seaweed.

Following capture of the *Mojako,* the fishing vessels return to port within two days to minimize cannibalism, and if transportation time exceeds 3 days artificial granulated feed is provided to the fish in holding tanks. Since the early days, the traditional *Mojako* fishing technique has improved considerably, ensuring that the young fish remain in good health. Proper handling and feeding during these early stages will ensure almost complete survival of the wild fingerlings during subsequent farming (<2 percent mortality).

SOCIAL AND ECONOMIC IMPACT OF FARMING

Two million people are estimated to be engaged in mariculture in Japan, with women and older workers involved in all stages of yellowtail culture and trade except for harvest of the wild fish. Most yellowtail products are handled by the fishermen's cooperative association (FCA) which also provide working capital (as loans) to purchase seed and feed. Traditionally, the FCA used to sell the products to the fish markets in neighbouring towns and cities. However, more recently, supermarket chains purchase the product at lower prices in order to guarantee their yearly contracts. Hence producer's prices and farmer's profits have fallen.

In an effort to create higher returns, there has been an increase in intensive net pen culture, which has in turn caused water pollution, increased the occurrence of red tides, but also decreased the number of feeding days. Many family-owned aquaculture businesses have gone bankrupt as they have been unable to keep up with the production costs. Such businesses have transferred their aquaculture rights to others and have often become employees of such new operations. The number of existing mariculture farms has declined dramatically.

Although consumers in Japan can purchase cheaper and higher quality fish from the new chain of discount shops, the purchasing power of the Japanese public has decreased because of the extraordinary demand for quality and low prices in international competition.

Trade of farmed fish

The consumer is gradually accepting cultured fish as being of higher quality than wild fish, although high level restaurants still prefer wild rather than cultured fish. The strongest competitor for cultured yellowtail is not pork or beef, but wild small *Buri* (50–60 cm in body length) caught using set nets. If a large quantity of young *Buri* is landed at one time, their market price may drop as low as ¥200–300/kg (US$1.9–2.9/kg), which is significantly cheaper that the lowest price for cultured yellowtail of ¥800/kg (US$7.7/kg).

The market for cultured yellowtail can be divided into that for (i) high class Japanese restaurants that deal mainly in live fish, (ii) wholesale stores and supermarkets dealing with fresh and frozen fish, and (iii) direct delivery of processed fillets to individual restaurants and homes (Satoho and Homma, 1990).

Although yellowtail was once sold strictly by weight, consumers have now become more selective about product quality, and farmers have started to produce higher quality fish. Currently, branded farmed yellowtail fetch a higher price than other yellowtail and other cultured fish. Maintaining a stable quality product by discarding second grade fish, and paying special attention to maintaining freshness has become highly valued by the intermediate dealers. At supermarkets and retail fish stores, sales have expanded through the marketing of special brands of cultured fishes produced by such organizations as the Kagawa and Kagoshima Federation of Fisheries Cooperatives.

In order to maintain a high product quality, the fish should be fasted before harvesting, as it allows consumed food to be digested. Furthermore, to retain product freshness, the fish should be killed immediately after being taken from the water by severing the *medulla oblongata*, and bled by cutting the caudal artery. If it is impossible to treat the fish individually, they should be held in a tank with a large amount of chipped ice. If the moribund state is prolonged, or the fish are shipped without enough chilling, early *rigor mortis* reduces product quality. The quality of fish deteriorates very rapidly and it is vital to get the fish product to consumers quickly after harvest. With cold storage, fish can be served as sashimi for approximately three days, depending on rearing conditions and treatment after harvest. Rapid killing, bleeding, filleting, and proper packaging and refrigeration, can result in excellent quality yellowtail. Amberjack and gold-striped amberjack are more popular than yellowtail for sashimi as they can be kept for >3 three days under refrigeration without losing flavour, colour and firmness. Currently, demand for amberjack exceeds the supply.

Economic benefits and loses from aquaculture

Among the different parties involved in yellowtail aquaculture, the distributor usually gains the greatest economic benefit. The fishery cooperatives and fishing companies cooperate, manage the seed supply and marketing, and sometimes dominate management. Farmers receive relatively little economic benefit, and have thus become relegated to being only fish producers. Many aquaculturists sell their products through a relatively new system of direct sales, where private brokers buy fish directly from the producers and transport them to consumers using live-fish trucks. However, despite its popularity, many private brokers are experiencing difficulties because of serious "price competition".

Seed production by artificial incubation for high priced fish can be lucrative. In comparison with adult fish culture, the seed fish business can easily be carried out, requiring only small ponds and limited technical knowledge. However, income from hatchery operations faces strong competition from seed material from the wild.

Fish farmers are currently also facing economic difficulties due to the stagnant national economy which has increased competition among the producers and brought a drastic decreased in the yellowtail market prices. There has been a 75 percent decrease in the number of yellowtail farmers in the last 30 years from the 4 162 enterprises in 1978 to 1 049 enterprises in 2004.

There are no full-time *Mojako* fishermen as this activity is rather a part-time job undertaken along with other fishing activities. Yellowtail farmers have concentrated in maximizing production and profits rather than determining proper farming densities and feeding regimes. Hence, management techniques have not developed. In 1999, legislation was enacted setting limits on the number of individual cultured fish per unit area, the amount of feed used and the number of cages per given area; this legislation is strictly enforced.

CONCLUSIONS

An urgent need in Japanese yellowtail aquaculture is the production of better quality juveniles, with better growth rates and less vulnerability to disease. This should be accomplished through selective breeding, which requires collection of different strains in order to select the required broodstock.

A further additional development may be culturing marine species, such as yellowtail, on land. If the culture of yellowtail and related species becomes possible on land without polluting coastal areas, it will be a welcome approach for producing high quality fish (Kikuchi, 1998). Previously land-based culture was not considered because of the high initial cost for facilities; however it may now be a feasible approach. The fish can be raised in controlled quality water, resulting is fewer diseases and reduced exposure to pollutants. This approach is attractive to consumers, who increasingly prefer cultured fish which they know have not received medication. A moist pellet for yellowtail was developed ten years ago, as well as formulated feed. Furthermore, artificial seawater systems that perform better than natural seawater for larval production have been developed and techniques for closed systems and automatic feeding systems are improving regularly (Nakada, 1997b). However, there remains the problem of finding suitable heat sources to control water temperature.

At present, there are no proper countermeasures for the declining productivity of the fish in growout areas, or for controlling disease in intensively cultured fish. For economical and sustainable fish culture it is necessary to maintain an optimum stocking density based on carrying capacity. Hirata and his colleagues (Hirata, Kadowaki and Ishida, 1994) proposed developing a distribution graph of dissolved oxygen concentrations in culture areas to aid proper water management. This can now be supported by the recent availability of real time information on the dissolved oxygen and water temperature of particular areas from the fisheries experimental station and fishery cooperatives.

In order to alleviate the environmental problems associated with marine fish farming, various measures are needed such as dredging accumulated sediment from the sea bottom, using chemicals to stimulate decomposition of organic materials, prohibiting the use of minced raw fish, and prohibiting the culture of large yellowtail in favour of culturing smaller, less polluting fish. Additional measures include increasing the propagation of lugworms, which consume organic material in the mud, and cultivating algae, which absorb dissolved nutrients excreted by fish. The comprehensive utilization of natural productivity may be the correct direction of aquaculture in the future (Tsutsumi and Montani, 1993).

It is time to consider a comprehensive culture approach that utilizes the natural purification ability of the environment. Such an approach may involve polyculture not only of several species of fishes, but also of crustaceans and algae (Hamauzu and Yamanaka, 1997).

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