Status of Mariculture in Japan

Country Report for the Regional Mariculture Workshop in Guangzhou, China

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I. Recent Changes in the Environment Surrounding Fishery Business Management and its Problems

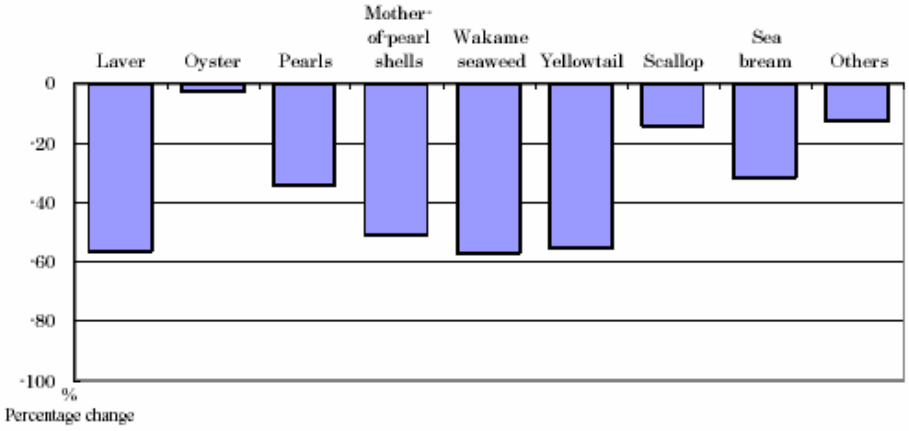
1. Current status of fishery business management

1-1) Decline in fishery operators in marine aquaculture

In the 15 years to 2003, the number of marine fishery operators in Japan declined 30% to 132,000. A sharp decline was seen in the less-than 3-ton category for coastal fishery operators and the 50-ton-or-greater for small and midsized fishery operators. The number of large fishery operators also decreased substantially.

Among marine aquaculture operators, those cultivating laver, wakame seaweed, yellowtail, pearls and mother-of-pearl shells posted a large decline. Oyster and scallop cultivators leveled off or decreased slightly (see Figure I-2).

Figure I-2 Change in the Number of Aquaculture Operators (from 1988 to 2003)



Source: "Fisheries Census," Ministry of Agriculture, Forestry and Fisheries
Note): Figures for 2003 are provisional.

1-2) Income and expenditure of marine aquaculture fisheries

For marine aquaculture households, meanwhile, income is unstable in the areas of yellowtail and sea bream aquaculture, which features large income and expenses, and relatively stable in the area of oyster, scallop and laver aquaculture. Income from wakame seaweed cultivation is so limited that wakame cultivators depend greatly on non-fishery income.

2. Factors affecting fishery business management

2-1) Changes in consumption of fishery products

According to the annual family income and expenditure survey, the average purchase price for 100 grams of fresh fishery products in the recent years (average of years 2001-2003) by families with at least two members declined 12.4% from a decade earlier (average price of years 1991-1993).

However, per capita annual purchases in volume remained stable between 13-14 kilograms. Looking at the trend by age group of household heads, higher age groups tended to purchase more fishery products. The fishery product purchases tend to decline until the household heads become 40 and increase after they reach 40. Later generations tend to depend more on eating out and cooked meals and reduce fishery product purchases.

2-2) Changes in fishery product consumption patterns

A breakdown in family food consumption by food type shows that families have increased their consumption of and dependence on cooked meals as more women have participated in society and single-person households increased. Spending on fishery and meat products for cooking use has tended to decline according to the price drops. Spending on eating out has meanwhile shifted from slow growth to zero growth over the past few years.

2-3) Changes in fishery product distribution channels

Supermarket outlets, which are winners in the convenience food area, have expanded their share of fresh fish retail sales. Their share in 2003 was close to 70%.

Supermarket stores and restaurants have become the main demand source for fishery products as retailing and consumption patterns have changed. These large demand sources require four stable supply conditions (consistent volume, quality, prices and deliveries), increasing direct purchases from and bargaining with producers.

3. Producers' efforts in the business management

3-1) Higher value added

Fishery cooperative associations and other groups are promoting brand development and other efforts nationwide to increase value added to their products in response to consumers' growing interest in food safety. Some are trying to construct traceability systems for fishery products.

3-2) Rationalization through fishery cooperative association mergers and local market integration

Rationalization has been progressing, including mergers between fishery cooperative associations, and the integration and expansion of local markets. The number of fishery cooperative associations in coastal regions has declined 30% over the past 15 years. Local fish markets are not only enhancing their distribution functions but also expanding their exhibition and sales facilities and transforming themselves into tourist spots to revitalize regional economies.

3-3) Resources management aimed at resources recovery

Appropriate management of fishery resources is important for the stable continuity of the fisheries industry. Under agreements between relevant fishermen, resources recovery plans have been developed for deteriorating fish stocks. Under such plans, no-fishing period bans on catches of small fish and other fishing restrictions have been imposed, releases of seedlings have been promoted to enhance fishery resources and environment of fishing grounds have been restored and conserved.

3-4) Export Promotion

Moves have recently emerged to develop export markets such as Korea and China. As a result, Japan’s fishery product exports in volume have continued an upward trend since 1999.

4. Future challenges

4-1) Enhancement of fishery operators’ strength

Regarding vessel-using fishing, it is difficult to realize any further cost reduction under current style of vessel operation and labor management. Therefore, fishermen and their groups should make their own efforts such as labor saving and rationalization of labor management and shift priority from gaining larger amount of catch to seeking profitability. They need to be aware of the need for such shift.

While consumers tend to limit spending on foods including fishery products, fishing earnings have remained unstable. Fishery operators should make efforts to diversify their operations by increasing the value added to their fishery products through processing, promoting producers’ direct sales and taking advantage of fishing to attract tourists. They also need to develop new businesses that can revitalize regional economies.

Since the aging of fishermen has been responsible for a decline in activity, efforts

are also required to secure young fishermen to take over the fishery industry's future reins.

4-2) Enhancement of producers' direct sales

As an appropriate response to changes in and diversification of demand and distribution channels, fishery operators need to integrate local markets to secure a wider range of sales channels, and meet the growing demand for quality and safe food.

Efforts have been seen throughout Japan to increase the value added to fishery products through brand development and other measures. Fishery operators should further change their way of thinking in order to promote strategies to make consumers better informed and aware of products' originality or supremacy and to enhance quality control.

Some aquaculture operators have sponsored aquaculture inspection tours to promote exchange with consumers. The development of such direct relations with consumers is important.

4-3) Export-expansion efforts

The Japanese diet has recently attracted attention as healthy food in the Western world and as luxury food for high-income people in China and South-East Asia whose economies are enjoying remarkable growth. At a time when domestic fishery product prices are falling, fishery operators should not only defend themselves from imports but also take advantage of trade liberalization to aggressively develop overseas markets. Adding value to fishery products through brand development and other measures is strategically important for overseas market development.

II. Supply and demand of fishery products in Japan

1. Domestic fishery production (Fishery and aquaculture production)

In 2003, Japan saw its fishery and aquaculture production increase 3% in volume from the previous year to 6.08 million tons (see Table II-1) and shrank 8% in value to 1.6 trillion yen.

Table II-1 Fishery and Aquaculture Production Volume

(Unit: 10,000 tons)

	1993	1998	2002	2003	Percentage change 2003/2002
Total	871	668	588	608	3
Marine fishery	726	531	443	472	6
Far seas fishery	114	81	69	60	△12
Offshore fishery	426	292	226	254	13
Coastal fishery	186	158	149	158	6
Marine aquaculture	127	123	133	125	△ 6
Inland water fishery and aquaculture	18	14	11	11	△ 3

Source: "Annual Statistics of Fishery and Aquaculture Production," Ministry of Agriculture, Forestry and Fisheries

Notes: 1) Due to fractional rounding, component figures may not add up to the exact totals shown.
2) Inland water fishery and aquaculture production in and after 2002 covers catch amount at 148 major rivers and 28 lakes and amount of production of cultured trout, Ayu (sweetfish), carp and eel.

2. Fishery product trade

Japan's fishery product imports in 2003 fell back both in volume (weight of products upon customs clearance, hereinafter the same) and value. In volume terms, the year's imports declined by 496,000 tons or 13% from the previous year to 3.325 million tons. In value, they dropped by 193 billion yen or 11% to 1,569.2 billion yen.

However, Japan has remained the world's largest fishery product importer both in volume and value, accounting for 14% of the world's total fishery product import volume and 22% of total import value (as of 2002). China has been the largest fishery product exporter to Japan since 1998. But such imports from China in 2003 decreased by 120,000 tons or 16% in volume terms from the previous year and by 22.9 billion yen or 7% in value terms.

On the other hand, Japan's fishery product exports in 2003 increased by 63,000 tons or 21% to 370,000 tons in volume terms from the previous year while decreasing by 1.1 billion yen or 1% to 135.4 billion yen in value.

Above fluctuated number in volume and in value of 2003 were calculated from the basis of 2002's statistics (see Table II-2).

Table II-2 World Fishery Product Trade

(5 largest exporters and importers in value and volume terms in 2002)

Unit: 1 million dollars in value, 10,000 tons in volume

Imports	Value	World total	Japan	U.S.A.	Spain	France	Italy	
	Share (%)	62,318 100	13,863 22	10,150 16	3,867 6	3,237 5	2,917 5	
	Volume	World total	Japan	China	U.S.A.	Spain	Denmark	
	Share (%)	2,774 100	382 14	248 9	207 7	146 5	140 5	
Exports	Value	World total	China	Thailand	Norway	U.S.A.	Canada	Japan (23rd)
	Share (%)	58,500 100	4,601 8	3,692 6	3,601 6	3,319 6	3,052 5	818 1
	Volume	World total	Norway	China	Peru	U.S.A.	Denmark	Japan (28th)
	Share (%)	2,742 100	210 8	206 8	186 7	136 5	127 5	31 1

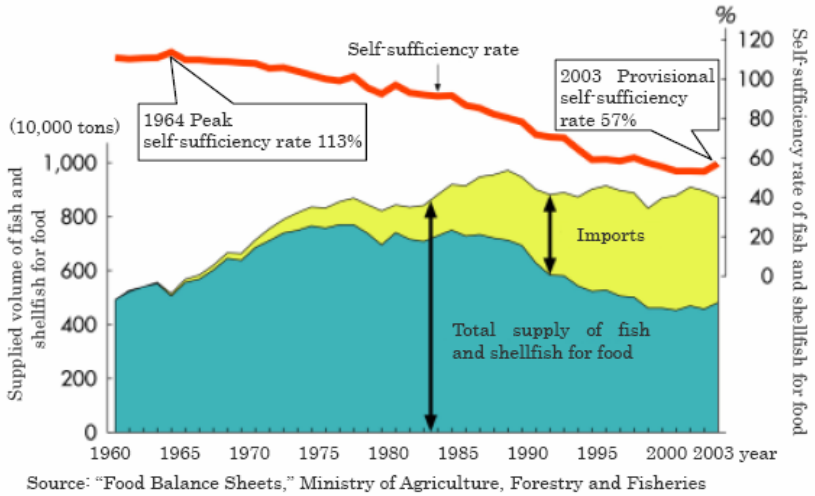
Source: "Fishstat (Fisheries Commodities Production and Trade 1976-2002)," FAO

3. Consumption of fishery products and self-sufficiency rate

In 2003, the fish and shellfish (on an original weight basis) supplied for domestic consumption decreased 2% to 10.98 million tons from the previous year, of which about 80% was supplied for human consumption, down 2% to 8.39 million tons. Per capita annual fishery product consumption came to 65.7 kilograms on a crude food weight basis and to 36.2 kilograms on a net weight basis.

The self-sufficiency rate of fish and shellfish for food consumption in 2003 rose by 4 percentage points to 57% as domestic production increased with imports decreasing (see Figure II-1).

Figure II-1 Changes in Self-Sufficiency Rate of Fish and Shellfish for Food



Source: "Food Balance Sheets," Ministry of Agriculture, Forestry and Fisheries

III. Existing Major Mariculture species and Farming Technologies

1. Status of farming of selected species

1-1) Target species and those production (Table III-1)

In Japan, aquacultures of oyster and laver have been prosperously practiced since the early seventeenth century. Statistics of 2004 [1)] show that the gross of mariculture production was amount to 435.6 billion yen. In detail (unit: billion yen), fish, seaweed, shellfish, pearl, prawn, and the others showed 196.5, 118.5, 72.5, 19.9, 8, and 20.2 respectively. List of major mariculture species were show as follows; Yellowtail, Amberjack, Red sea bream, Silver salmon, Tiger puffer, Japanese flounder and Striped jack in fish, Kuruma prawn in crustacean, Common scallop, Japanese oyster and Japanese pearl oyster in shellfish, Laver, "Konbu" tangle and "Wakame" in seaweed. The top five mariculture species in term of production value were firstly Yellowtail& Amberjack, secondary Laver, thirdly Red sea bream, fourthly Common scallop, and fifthly Japanese oyster. These species were very popular in Japan and important as the foods for Japanese traditional cooking.

Table III-1 Existing major mariculture species and production in Japan

Target species		Annual production (in 2004)	
English name	Scientific name	(billion yen)	(1,000t)
Yellowtail	*Seriola quinqueradiata*	72.87	100
Amberjack	*Seriola dumerili*	36.43	50
Red sea bream	*Pagrus major*	50.72	81
Tiger puffer	*Takifugu rubripes*	10.82	4
Japanese flounder	*Paralichthys olivaceus*	7.71	5
Striped jack	*Caranx delicatessimus*	4.27	3
Silver salmon	*Oncorhynchus kisutch*	3.57	10
Japanese horse mackerel	*Trachurus japonicus*	1.85	3
the others fish		8.24	7
Subtotal in fish		196.46	261
Japanese oyster	*Crassostrea gigas*	36.78	236
Common scallop	*Patinopecten yessoensis*	33.99	215
the others shellfish		1.69	2
Subtotal in shellfish		72.46	453
Kuruma prown	*Penaeuse japonicus*	8.04	2
Sea-squirt	*Halocynthia roretzi*	0.96	16
the others aquatic funa		0.47	0
Laver	*Porphyra sp.**	97.91	359
"Wakame"	*Undaria pinnatifida*	9.70	62
"Konbu",Tangle	*Laminaria sp.**	8.49	47
"Mozuku"	*Nemacystus sp.**	2.03	16
the others seaweed		0.36	0
Subtotal in seaweed		118.48	484
Pearl	*Pinctada fucata* **	19.85	31
Seed for aquaculture		18.84	-
Total		**435.55**	**1,216**

(Reference: Statistics of Agriculture, Forestry and Fisheries 2004)
* representative species
** mother shell

1-2) Remarkable target species

Recently, the first on the remarkable target species in Japan is bluefin tuna, *Thunnus thynnus*.[2)] Some reasons for future success in this species are; i) high market value and potential demand by fitness on Japanese taste, ii) decrease of wild fish population and regulation of pelagic fisheries, iii) technical development for production of high quality fish, iv) production of artificial seed for aquaculture by progress of rearing research. Next, barfin flounder, *Verasper moseri*, is an important species that can grow up to large size. Because of its high commercial value and rapid growth in the cold waters of northern Japan, [3)] aquaculture of barfin flounder has been expanding in Hokkaido and Iwate prefecture. And aquacultures of some grouper, *Epinephelus sp.*, have been practicing in western part of Japan, but many producer of aquaculture have hesitated the trial of this species because of its disease, VNN (Viral Nervous Necrosis). [4)]

In seaweed, "Mozuku", *Nemacystus sp.* and "Okinawa mozuku", *Cladosiphon okamuranus*, is remarkably species that have high content of "fucoidan" (kind of glycan). [5)] It has been reported fucoidan is effective substance for immune response. Recently healthy foods boom were supported its demand, and production of "Okinawa mozuku" is rapidly increased in Okinawa prefecture.

Thus, tendency of newly target species for aquaculture have reflected both of the expensive taste in personal consumption and the healthy boom. Therefore production of materials of functional foods for human health will be specially increased in the future.

2. Priorities for development and research

Present and future priorities for development and research, which is important for mariculture in Japan, are listed as follows.

2-1) Development for fine breeding

By application of molecular biological method, development for creations of fine breeding, which have character of high growth and strong tolerance to disease, is important subject. In Japan, selection of breeding had been practiced in gold fish and carp for a long time. Recently many trials of breeding technology (e.g. hybridization, diploid, triploid and clone) have done in Japanese parrotfish, red sea bream, Japanese flounder, laver, Japanese oyster etc.[6)] Rapidly advance of newly genetic research, especially marker-aided selection by microsatellite DNA maker's analysis, is led to newly possibility of breeding on fisheries.

2-2) Development of efficient feeding method and artificial food.

Problem of self-pollution by mariculture is caused serious damage to the coastal environment in Japan. Therefore development of artificial food for higher food conversion efficiency and introduction of demand feeding system that is self-selection of diet in mariculture is necessary as environmental conservation. Demand feeding system is effective method for reduction of scraps of food and it has been tried in some fish (e.g. red sea bream, yellowtail, grouper, tiger puffer and rainbow trout etc.). [7)]

2-3) Preventive measure against disease

At present, it have been reported that annual loss of aquaculture production have amounted to 15~25 billion yen (3~6% of total production) by influence on fish disease in Japan. Therefore preventive measure against disease is a matter of great urgency. Recently serious threat of some virus disease (e.g. YAV, HRV, BMN, VEH, VHS, and VNN) that invited mass mortality is expanding in seed production and aquaculture. Many researches have practiced the establishment of method for examination of virus, the search for characteristic of specific virus and source of the infection, the interception of the route of infection, the development of effective and safe vaccine, and the reinforcement for function of immunity in fish by special diet and control of environmental condition.[8)]

2-4) Polyculture system

Effective utilization of aquaculture space is considerable subject for increase of productivity. Multiple aquacultures can be easy for producer to trial and have possibility of its benefit. Fundamental concept of multiple aquacultures is “Zero Emission” and multiple aquacultures is practiced the combination of some kinds of species which have different feeding and different behavior and ecological pattern. Most of important factor is unaffected each other. In some case study, fish, seaweed, sea cucumber and abalone were tested and these experiments were shown high usefulness and high productivity.

2-5) Utilization of deep sea water

Deep sea water is pump up under the water depth below 300 m (e.g. Kochi prefecture). Characteristics of deep sea water are 1) stable low temperature (below 10 degree), 2) pure sea water (especially low concentration of marine bacteria), and 3) rich nutrient salts (inclusion of nitrogen, phosphorus acid and silicate). Technology for the aquaculture of Japanese flounder and deep sea animals can be developed. Nutrient-rich deep seawater can provide a good environment for the cultivation of phytoplankton, kelp and other seaweed, etc. Deep seawater contains very little pathogenic bacteria making it possible to prevent disease.

2-6) Promotion of aquaculture without food supply

Aquaculture of shellfish and seaweed are practiced without food supply. Shellfishes are grown by the consumption of phytoplankton and organic suspended particle. Seaweeds are grown by the consumption of nitrogen and phosphorus acid. These aquaculture types give some benefits for coastal environment. One of reason is direct effect of removal of excess nutrient salts and organic suspended matter and another reason is indirect effect of removal of nitrogen and phosphorus acid by harvest of products (shellfish and seaweed). These factors lead to remove nitrogen and phosphorus acid in sea water.[9)] Therefore we think that promotion of aquaculture without food supply is supported to conservation of coastal environment.

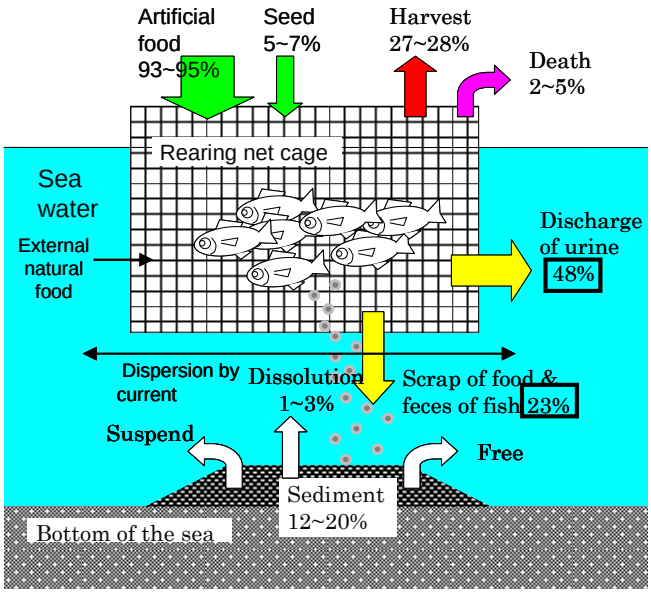
2-7) Aquaculture by a closed recirculation system

Refer to report of following III-3-3).

3. Identification of better management practices for existing farming species and systems, to mitigate environmental impacts

3-1) Problem of existing mariculture

Recently decrease of self-sufficiency rate attendant on both decrease of fishery products and increase of import is serious problem. Self-sufficiency rate in fish and shellfish for food was reduced by half during the past 30 years in Japan and it was shown 57% in 2004 (Fig.II-1).[2)] Therefore status of aquaculture in Japanese fishery is relatively raised up and promotion of aquaculture will be necessary to recover the self-sufficiency rate. But there is strong possibility to prevent the promotion of aquaculture by problems of mariculture in Japan. As the problem, the residual of medicine for fish disease and environmental pollution at the mariculture ground and the surrounding water are led to giv consumer and reduce the consumption of aquaculture products. Especially, the most serious problem is environmental pollution by organic matter (e.g. scraps of food, urine



(Hal et al 1992 was altered)

Fig.III-1 Nitrogen balance of mariculture by net cage rearing. (Case study in rainbow trout)

and feces of fish etc.) which is discharged into the coastal waters by the mariculture in Japan (Fig.III-1). There are some reports which make a trial calculation of the level of coastal pollution by exchange the human population.[10, 11] Trial calculation is carried out by comparison of daily discharge of nitrogen and phosphorus acid between human being and fish of mariculture. According to this report (Table III-2), level of pollution by mariculture in Japan is estimated to be equal to between 5 million to 7 million people in nitrogen, and between 9 million to 10 million people in phosphorus acid.[11] These results clearly show that environmental pollution by mariculture has reached serious condition in Japan and it is suggested that management should be carried out quickly.

Table III-2 Trial calculation of the level of coastal pollution by exchange the human populations (Maruyama T. 1999)

Origin for estimation	ammount of production (thousand t)	Estimated human populations (million people)	
		TN	TP
Amount of aquaculture production	325	7.5	10.0
Amount of artificial food production	500	5.4	9.6
*Standerd unit for pollution	TN: 100kg-TN/t-aquaculture production TP: 20kg-TP/t-aquaculture production		
*Standerd unit for exchange to person	TN: 12.0g-TN/person・day TP: 1.8g-TP/person・day		

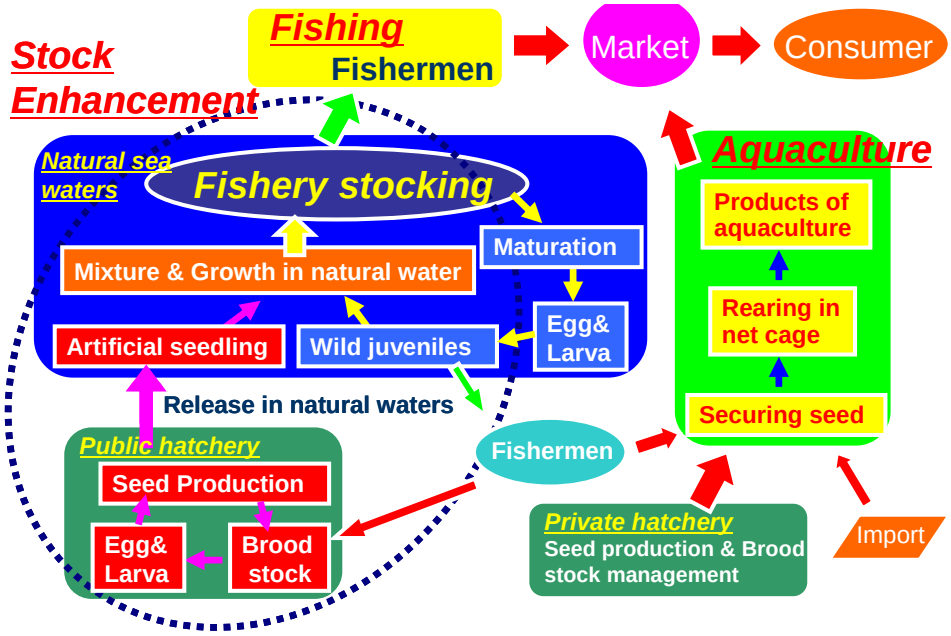
3-2) Stock Enhancement; Trial of type in harmony with environment (Fig.III-2)

In Japan, stock enhancement (sea farming), which is in harmony with environmental as a key measure in preserving and enhancing fisheries stock, has been practiced. National Center for Stock Enhancement in Fisheries Research Agency started the technical development of stock enhancement in 1963 by releasing artificial seed (juveniles) for a project to actively recover the decreasing fishery stock.[12] Stock enhancement is operated following system as the experiment-ecological trial. System of stock enhancement is consisted of i) selection of target species, ii) brood stock management, iii) securing fertilized egg, iv) seed production, v) rearing in nursery and acclimation to natural environment, vi) release, vii) comprehensive stock management (release and natural stock), and viii) monitoring of stock and evaluation of stocking share by feedback in future. Until now, many kinds of marine species were tried to release in natural water. In some species (e.g. dog salmon, *Oncorhynchus keta* and

common scallop, *Patinopecten yessoensis*), effect of stock enhancement were clearly reflected on the increase of fishery production.[12, 13] Recent advance in marker's techniques supported the investigation to assess effectiveness of the stocking, and the case studies reported high return rate (8~50%) in red sea bream and Japanese flounder and abalone etc.[13]

As the characteristic of this trial, knowledge of ecological information in target species is necessary and it emerged that the release operation on ecological fitness in target species is necessary condition for the guarantee of highly stocking effectiveness.

FigIII-2 The concept of stock enhancement and system of Japanese fisheries



3-3) Land aquaculture by the closed recirculation system; Trial of type of environment preservation

As the viewpoint of coastal environment preservation, closed recirculation system is spotlighted on the rearing technology that is type of "Zero Emission" by few discharges for fish rearing. Research for a closed recirculation system in the world was started in the 1950s.[14] Dr. Saeki and Hirayama were the pioneers of research for a closed recirculation system by development and fundamental research of the bio-filter.[14, 15] Completely system control is led to a lot of benefit which are i) reduction of pollution, ii) avoidance of external risk (e.g. disease and bad water quality etc.), iii) highly stable productivity, and iv) energy-saving benefit. Therefore the development of formation of hardware and software for rearing technology will be demanded quickly. Some trials of closed recirculation system for aquaculture in Japan were reported in region for research

(e.g. high density rearing in Japanese flounder and eel) [16, 17, 18], but promotion into private company and fishermen have just started. In the near future, the newly research group of industry–university -government cooperation for this subject will be started and some projects will be realized.

In Yashima station, NCSE, FRA, technical development of closed recirculation system for seed production in red sea bream were started from 2000.[19] Closed recirculation system in this center are consisted of i) foam separation unit, ii) bio-filtration system and iii) UV system and these function are i) removal of organic matters in rearing water, ii) nitrification, iii) sterilization of bacteria respectively (Fig.III-3).

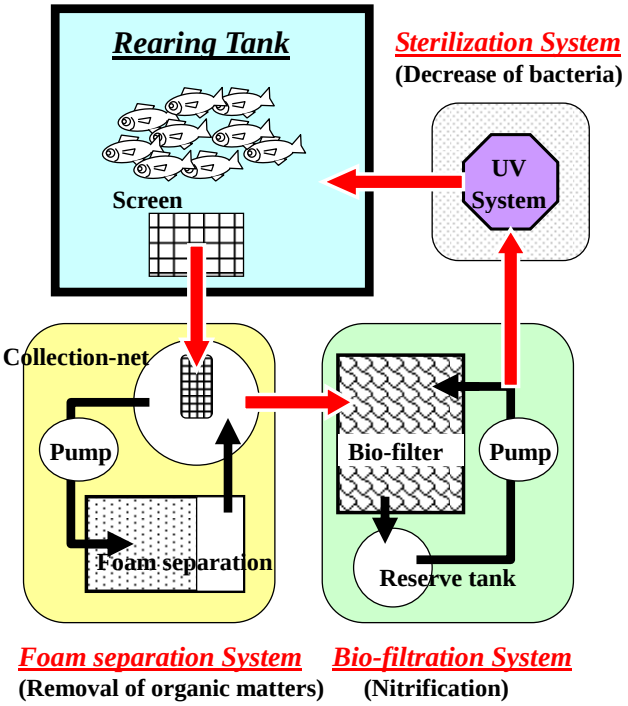


Fig.III-3 Composition of seed production by closed recirculation system on Yashima station, NCSE, FRA

At present, technical level of seed production by this system is higher than flow-through rearing.[20] By closed recirculation system, survival and production densities from hatched larva to juveniles of 30 mm in TL are 45~70 % and 5,000~7,000 individuals / k*l* [20] and those in case of juveniles of 60 mm in TL are 50% and 5,000 individuals / k*l* respectively. Water exchanging rate is few (below 0.5%/day). Therefore we can establish the near-perfect no discharge system for seed production. Also water qualities in rearing periods (about 50 days) from hatch to juveniles of 30 mm in TL are investigated. Concentrations of ammonia nitrogen and nitrite-nitrogen in rearing water are kept below 1.0mg/*l* and 0.5mg/*l* respectively. Therefore under the condition of little water exchanging rate, seed production by closed recirculation system is kept in suitable water conditions for juveniles of red sea bream. In the future, this closed recirculation system will be applied to the other species which is difficult for seed production and aquaculture.

3-4) Finally

In Japan, system of fishery is constituted in fishing, aquaculture, and stock enhancement (sea-farming). We supposed that relative closed coastal waters in natural

sea are corresponded to the large mariculture region, and we suggested the conception of stock enhancement (sea-farming) & sea ranching that is the intermediate between fishing and aquaculture. And we will aim to establish the fuzzy and comprehensive formation for fishery in Japan and to control the fishery stocking by release for stocking recovery, rational fishery that is fisheries regulations (e.g. catch limitation, fishing gear, fishing period). Marine fundamental productivity is supported to the fishery. But condition of fundamental productivity of natural coastal water is exhausted by disappearance of tide land and Zostera zone and seaweed bed.[21)]

Therefore as the national policy, which aims to rise up the self-sufficiency rate of fish and shellfish, time has come to consider seriously to promote the aquaculture and to switch into the aquaculture by a closed recirculation system that is type of environment preservation.

In the future, we consider that it should be necessary for support by Japanese government to target on the aquaculture company that switch into a closed recirculation system and the company of newly entry for business chances.

References

1) Ministry of Agriculture, Forestry and Fisheries of Japan (2005) Statistics of Agriculture, Forestry and Fisheries 2004, 1-27. (In Japanese)

2) Ministry of Agriculture, Forestry and Fisheries of Japan (2005) Part 1 Developments in the fisheries --summary, Annual report on the development in the fisheries in FY 2004, 1-33.

3) Andoh T., Watanabe K. Matsubara T. (1999) Problems and perspectives in stock enhancement of Barfin Flounder (review). *Bull. Hokkaido Natl. Fish. Res. Inst.*, **63**, 19-33. (In Japanese)

4) Furuta, Y. (1996) Mass mortality of cultured seven band grouper, *Epinephelus septemfasciatus*, associated with viral nervous necrosis, *Fish Pathology*, **31**, 165-170.

5) Noda H. (1994) 7. Seaweed, VII. Chemistry, In *Recent advances in fisheries science.* (Ed. by Publish committee of Japanese society of Fisheries Science), Koseisha-koseikaku Co., Ltd. Tokyo, pp.320-329. (In Japanese)

6) Taniguchi N. and T. Aoki (1994) 4. Genetics, IV Aquaculture, In *Recent advances in fisheries science*. (Ed. by Publish committee of Japanese society of Fisheries Science), Koseisha-koseikaku Co., Ltd. Tokyo, pp.143-161. (In Japanese)

7) Kohbara, J., I. Hidaka, I. Kuriyama, M. Yamashita, M. Ichikawa, K. Furukawa, K. Aida, FJ. Sánchez-Vázquez and M. Tabata (2000) Nocturnal/diurnal demand-feeding pattern of yellowtail *Seriola quinqueradiata* under different keeping conditions. *Fisheries Science*,

66 (5), 955-962.
8) Muroga, K. (1994) 3. Disease, IV Aquaculture, In *Recent advances in fisheries science.* (Ed. by Publish committee of Japanese society of Fisheries Science), Koseisha-koseikaku Co., Ltd. Tokyo, pp.136-143. (In Japanese)
9) Matsuda, O. (2002) 3. Holistic approach to fisheries management from the view point of environmental conservation, I. Multiple role of fisheries in environmental management, Role of fisheries in environmental management and remediation. (Eds. by Matsuda, O., K. Furuya, K. Taniguchi and A. Hino), Fisheries Series 132, Koseisha-koseikaku Co., Ltd. Tokyo, pp.32-43. (In Japanese)
10) Maruyama, T. and Y. Suzuki (1998) The present state of effluent control in Japan and pollutant load from fish culture to environment –Possibility of intensive recirculating fish culture systems- (summery). *Nippon Suisan Gakkaishi,* **64**(2), 216-226. (In Japanese)
11) Maruyama, T. (1999) 1. Present status of quantity, contents and environmental load of the wastewater from aquaculture, I. Environmental load by aquaculture. Reduction of environmental emissions from aquaculture. (Eds. by Hino, A., T. Maruyama, and H. Kurokura), Fisheries Series 123, Koseisha-koseikaku Co., Ltd. Tokyo, pp.9-24. (In Japanese)
12) Imamura, K. (1999) The organization and development of sea farming in Japan. In *stock enhancement and sea farming*. (Eds. by B. R. Howell, E. Moksness and T. Svasand), pp.91-102, Blackwell, Oxford.
13) Kitada, S. (2001) Fish stock enhancement assessment with Japan example. Kyoritsu Shuppan Co., Ltd. 1-329. (In Japanese)
14) Saeki, A. (1958) Studies on fish culture in the aquarium of closed-circulating system. Its fundamental theory and standard plan. *Nippon Suisan Gakkaishi,* **23**, 684-695.
15) Hirayama (1970) Studies on water control by filtration through sand bed in a marine aquarium with closed circulating system-VI. Acidication of aquarium water. *Nippon Suisan Gakkaishi*, **36**, 26-34.
16) Kikuchi, K., S. Takeda, H. Honda and M. Kiyono (1991) Effect of feeding on nitrogen excretion of Japanese flounder *Paralichthys olivaceus*. *Nippon Suisan Gakkaishi*, **57**, 2059-2064.
17) Honda, H., Y. Watanabe, K. Kikuchi, N. Iwata, S.Takeda, H. Uemoto, T. Furuta, and M. Kiyono (1993) High density rearing of Japanese flounder, Paralichthys olivaceus with a closed seawater recirculation system equipped with a denitrification unit. *Suisanzosyoku*, **41**(1), 19-26.
18) Suzuki, Y. and T. Maruyama (1999) 10. Performance of a closed recirculating system with foam-separation, nitrification and denitrification units for intensive culture of Japanese eel, III Developments of recirculation aquacultures, Reduction of

environmental emissions from aquaculture. (Eds. by Hino, A., T. Maruyama, and H. Kurokura), Fisheries Series 123, Koseisha-koseikaku Co., Ltd. Tokyo, pp.98-115. (In Japanese)
19) Tomoda, T., H. Fushimi and H. Kurokura (2005) Performance of a closed recirculation system for larviculture of red sea bream, *Pagrus major. Fisheries Science*, 71, 1179-1181.
20) Kamoshida, M., H. Yamazaki and Y. Yamamoto (2006) Seed production of red sea bream, *Pagrus major* using a closed recirculation system. *Saibaigiken*, in press (In Japanese)
21) Shibagaki, T. (2002) 2. New environmental conservation policy of the Seto Inland Sea, I. multiple role of fisheries in environmental management, Role of fisheries in environmental management and remediation. (Eds. by Matsuda, O., K. Furuya, K. Taniguchi and A. Hino), Fisheries Series 132, Koseisha-koseikaku Co., Ltd. Tokyo, pp.16-31. (In Japanese)