AQUACULTURE DEVELOPMENT IN JAPAN

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ABSTRACT

Along with the growth of the national economy, aquaculture in Japan has steadily developed in recent years. From 1976 to 1985, production of cultured fish and shellfish increased by 28% from 927 thousand mt to 1184 thousand mt. The contribution of aquaculture to total domestic production constituted 22% in value and 9.7% in weight for 1985. Increase in aquaculture production may be attributed to stronger domestic consumer demand for high grade fish products.

The principal species for culture include sea bream *(Pagrus major),* black sea bream *(Acanthopagrus schelegi),* yellowtail *(Seriola guinqueradiata),* Japanese flounder *(Paralichthys olivaceus),* pufferfish *(Takifugu rubrives),* Kuruma ebi *(Penaeus japonicus),* abalone *(Nordicus discus),* blood ark shell *(Scapharca broughtonii)* and edible seaweeds *(Porphyra, Undaria, Laminaria).* Rapid strides in improved culture techniques have been attained in seed production, grow-out, harvest and disease control in these various species.

Present trend show increasing reliance on cultured rather than fishery products to meet market demand. In some species, e.g., coho salmon, rainbow trout, oyster and laver, production depends entirely on culture. In other species, production by aquaculture contribute a significant portion to total production. However, to maintain the balance between supply and demand for certain principal aquaculture products, controlled production is now being practised for certain species. In addition to these trends, technical improvements in aquaculture has led to a decrease in the number of management units and area of facilities devoted to production.

In the future, greater efforts will be directed to diversify the species cultured to suit consumer preference. Emphasis will also be placed on improving taste and texture of cultured products. New types of feed that will not pollute areas around the culture facilities will be developed. Remarkable achievements in biotechnology will also be applied in aquaculture to improve seed quality.

Parallel with developments in aquaculture, Japan is exerting greater efforts to propagate fishery resources in coastal waters through stock enhancement activities. This is aimed at establishing a multiple fish and shellfish propagation system in the seas surrounding Japan to maintain or increase production from fishery resources.

PRODUCTION AND DEMAND FOR FISH AND FISH PRODUCTS

The total supply of fish and shellfish was 13.7 million mt in 1985. Of this total, the domestic production accounted for 11.4 million mt (excluding seaweeds) and the balance of 2.3 million mt was imported. The domestic consumption was 13.5 million mt with human consumption accounting for 8.4 million mt. Non-human consumption, mainly material for fish meal and food for aquaculture, totalled 3.8 million mt. A total of 1.3 million mt was exported, and there was an increase in stock amounting to 0.2 million mt. As a result, the per capita annual net food supply increased by 0.3 kg from the previous year to 35.8 kg.

The production of fisheries and aquaculture in recent years is shown in Table 1.

PRESENT STATUS OF MARINE AND FRESHWATER AQUACULTURE

Aquatic animals and plants have long been regarded as common properties in Japan. However, with the development of stock enhancement, the aquatic organisms which are protected in a restricted area or released artificially into the water area are now being recognized as intermediate between common property and private property. Consider fisheries from this viewpoint, and aquaculture can be defined as the activities of growing edible aquatic organisms whose ownership is clearly established. Therefore, feeding them or controlling their life histories to some extent are of no concern in the definition of aquaculture. Growing inedible animals such as pearl oyster and gold fishes is usually considered as aquaculture in Japan.

Table 1. Production of fisheries and aquaculture. Upper figures denote weight in 1000 mt., lower figures in parenthesis, value in billion yen including whaling

Year	Total	Marine Fisheries & Culture Method					
		Far sea	Offshore	Coastal	Culture	Fishery	Culture
1981	11 319 (2789)	2165 (584)	5940 (826)	2038 (733)	960 (457)	124 (63)	92 (106)
1982	11 388 (2977)	2089 (641)	6070 (902)	2072 (770)	938 (456)	122 (71)	97 (125)
1983	11 967 (2916)	2132 (640)	6428 (820)	2136 (746)	1060 (519)	117 (62)	94 (117)
1984	12 816 (2947)	2280 (693)	6956 (786)	2265 (752)	1111 (517)	107 (61)	97 (123)
1985	12 171 (2902)	2111 (684)	6498 (757)	2268 (751)	1088 (522)	110 (61)	96 (115)
1986	12 677 (NA)	2262 (NA)	6801 (NA)	2225 (NA)	1190 (NA)	106 (NA)	94 (NA)

Production Trend

Marine and freshwater aquaculture in Japan has steadily developed to meet strong demands for high grade fish as a consequence to improved food habit with the growth of national economy. Production increased from 0.9 million mt in 1976 to 1.2 million mt: in 1985 representing 28% increase in 10 years. In terms of value the production increased by 1.7 times from 374 billion yen in 1976 to 638 billion yen in 1985.

However, stagnating production is being observed in some species in recent years, mainly due to keeping the balance between demand and supply in principal aquaculture products such as yellowtail, red sea bream, eel, oyster, scallop, and laver. Moreover, full use of waters suitable for aquaculture prevents further expansion of production facilities. It is, therefore, anticipated that aquaculture production in Japan will be stable in the coming few years.

Aquaculture production by species together with that fished from the wild is shown in Tables 2 and 3. If viewed by species, production of coho salmon, rainbow trout, tilapia, oyster, and laver depend entirely upon culture, and production from culture are 26.0, 12.2, 4.5, 2.4, and 1.9 times as much as production from fisheries for respective species of eel, *Undaria,* yellowtail, carp and red sea bream in 1985. While production from culture of scallop, sweetfish, Kuruma prawn, and *Laminaria* are between 29% and 48% of the total production of these species, and those of plaice and crucian carp are about 15% of the total production, that of horse mackerel, however, is only 0.3% of the total production. Aquaculture always competes with fisheries in the supply of products, especially that of high-priced ones. Since aquaculture can supply products with equal size and quality regardless of season, it has developed greatly with the decrease in the supply of high-priced fishes by capture fisheries.

The changes in the number of aquaculture management units and the area of facilities are shown in Tables 4-10. Trends of their changes are not always consistent with those of production. For example, in spite of the steady increase of production as observed in eel and scallop cultures, the management units and their areas of facilities have decreased year by year in recent years.

In the beginning, marine aquaculture developed mainly in calm areas less than 20 m deep. However, these waters have been polluted

Table 2. Production trend (in metric tons) by species, cultured and wild

Year	Horse mackerel		Yellowtail		Plaice		Red sea bream	
	Culture	Wild	Culture	Wild	Culture	Wild	Culture	Wild
1976	721	127 704	101 619	42 763		7158	6 453	16 995
1977	772	87 457	114 866	26 915	-	6446	8 120	17 020
1978	815	57 992	121 728	37 414	-	7202	10 844	16 160
1979	1460	82 515	154 872	44 970	-	6818	12 253	15 378
1980	2283	53 664	149 311	42 009	-	7113	14 757	15 170
1981	3229	61 815	150 754	37 774	-	6332	17 953	13 709
1982	3629	105 125	146 304	38 445	-	6387	20 246	14 954
1983	4305	130 230	155 879	41 822	648	6661	25 000	14 699
1984	3710	135 763	152 498	41 212	838	7095	26 156	15 956
1985	5008	152 929	150 961	33 422	1572	8184	28 430	14 723

Year	Eel		Sweetfish		Carp		Crucian carp	
	Culture	Wild	Culture	Wild	Culture	Wild	Culture	Wild
1976	26 251	2040	5726	13 272	26 289	6960	954	10 113
1977	27 630	2106	5875	13 451	29 295	6760	1007	10 316
1978	32 106	2068	7185	13 363	29 160	7376	1292	10 751
1979	36 781	1923	8455	14 822	27 452	7856	1263	10 948
1980	36 618	1963	7989	14 723	25 045	8479	1151	10 066
1981	33 984	1920	9492	15 405	23 784	8108	1289	9138
1982	36 642	1927	10 222	14 872	24 093	8202	1215	8441
1983	34 489	1818	10 318	15 579	22 397	7545	1592	8005
1984	38 030	1573	11 705	14 919	21 071	7594	1492	8034
1985	39 568	1526	10 967	14 492	19 105	7830	1455	7987

Year	Kuruma prawn		Scallop		Luminaria		Undaria	
	Culture	Wild	Culture	Wild	Culture	Wild	Culture	Wild
1976	1042	2579	64 909	30 270	22 089	159 162	126 723	19 337
1977	1124	2440	83 180	43 502	27 249	132 989	125 833	20 180
1978	1184	2673	67 723	59 664	21 890	108 911	102 682	12 213
1979	1480	2468	43 614	79 734	25 291	131 546	103 791	12 131
1980	1546	2307	40 399	83 134	38 562	124 816	143 352	15 759
1981	1666	2864	59 095	91 139	44 221	112 178	91 272	13 993
1982	2000	3068	76 866	99 505	42 980	145 952	118 340	12 155
1983	1949	3578	83 111	128 136	44 345	129 043	112 835	9 565
1984	2037	3356	73 948	135 239	62 756	114 221	114 586	9423
1985	2151	3741	108 509	118 277	53 593	132 903	112 375	7238

or the area may no longer be used due to increased reclamation projects and the expansion of harbor facilities. In view of these developments, culture areas have gradually expanded from bay areas to the outer sea. Newly developed culture techniques such as flowing-current style for laver, middle and bottom layer cage culture for fish, long-line facilities for *Undaria, Laminaria,* scallop, and pearl oyster together with the installation of wave breaker facilities make the expansion of culture areas possible. Accordingly, the area utilized for marine aquaculture has been maintained at around 100 000 ha for the last ten years or so.

Table 3. Production trend (in metric ton) by species, depending entirely on culture

Year	Coho salmon	Rainbow trout	Tilapia	Ascidian	Oyster	Laver
1976		15 322	34	8390	226 286	291 050
1977	—	16 033	56	7463	212 786	279 031
1978	72	17 166	416	5759	232 069	350 471
1979	370	16 714	1526	5287	205 509	325 686
1980	1855	17 698	2392	5749	261 323	357 672
1981	1150	17 819	2465	6909	235 241	340 510
1982	2122	18 230	2640	7382	250 288	263 312
1983	2760	17 817	3233	7889	253 249	360 694
1984	5049	16 773	3544	8903	257 126	396 530
1985	6990	16 324	4180	7660	251 247	351 788

Table 4. Changes in number of aquaculture management units

	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
Horse mackerel	108	149	223	363	599	737	830	821	718	723
Sea breams	1431	1781	2069	2413	2689	2831	2940	2924	2894	3014
Yellowtail	3809	3991	4162	4100	3941	3883	3878	3670	3411	3205
Ascidian	2485	2418	2264	2122	1887	1957	1837	1840	1698	1699
Scallop	8058	7689	6775	6399	5800	5507	5558	5507	5564	5452
Oyster	5522	5695	5973	6157	6211	6135	5977	5911	5781	5781
Pearl	2175	2131	2138	2078	1941	1953	1958	1996	2029	2048
Kuruma prawn	105	104	119	120	121	128	129	134	142	148
Laver	33 625	31 763	30 226	29 560	28 325	26 495	24 436	22 044	21 297	20 405
Undaria	18 887	17 205	16 354	15 337	14 544	14 289	14 142	13 570	13 027	12 985
Laminaria	3110	2828	2991	2882	3270	3913	4052	4037	4352	4451

On the other hand, the water area for major freshwater aquaculture in leading production area decreased from 7997 ha in 1976 to 4948 ha in 1985. In association with the development of intensive culture methods, a sharp decrease in culture area for carp and eel culture has taken place.

Stock Enhancement in Coastal Waters

Until quite recently fisheries meant mainly capturing fish; however, efforts are now being made to develop a new type of fisheries which does not merely catch fish but also increases them naturally. This is similar to the transition from hunting to farming and cattle-raising age.

Within the 200-mile area, it is all the more imperative to develop the seas surrounding Japan to meet the increasing demand for fish and shellfish, especially high-quality ones. However, the production of these high-quality fish and shellfish* has decreased for many reasons. These fisheries resources must not only be maintained, but should also be increased significantly more and more in the future. Along this line, the country is making a very strong effort to promote fish propagation and fishery conservation in all its waters.

Numerous types of stock enhancement technology are being practised, some having been established already as an industry for a long time, and some still being developed at present. For instance, stock enhancement of chum salmon, red sea bream, scallop, and also abalone, prawns, and crabs has been successful. The stock enhancement is conducted mainly by producing large numbers of seedlings of fish and shellfish, releasing them into the sea suitable for their further growth, protecting them until they attain commercial size and harvesting them by the ordinary fisheries methods.

The concept of stock enhancement is to use the wide ocean itself as a pasture for propagating fisheries resources in large amounts, mainly the medium and high-quality species which are widely in demand among the population. The aim of stock enhancement is to create a multiple fish and shellfish propagation system in which different species can be possibly increased when stocked together. To accomplish this, the technology applied to stock enhancement is based on ecological aspects while the technological development of aquaculture has been made through physiological considerations.

Table 5. Aquaculture management units and area of facilities for yellowtail (size in ha, initial number of fish in 1000, food in 1000 mt)

Year	Bank type		Net demarcation		Cage Net		Number of fish	Food	
	No	Size	No	Size	No	Size		Fresh	Others
1976	10	51	99	109	22 394	198	81 132	964	5
1977	7	42	93	111	23 635	205	76 007	966	6
1978	6	14	107	128	27 002	243	83 574	1125	11
1979	6	14	97	129	29 172	249	80 602	1316	8
1980	4	9	82	95	28 878	267	75 327	1296	2
1981	3	7	71	91	27 669	273	80 409	1306	6
1982	2	5	75	85	32 313	299	85 142	1303	5
1983	2	5	66	78	29 452	305	83 803	1344	8
1984	2	5	59	49	27 395	272	66 887	1382	10
1985	2	5	60	72	25 720	248	68 364	1256	24

Table 6. Aquaculture management units and area of facilities for seabream (size in ha, initial number of fish in 1000 mt, food in 1000 mt)

Year	Bank type		Net demarcation		Cage Net		Number of	Food	
	No	Size	No	Size	No	Size	fish	Fresh	Others
1976	6	NA	7	NA	6066	NA	18 813	69	NA
1977	4	NA	3	NA	7869	NA	21 577	106	NA
1978	3	NA	26	NA	9128	NA	29 364	154	NA
1979	4	NA	7	NA	10 862	NA	28 231	147	NA
1980	2	NA	2	NA	14 243	112	36 084	194	NA
1981	6	NA	2	NA	15 499	125	34 007	256	NA
1982	16	NA	4	NA	15 644	136	42 052	221	NA
1983	4	12	6	5	17 228	173	47 512	206	22
1984	7	13	7	7	17 698	139	55 182	244	35
1985	6	12	7	6	19 274	151	56 230	261	42

Table 7. Aquaculture management units and area of facilities for pearl (standard size of raft 6.35 × 45 m with 3000 pearl oysters, one unit of long rope 60 m, size in ha)

Year	Raft		Long rope	Production	
	No	Size	Unit	Weight (kg)	Value (mill yen)
1976	112 299	163	NA	33 774	22 158
1977	114 282	176	NA	38 565	26 456
1978	123 803	172	NA	37 586	22 128
1979	117 668	160	NA	40 137	32 176
1980	49 783	216	81 452	42 345	46 062
1981	47 013	203	79 487	45 861	48 925
1982	36 136	138	93 515	51 856	47 817
1983	33 891	140	97 346	57 520	65 682
1984	37 326	129	98 059	64 160	65 682
1985	36 602	126	93 114	61 655	57 833

Table 8. Aquaculture Management Units and Area of Facilities for Oyster (standard size of raft 18.2 × 10.9 m, one unit of long rope 54.54 m, size in ha)

Year	No	Size	Long rope Unit	Simple hanging Size	Sticks Size	Sown on ground Size
1976	14 615	NA	12 942	270	21	126
1977	15 388	NA	14 244	174	23	126
1978	15 782	NA	15 420	164	22	133
1979	16 642	NA	15 312	159	22	133
1980	16 509	329	16 778	130	22	141
1981	16 851	335	19 740	117	22	143
1982	17 769	347	17 899	114	16	140
1983	17 585	447	24 792	281	24	141
1984	17 128	340	26 662	282	26	140
1985	20 235	401	25 997	282	26	140

Table 9. Aquaculture Management Units and Area of Facilities for Laver (number in 1000 units, standard size of net 18.2 × 1.5 m, size in ha)

Year	Sticks held Net		Floating Net	
	No	Size	No	Size
1976	1830	11 084	1302	5229
1977	1854	11 120	1165	5054
1978	1876	11 268	1273	5483
1979	1952	10 189	1378	5689
1980	1966	10 108	1421	5505
1981	1854	10 057	1356	5299
1982	1763	9486	1277	4971
1983	1615	8896	1221	4839
1984	1683	8951	1322	4752
1985	1609	8654	1263	3852

Contribution of Aquaculture to Fish Production

The proportion of aquaculture products to the total fisheries production in Japan is considerably high in terms of value although it is still low in volume. In 1985, the production of aquaculture constitutes 22.0% in value and 9.7% in volume of the total fisheries production. When these figures are compared with those of combined coastal and inland fisheries production, they become as high as 41.0% in value and 32.4% in volume in coastal fisheries. As the production of aquaculture for principal species exceeds that of fisheries, aquaculture is taking an important role in the supply of these species. With the expansion of market for restaurants, aquaculture becomes extremely important in providing materials for them. As a result, aquaculture is asked to further increase its link with the restaurant industry by supplying the latter with such products to meet its needs.

FUTURE STATUS OF AQUACULTURE

Judging from the general trend of consumers' preference for food, aquaculture can produce many varieties of species of desired quality. Therefore, the culture of puffer, striped jack, tuna, black sea bream, sea bass, parrot fish, octopus, cuttle fish, and abalone will develop in the near future. At the same time, improvement in taste and

Table 10. Changes in the number of management unit and size of facilities of freshwater aquaculture in leading production area (size in ha)

Year	Carp		Eel		Salmonids		Crucian carp		Sweetfish	
	Unit	Size	Unit	Size	Unit	Size	Unit	Size	Unit	Size
1976	3621	3106	2735	2570	1353	164	333	2108	322	49
1977	3358	2986	2656	2485	1234	165	312	1972	318	44
1978	3849	3394	3218	2477	2007	291	972	2205	498	64
1979	2745	2440	1959	1719	1142	153	231	2043	295	44
1980	2393	2259	1816	1606	1137	156	223	1949	293	43
1981	2240	2000	1682	1421	1143	151	242	2265	285	43
1982	2031	1928	1564	1269	1126	137	234	2152	271	45
1983	1901	1399	1435	1148	1153	160	257	2383	283	48
1984	1712	1573	1569	1199	1136	150	252	2233	295	46
1985	1593	1473	1478	1125	1094	135	249	2181	279	44

texture of aquaculture products is being taken into account to meet the consumers' demand. In this connection, successive efforts will be made to develop assorted feeds like the pellet, and culture facilities for deeper and outer waters. The development of a new type of feed is also expected to prevent water pollution around the aquaculture site.

With the remarkable development of high technologies in such fields as biotechnology, electronics, and new material technology, expectations are placed on the development and application of these high technologies to aquaculture for its further expansion. Since most of the species cultured are wild, great hardships are encountered in keeping them under control. Efforts to improve the seeds suitable for culture by the application of biotechnology, such as cell fusion and chromosome technology, are being made.

FINFISH CULTURE

Broodstock Production

Rearing facilities. Parent fishes of marine species are usually maintained in a concrete tank. The tank capacity depends upon size and swimming and feeding habits of the species. About 20-100 m^3 circular and rectangular tanks are commonly employed as spawner reservoir. There are no rational bases for the choice of shape and dimension of tanks. They might be determined by land space, ease of maintenance, and water supply system. Tanks less than 3 m deep are preferred relative to pump capacity and maintenance procedures. The tank is usually roofed or covered with sheets to protect against sunlight and to avoid unexpected stress.

Rearing method. A sex ratio of one female to one male or one female to two males is widely adopted for mating and spawning in most hatcheries because poor fecundity resulting from unbalanced sex ratio has been proven experimentally. Then parental fish larger than about 600 g are generally maintained at a density of 1-1.5 fish/ m^3 and smaller fish at 0.8-1.5 kg/ m^3 Sea water is supplied by a pumping system through filtration. Pelagic eggs spawned in tank are collected through water overflow by fine mesh net set at the outlet. Heated sea water is used sometimes to induce early maturation in Sparid fish and Japanese flounder. Warm effluent from a thermal power station is utilized to ensure the early maturation of the commercially valued broodstock. Photoperiod control, which has been used in Ayu fish (sweet fish), has recently been applied to effect the natural spawning of Japanese flounder. The pituitary of grass carp and human chorionic gonadotropin (HCG) are occasionally used to obtain viable eggs from sea bass, yellowtail, and Japanese flounder.

Feeds and feeding. Various low-priced fishes are preferably fed by hand to spawners. Sardines, anchovies, sand lance, mackerel, and *Euphausia* are popular feeds. In addition, formulated feeds are also used together with these raw materials. The parental fishes are fed at the rate of 2 to 8% of body weight every morning. Many species anticipate feeding time at a particular part of the tank. Regular feeding schedule has effects on the acclimation of spawners in captivity, resulting in high fecundity of the broodstock.

Capture, handling, and transport. Spawners are captured from the wild or raised from larval stage in the hatcheries. They are usually cultured in floating net-cages, except during the spawning season, and transferred to spawning tanks 4 or 6 weeks before spawning. This procedure is advantageous for the effective utilization of facilities, in reducing cost of broodstock culture and in avoiding accidents in the water supply system during breeding.

No reliable methods are known for monitoring gonad maturation and sex identification. However, spawning behavior in captivity and the temperature at which spawning begins are well investigated to predict the spawning season in various species. Only in few species is sex distinguishable by body color and swelling of abdomen.

Diseases and Parasites. No serious mortality has been generally observed in spawning tanks as broodstock for many species is maintained at low density under good feeding conditions.

To utilize the hatchery facilities economically and effectively, various fish larvae must be reared throughout the year. Therefore, running and maintenance costs are needed to culture numerous broodstocks of different fish species in each hatchery. The utilization of HCG which often results in unstable hatchability must be worked out to obtain viable eggs for yellowtail since the techniques for natural spawning is not yet established.

Seed Production and Nursery Operation

Rearing facilities. Rearing tanks of larvae vary widely in size, shape, and materials. For mass production of fry the smallest tank is 0.5 m^3 the largest, 400 m^3 Most tanks are from 20-100 m^3 with depths of 1.0-1.5 m. Recently, plastic material (polycarbonate and fiber-reinforced plastic) is used to make circular and rectangular tanks from 0.5-4.0 m Simplified tanks of canvas sheet are also employed for larval rearing as well as phytoplankton culture because these are cheaper. All these tanks are commercially available anywhere.

Large tanks with more than 100 m^3 capacity in Hiroshima Prefectural Fisheries Center equipped with automatic feeder and vacuum cleaner were used to save on labor and to mechanize the rearing procedure. The use of an automatic pilot is gradually gaining acceptance in the fisheries centers run by the central and federal government for large-scale production.

Smaller net-cages are commonly used for nursery breeding in the sea. The net-cages measure 2-4 m^2 with depths of 1.5-3 m. Some facilities are installed for electric lighting to attract zooplankton to caged fry at night. A cover net is usually set on the raft to avoid bird predation. The stocking density is controlled relative to fish size and their growth. Fry 1-1.5 cm are kept at a density of 10 000-30 000 ind/m^3 ; 2-3 cm fry at 1000-2000 ind/m^3 and over 4 cm fry at 700-1000 ind / m^3.

Rearing method. Naturally spawned eggs are preferred for mass production because of its high hatchability. Naturally spawned eggs are frequently transported from power station or fish centers in warm districts, where spawning occurs earlier, to fisheries centers and farmers' hatcheries. Vinyl bags filled with oxygen are practical and cheaper as means of transporting eggs and larvae.

Newly hatched larvae, before the mouth-opening stage, are transferred from incubation net enclosures to rearing tanks, after which the density of larvae is estimated volumetrically by taking aliquots from the aquaria. Pelagic eggs are introduced directly to rearing tanks. Egg number is determined by multiplying its number in fixed volume or weight. Stocking density of newly hatched larvae and eggs are dependent largely on tank capacity. About 25 000-40 000 larvae or eggs are maintained in the smaller 0.5-50 m^3 tanks. Stocking density decreases with increasing tank capacity. The larvae and eggs are maintained at lower density of 5000-10 000/ m^3 in tanks larger than about 70 m^3.

During the initial phase, larvae are reared in a static system with aeration, and afterwards in a semi-static system where the water column is replaced partly. Flow-through system is employed when the fish swim actively or approach the transitional stage from larvae to juveniles.

Feces and sediments at the bottom are siphoned everyday. Some fish culturists inoculate *Chlorella* sp. into the rearing tank at the concentration of 30-500 × 10^4 cells/ml as a "water conditioner", which reduces the deterioration of rearing water and prevents starvation of rotifers.

Feeds and feeding. Rotifers, *Brachionus plicatilis,* are well known as useful food for fish larvae. This organism is initially fed to most marine fish larvae from the time of mouth-opening to about 4 weeks after hatching. Rotifer density given in tanks varies widely from 3-10 animals/ml due to the swimming and feeding activities of larvae. *Artemia* nauplii, subsequently, are given with overlapping of feeding period of the previous foods. *Artemia* is provided in 2-6 weeks after hatching. Adult *Artemia* enriched by fatty acid is often used as a supplemental food for metamorphosed flatfish and plaice. Cultured copepod, *Trigriopus japonicus* and wild zooplankton are also used as substitutes for *Artemia* nauplius to save on production cost because *Artemia* cyst is expensive. Formerly, oyster trochophores *(Crassostrea gigas)* were fed to larvae of fish such as grouper and whiting. Recently, however, oyster larvae are no longer used because of the difficulty in mass producing it. Weaning to dry pellets is done when fish reaches the juvenile stage or is completely metamorphosed. The formulated pellet is also provided with minced fish meat (sardine, anchovy, and sand lance) and *Euphausia* and fed 2-4 times daily, depending on fish size and species.

General composition of the pellet is 50-60% crude protein, 5-20% crude fat, 10-2% crude ash, 3-4% calcium, 2-3% phosphorus, and doses of vitamins and fatty acids. Recently, weaning experiments with pellets have been carried out vigorously at the early larval stages of the red sea bream and Japanese flounder as well as Ayu fish.

In the nursery, the fish is usually fed with minced fish meat and *Euphausia* more frequently than before, 4-6 times, at a ration of 10-20% body weight per day. Uniform fish size usually ensues from frequent feeding at early phase of transfer from indoor to outdoor facilities.

Disease control. Vertebral malformation which is frequently found in hatchery-reared red sea bream has been overcome through technical improvement in feeding and aeration methods. The feeding of rotifers cultured with baker's yeast resulted in high mortality and malformation. The quality of the yeast has been improved by the addition of highly unsaturated fatty acids, especially of the $\omega 3$ type. Light aeration of less than 100 $ml/min/m^3$ is commonly used to ease the initial inflation of the air bladder which prevents the abnormal development of the vertebrae.

Fish larvae and fry in hatcheries often contract diseases caused by *Vibrio* spp., *Flexibacter maritimus, Edwardsiella tarda,* and others. Diagnosis and treatment are generally performed by qualified pathologists allocated to each prefecture. They also recommend drugs for the optimal cure based on the symptoms in diseased fishes and suggest the countermeasure to prevent the disease. Generally when the fishes are transferred or handled, they are immersed in 50 ppm Nitrofuran to prevent infection.

Harvesting. Initial rearing conducted indoors usually terminates in 30-100 days following hatching, about 30-40 days for most fishes spawned in spring to summer and 100 days for winter species, Ayu fish and flat fishes. About 30-60% of initial stock is obtained consistently at the termination of the indoor rearing for sea breams, Japanese flounder, Ayu fish, puffer, and plaice. The yield of more than 4000 one cm $fish/m^3$ is satisfactory for culturists. Fish fry raised indoors are transferred to the floating net cages as well as to outdoor tanks. Size sorting, selection of malformed individuals, and determination of survivors are conducted at transfer. Hatchery-bred fry are siphoned directly into the net-cage or scooped. Overall survival of more than 30% from egg stage to fry of 3 m is well achieved. Fish fry after nursing are utilized for aquaculture projects and for intensive aquaculture by fish farmers.

Production constraints. Main obstacles in seed production might be attributed to abnormality in morphological characters and in pigmentation. Vertebral deformity has been solved by improvement of feeding and rearing techniques. Albinism, however, occurred at high percentage, usually in plaice and Japanese flounder. Supplemental feeding of wild plankton, mainly copepods, is well known to decrease incidence of albino fish; however, the cause of albinism and the effect of diet is still under study. Various diseases occur during the course of rearing, and fish culturists use drugs for treatment. More studies are needed to find optimal rearing conditions to prevent the occurrence of diseases.

Fry raised in the hatchery are used both for cage culture and restocking program. In the latter case, survival capability and size should meet the necessary criteria before releasing fish to achieve success in the restocking activity. No biological information and criteria for releasing fish are known at present.

Automation of counting the fish fry and mechanization of rearing procedures are highly required to increase the harvest in the hatchery.

Production of Marketable Fish

Rearing facilities. Floating raft, consisting of net-cages, bamboo, anchors, and styrofoam buoy, is a typical facility in the culture of marine animals for commercial purpose. The size and materials of net-cages depend on fish species and farming grounds, for instance, depth, current velocity, and topography. Fish younger than one year are maintained in square cages ranging from 4-6 m. The surface of the cages are covered with fish net to prevent bird predation, and they are generally rafted four or more abreast, anchored to the bottom. Adult fish are stocked in larger cages from 6-8 m^2 with 4-6 m depth. Circular floating cages 12-14 m in diameter, constructed of steel frame and wire net are used in the southern part of Japan to cultivate yellowtail weighing 2-5 kg. These facilities are generally located in bays or inlets. In the gulf area, where more rough oceanographic conditions occur, a fish coral measuring about 8 m^2 is commonly employed for cage culture. The fish coral is equipped with a device that sinks it during typhoons. Adoption of this device widens the farming area for culture.

Rearing method. Tremendous strides in yield of yellowtail in Japan are due to the ease of obtaining wild seeds. Other species, however, are cultured from hatchery-reared seeds. Demersal species, flatfishes, and rockfish are cultured at a density 4-5 kg/ m^3 lower than the pelagic ones. A stocking density of 5-9 kg/m^3 is standard for culturing sparid fish and yellowtail in net cages. The wire net system is capable of stocking yellowtail at 10-15 kg/m^3 because the surface of the wire net is smooth enough to prevent the settlement of fouling animals and is, therefore, effective for water flow. Cage capacity and mesh of fish net is changed with fish growth and when fouling organisms settle on the surface of the net. A few omnivorous fish are often cultured together to help the removal of fouling animals, barnacles, seaweeds, and ascidian.

Feeds and feeding. Different species and types of material are utilized for feeding. Sardine, anchovy, sand lance, mackerel, and *Euphausia* are popular food given fresh or frozen. The composition of anchovy and sardine is 3-5% crude fat, 16-20% crude protein, and 70-75% water, and that of sand lance is about 10% crude fat, 20% crude protein, and 65% water. These contents change with seasons and storage methods. Minced and chopped meats mixed with the diet increase nutrient contents of feeds. Feeding of adult fish is less frequent than that of the young. They are fed twice daily, morning and afternoon when active feeding behaviors are observed. Yellowtail and red sea bream are fed every 3-4 days in winter. Table 11 shows a summary of the feeding and growth rates of marine finfish.

Table 11. Daily feed and conversion ratio of major species cultured with raw material

	Daily feeding rate*			Conversion ratio**		
Species	0yr	1yr	2yr	0yr	1yr	2yr
Yellowtail	8-20	4-6	3-5	5-7	6-9	10-14
Red seabream	8-12	6-8	4-6	6	9-12	16-20
Japanese flounder	8-20	4-10		2-5	4-6	

Each value varies considerably with rearing conditions of food items, temperature, feeding strategy, etc.

* = percentage to body weight
** = amount of food fed divided by weight gain.

The composition of formulated pellet resembles that of fingerlings: 45-47% crude protein, 15-18% crude ash, 3-5% crude fat, 2-4% calcium, and 1-2% phosphorus. The pellet is given at 1-3% body weight, one to four times a day, depending mainly on water temperature. Recently, moist pellet, which consists of raw fish, mash pellet, and binder, has been gradually used to culture yellowtail and sea breams. The moist pellet is considered beneficial in preventing pollution, nutrient enrichment, feeding strategy, and production cost.

Disease control. Most cultured finfishes contract diseases from various bacteria, virus, fungi, parasite, food, and stress. Disease increases markedly with increment of farming facilities and aquaculture production, suggesting over-stocking and environmental deterioration. *Pasteurella pisciciba* and *Streptococcus* sp. are the most common and critical pathogens damaging yellow-tail crops. *Benedenia seriola* and *Axine heterocerca* are often observed in cultured yellowtail. Immersing parasitized fish in increasing or reducing salinity is effective and less costly than using drugs. Various disease reports include 162 pathogens for cultured finfish, 98 for freshwater, and 64 for marine fish. Diagnosis of diseased fish and identification of disease agents are usually conducted by qualified technician and optimal use of prophylactic drugs (Antibiotics, Sulfa drugs, Nitrofuran derivative) and supplemental nutrient is suggested to the fish farmer. Appropriate stocking density, feeding, transfer, and other culture techniques are also suggested to prevent infestation and spread of epizootic.

Harvesting. Most marine species are cultured from 1-2 years. Japanese flounder weighing 600-800 g is harvested in less than one year. Commercial fish farmers harvest periodically or seasonally. Caged fishes are harvested for hauling by narrowing the fish net or scooping. Fish hauling differs somewhat from harvesting for the market. Quantities of fish are generally hauled on ice to the wholesale market. Cultured products particularly sea bream, parrot fish, and Japanese flounder have been transported recently to restaurants and other markets by placing the fishes in live-hauling tanks in trucks. Fish hauled alive command a price of 30-60% higher than fish caught the conventional ways.

Production constraints. The development of intensive aquaculture has contributed partly to the effective conversion of trash fish to high protein foods. Feeding of trash fish, in turn, is one of the causes of pollution and environmental deterioration around the farming ground. It also causes mortality and retards the growth of caged fish.

Red tide is the most serious danger to fish aquaculture, especially to yellowtail because of the physiological weakness of this fish to the bloom of red tide organism, *Chattonella* spp., *Gymnodinium* sp., and others. Disease control is also a critical problem preventing stable production. Suitable management method, for instance, optimal stocking density, number of facilities, and feeding method in finfish culture must be pointed out before the use of drugs is suggested to the fish farmer. Recently, various studies on feed material and culture strategy have been carried out to reduce the fat content of cultured finfish which is disliked fairly by individual markets.

Table 12 lists the finfish species cultured in Japan.

SHRIMP AND PRAWN CULTURE

Broodstock Production

Rearing facilities. A total of 17 crustacean species are artificially reared for the restocking program and 9 of these are shrimps. Only the Kuruma prawn is cultivated commercially. An indoor tank made of concrete is commonly used to hold the parent prawn. The tank capacity varies between 60-200 m^3 with depth of 1.5-3 m, either square or rectangular. The tank is provided with an aeration system and heating facilities. The bottom is inclined slightly for complete drainage at harvest.

Rearing method. Only gravid females are introduced to the indoor tank. One female weighing 70-130 g per m^3 is a common stocking density in the breeding tank. The breeding tank is filled with filtered sea water at half level, and the sea water is heated to about 25°C immediately after the spawners are stocked in the tank. Ablation of eyestalk and spawner breeding in earthen pond have been experimented in the Japan Farming Fisheries Center. In both trials, viable nauplii are obtained in small numbers and are still being studied for mass production.

Feeds and feeding. No feed is given to the spawners in the tank. The mother shrimps are removed from the tank for a couple of days after spawning.

Capture, handling, and transport. All females are captured by fishing gears and their maturation level determined with naked eyes. Only gravid females are hauled to the shrimp hatchery by sawdust cartons of fish-hauling tanks. During transfer, 100 kg females are stocked in 1 m^3 capacity tank.

Table 12. Finfish species cultured by hatchery breeding and cage culture

	Clupeidae			Serranidae			Sebastes inermis	CR
Δ	Clupea pallasi	R		Epinephelus septemfasciatus	C	A	Sebastes schlegelii	CR
	Carangidae			Epinephelus akaara	CR		Seastes pachycephalus	R
	Tranchurus japonicus	CR		Epinephelus moara	R		Sebastiscus marmoratus	R
	Caranx delicatissimus	CR		Plectropomus leopardus	R		Synanceiidae	
	Caranx speciosus	R		Epinephelus microdon	R		Inimicus japonicus	R
	Seriola quinqueradiata	CR		Sillaginidae			Paralichthyidae	
Δ	Seriola aureovittata	CR		Sillago japonica	R	O	Paralichthys olivaceus	CR
	Seriola dumerili	R		Sparidae			pleuronectidae	
	Girellidae		O	Pagrus major	CR		Limanda yokohamae	R
	Girella punctata	C		Evynnis japonica	CR		Pleuronichthys cornutus	R
	Lethrinidae		O	Acanthopagrus schlegeli	CR		Eopsetta grigorjewi	R
	Lethrinus nebulosus	R		Acanthopagrus latus	R		Hippoglossidae dubius	R
	Lutjanidae			Sparus sarba	R		Kareius bicoloratus	R
	Lutjanus sp.	R		Acanthopagrus sivicolus	R		Limanda herzensteini	R
	Oplegnathidae			Trichodontidae			Liopsetta obscura	R
	Oplegnathus fasciatus	CR		Arctoscopus japonicus	R		Microstomus achne	R
	Oplegnathus punctatus	R		Scombridae			Tanakius kitaharai	R
	Percichthyidae			Scomberomorus niphoninus	R		Monacanthidae	
	Lateolabrax japonicus	CR		Thunnus thynnus			Stephanolepis cirrhifer	C
	Pomadasyidae			Siganidae			Navodon modestus	C
	Parapristipoma trilineatum	CR		Siganus fuscescens	R		Aluterus monoceros	R
	Hapalogenys nitens	R		Siganus guttatus	R		Tetraodontidae	
	Plectorhynchus cinctus	R		Platycephalidae		Δ	Takifugu rubripes	CR
	Sciaenidae			Platycephalus indicus	R			
	Nibea mitsukurii	R		Scorpaenidae				

R indicates species reared in hatchery and C species cultured commercially in net cage.
Open circles indicate species reared at 10-million level and triangles at a million level at seedling size (15-80 mm).

Disease control. No specific treatment can prevent disease among broodstock. It is important, however, that contamination be avoided by washing spawners well with filtered sea water before introducing them into the tank and by immediately removing dead spawners after spawning. The breeding tanks are used not only for spawning, but also for the culture of diatom and nauplii in succession.

Production constraints. The supply of spawners is entirely dependent on the wild stock in southern Japan. The scarcity of gravid females greatly influences the market price of mother shrimp and the success of broodstock production. The number of viable eggs spawned by the mother shrimp is highly variable. Only 10-50% of the initial stock will spawn resulting in unstable yield of shrimp fry.

Seed Production and Nursery Operation

Rearing facilities. The same tank used for spawning female is used to rear the larvae until P_{20} (about 12-16 mm long) or more developed stage. A small earthen pond is usually used as nursery.

Rearing method. Nauplius density varies between 10 000 and 80 000/m^3 in the tank, depending on the spawning capacity of the female.

Nauplii are cultured in standing water with heavy aeration and slow agitation until the postlarval stage. Exchange of rearing water or running water are introduced after the postlarval stage when ground meat of short neck clam or *Euphausia* and pellet are fed. The rearing sea water is drained through a strainer. The mesh of the strainer is changed relative to larval growth.

Feeds and feeding. Diatoms, *Chaetoceros* spp. and *Skeletonema* spp., are cultured as initial food organisms. The rearing water are enriched by several fertilizers: 15-30 g KNO_3, 2-4 g Na_2HPO_4, 1-1.5 g NaSio , and 7-15 g EDTA per 100 m^3 Under these conditions, diatoms introduced from the sea are inoculated in the tank. The diatoms are cultured at a concentration of 3-10 × 10^4 cells/ml. The diatom culture is a prerequisite for rearing shrimps from nauplius to early postlarval stage. *Artemia* nauplius and meat of marine organisms are fed after the postlarval stage. The percentage of these stuff given to the fry varies from 100-180% of the total biomass in the tank.

In many hatcheries cultured rotifers and formulated pellet are used as substitute for *Artemia* to save on feeding cost.

Disease control. Two diseases are reported to occur in mysis to postlarvae, 6-9 mm in size. Both diseases are caused by *Baculovirus* and *Vibrio* infection, characterized by white intestine and black body surface. Unfortunately, appropriate treatment and prevention are not known.

Harvesting. Survival from nauplius to juvenile shrimp varies between 15% and 40%, yielding 4000-12 000 shrimps/m^3. Duration of indoor rearing usually exceeds 100 days during early spring to late autumn. In harvesting, tank water is removed through a strainer by siphoning or by underwater pump. Juvenile shrimps are held with drained sea water when the water level is reduced to 50-70 cm depth.

Production constraints. Technical development to increase the spawning rate of mother shrimp is requisite for reliable production. Other food items such as pellet, rotifer, and microbial flocks are highly desired as substitute for *Artemia* nauplius.

Production of Marketable Prawn

Rearing facilities. An earthen pond is commonly used for commercial farming. Pond area varies from 500 m^2-10 ha with a depth of about 1-2 m. The pond is usually banked with concrete, and the upper layer of pond bottom overturned partly or completely every year and dried to remove fish predators. Air supply is provided from a blower through a PVC pipe or propeller-driven aerator. A water gate is installed with a screen in the earthen pond to supply sea water from the outside.

Rearing method. Shrimp fry are released into earthen ponds. The stocking density is dependent on shrimp size: 50-90 shrimps/m^2 for 20 mg and 15-30 ind/m^2 for 1-2 g shrimp. Shrimps are fed with various marine animals and pellets. Sea water in the earthen pond is exchanged partly by a pumping system or tidal movement through the water gate.

Feeds and feeding. Food used are meat of short neck clam, mussel, *Mysis, Euphausia,* and formulated pellet. Shellfishes are given crushed; *Mysis* and *Euphausia,* chopped. Feeding rate varies largely with shrimp size, temperature, food quality, and other factors. The following feeding rates are widely used: 100-200% body weight for 20-100 mg, 40% for 1-3 g, 20% for 5-10 g, about 10% for 18-20 g shrimp, respectively.

Formulated pellet is fed from the zoea stage in combination with live food.

Disease control. A disease due to the fungi, *Fusarium* sp., is known to cause losses in shrimp aquaculture, and *Baculovirus* infection is also observed occasionally in shrimps cultured in tanks. No techniques to prevent and cure these diseases have been established yet.

Harvesting. The growing procedure lasts from 100-200 days, depending on fry size when released into the pond. Overall survival from releasing to harvest varies from 60-80% which yield roughly 350 g/m^2.

Various methods are employed to harvest shrimp from the grow-out pond. A pound net to trap and pump-net were used before and a pulse net utilizing electric shocks has been often used recently. Harvested shrimps are packed in cartons with cooled sawdust for transport. Culture shrimps are marketed between 8-100 g. Shrimp of higher price weighs between 25-30 g.

Production constraints. Shrimp culture might be using the most sophisticated techniques in marine aquaculture. Any obstacle along the various production processes influences directly the yield in tanks and ponds. The problems in induced spawning are still to be solved. Production cost must be reduced by modifying present feeding and breeding techniques. For comparison, yield per m^3 per annum is 5-10 kg for finfish, 10 kg for oysters, but only 400 g for shrimp.

MOLLUSC CULTURE

Broodstock Production

Rearing facilities. The total number of hatchery-reared shellfish is 19 species but only 12 species of the 19 are propagated artificially for aquaculture. Culture of edible mollusc is classified as to source of seeds as follows: wild seeds — short neck clam, oyster, half-crenata ark, pecten, and scallop; hatchery-bred seeds — blood ark shell, noble scallop, hard clam, top shell, and abalone. Blood ark shell and noble scallop are cultured artificially from egg stage to marketable size. Hatchery-raised abalones are usually released into the sea and harvested after grow-out.

Rearing facilities of broodstock are needed only for the latter species. A tank smaller than 3 m^3 is generally used for stocking shellfish. Some substrates (sand and/or mud) are occasionally provided in tanks.

Rearing method. Generally wild spats, except for clams, are collected in the sea by different kinds of collectors, namely, shells, plant leaves, and synthetic filaments. For the clam, burrowed seeds are collected at shallow coastal waters, then transplanted to the grow-out area.

Spawners caught in the wild are transferred to broodstock tank, and maintained at a density of 10-50 ind/ m^3 Various manipulations are conducted to induce natural spawning. UV irradiation and temperature are widely used to induce spawning in abalone and blood ark shell in hatcheries.

Feeds and feeding. Usually no feeding is carried out in breeding bivalve broodstock. However, if necessary, cultured phytoplankton (*Pavlova lutherii* and *Chlorella* sp.) are given. The gastropods are fed with *Laminaria, Undaria, Ulva,* and other seaweeds.

Capture, handling, and transport. Most spawners are caught by capture fisheries during the maturing season, then transferred to the hatcheries. Handling and transport are easier for shellfish than for finfish and crustaceans. Sex is determined only when spawners are dissected or to eliminate the gametes.

Disease control. No particular procedures are conducted to prevent diseases. Physically damaged individuals and moribund ones are immediately removed to avoid unexpected infestation.

Production constraints. With the development of fishing techniques, larger spawners have become scarce year by year. It has become increasingly difficult to procure sufficient number of spawners.

The techniques of inducing maturation are desirable for shellfish. In addition, predicting the settling of spats is a prerequisite for stable production of each species.

Seed Production and Nursery Operation

Rearing facilities. Larval culture of the blood ark shell is carried out in indoor tanks of 0.5-1 m^3 capacity. Small and circular tanks made of polycarbonate are preferred by culturists because these tanks arc effective in keeping a high density of diatoms and in distributing larvae evenly in the tank. Light aeration is provided with an air filter. Light intensity is controlled by covering the tank with sheets. Rectangular rearing tanks used in abalone culture vary between 1 and 6 m^3 with 1 m depth. Different kinds of facilities are employed for nursing. Lantern net is popular for the culture of scallop, pecten, and single oyster, and wire of vegetable cages, for the blood ark shell.

Rearing method. Naturally spawned eggs of the blood ark shell and abalone are collected by fine-meshed net, and washed well with filtered sea water. Fertilized eggs then are maintained at a density of 1-2 eggs/ml. Either no exchange, or 10-30% of rearing water is changed during breeding. The rearing water is aerated at 100-200 ml/min.

Larvae are fed with cultured phytoplankton at an optimal concentration according to size or age of larvae. Spat collectors are introduced to the rearing tank when larvae of the blood ark shell have attained about 240 µm. The plastic plate on which the diatoms grow is placed 5-7 days after hatching in the case of the abalone. Nursery breeding of the blood ark shell starts when the larvae are about 1-2 mm, 60-70 days after spawning. Small seeds of the blood ark shell are maintained in the cage, then hanged from the raft or buoy in the sea. More than 10 000 seeds of 1-2 mm are stocked per m^2 at beginning of nursing, and stocking density, cage size, and mesh size are changed as shell length increases. Hardening is always necessary to avoid high mortalities during summer and autumn in nursing oyster seeds.

Feeds and feeding. Diatoms used for rearing shellfish larvae are *Pavlova lutheri, Chaetoceros gracilis, Chaetoceros calcitrans, Skeletonema* sp. etc. These phytoplankton are cultured purely in high density using chemical nutrients. Cultured diatoms are given solely or mixed. Larvae of blood ark shell are fed in the early stages about 5000 cells/larva and the density is increased with larval growth. No feed is given to the blood ark shell during the nursing period when they reach more than 1.0 mm. For the abalone, seaweeds *(Ulva* and *Undaria)* are usually given in the nursery and grow-out in the sea. No food is given to bivalves after transfer to the sea.

Disease control. In the rearing tank of the blood ark shell, contamination by protozoans especially *Hypotrichida* occurs. The use of sodium hypochlorite solutions is effective in removing the harmful organisms . Rearing water is usually changed completely when harmful organisms are found in the rearing tank.

Harvesting. The survival rate of the cultured blood ark shell is about 10% from egg stage to 10 mm size, and 30-50% afterwards until 20-30 mm. On the other hand, about 1% survival is obtained from egg to 10 mm length for the abalone, then 50-80% until 20-30 mm.

Transport and counting of shellfish are easier than with other cultured animals because they can be moved separately and they settle individually on the substratum.

Production constraints. Survival among shellfish at early stage of development is very low especially in abalone. This may be due to the poor techniques used in induced spawning and poor quality of spawner and egg. To increase shellfish production in aquaculture, the common problems of obtaining sufficient quantity of viable eggs and the mass production of phytoplankton have to be overcome. In addition, techniques to rear cultured seeds to spawner must be developed to ensure high production.

Production of Marketable Shellfish

Rearing facilities. The oyster raft is the most sophisticated facility. It measures 10 × 20 m with 600-800 hanging strings, each 10 m long. The blood ark shells are maintained in large iron-framed cages (1 × 1.5 × 0.3 m) at the sea bottom. A cone net, 50 cm dia and 2 m height, is widely used at a density of 15-18 shells/level for culturing 10 cm scallop in northern Japan.

Rearing method. Blood ark shells, about 3 cm, weighing 5.0 g, are caged at 1500-2000 ind/ m^3 Stocking density is reduced with shell growth. Bottom culture is also carried out in the natural farming ground when the blood ark shell attains a length of 40 to 60 mm. Before releasing, starfish should be removed frequently by bait trap. The wild spats collected artificially are cultured by hanging methods (raft and long-line) for the oyster. The transplantation of the short neck clam is the common method performed in the coastal waters by fishermen. About 1 cm seeds of short neck clam are sown on tideland and cultured to marketable size.

Feeds and feeding. Short-term culture of the abalone for commercial purposes lasts a couple of months or more with *Undaria* and *Laminarta* as food.

Disease control. Diseases are relatively rare in shellfish aquaculture in the sea. About 15 years ago, mass mortalities of cultured oyster by adhesion of the annelid, *Hydroides elegans,* occurred. *Polydora* sp. and *Asterias* spp. are also harmful to various shellfishes cultured by the hanging and sowing methods. The harmful animals are usually removed by hand, drying, and bathing alternately in fresh water and high concentrated salty water. Generally, eradication of fouling animals, such as barnacle and mussel, is conducted by predicting the spawning and settling season around the farming ground.

Harvesting. The blood ark shells are harvestable in about one year following nursery operation. They grow to about 60 g with 50-60% survival in one year, and more than 150 g weight with 10-20% survival in two years. Released seeds for sowing culture are harvested by small dredge net. Yield of oyster meat per raft of 200 m^2 amounts to 2.0-2.5 mt. It takes about 1.5-2 years from spat hanging to harvest. Shellfishes are marketed shucked or with shells.

Production constraints. The eradication of predators and fouling animals is of primary importance in the shellfish aquaculture industry. Bait trap is effective and other practical measures are used to remove the starfish during the bottom culture of the blood ark shell in the natural ground. Unexplained phenomena of oxygen deficiency which is lethal for caged and liberated shellfish occur incidentally not only in the fisheries ground but also in the farming ground. Recently, high density cultivation has resulted in decreasing yield per unit of facilities or area and has retarded the growth of oyster culture in Hiroshima and of scallop culture in Aomori. How to keep the ecological balance between the total crop of cultured animals and the natural productivity is a common problem that should be solved to stabilize production in mollusc aquaculture.

Table 13 lists the shrimp and shellfishes cultured in Japan.

SEAWEED CULTURE

Rearing facilities. Nori (*Porphyra*), Wakame (*Undaria*) and Konbu *(Laminaria)* are typical, edible seaweeds in Japan. Indoor facilities are used in the culture of these species to obtain buds for further cultivation. The facilities for Nori and Wakame culture consist of a concrete tank 2-3 m with 70-80 cm depth, square and rectangular, a roof curtain for regulating illumination, a temperature control system and ventilation. A smaller container of about 100 1 is used for Konbu. Growing operation is carried out in the facilities at sea; floating-net system and stick method for Nori, and raft and long-line method for Wakame. Longer rope, more than 100 m, is used for Konbu culture.

Rearing method. Seaweed cultures are initiated by collecting spores released from the mature plants. The seedling is transplanted by using synthetic material when the temperature goes below 24°C for Nori, 20°C for Wakame, and 10-15°C for Konbu. The string and net with young buds are transferred to set them on the facilities at sea in autumn. Farming grounds suitable for Nori culture are the littoral zone and coastal waters of 10-30 m depth with slow current. Wakame is cultured in farming grounds with waves and fast current. The Nori, Wakame, and Konbu grow well during winter.

Diseases and parasites. The prevention and treatment of two diseases caused by *Olpidiopsis* sp. and *Pytium porphyrae* are well known. Nori buds are generally stored at freezing temperature to make them resistant to diseases. In Wakame culture, damages caused by bacterial diseases and predation of young buds by isopods and gastropods are often observed.

Harvesting. The first Nori harvest begins when the buds are 15-20 cm in length and the second crop is harvested 2-3 weeks later. Thus, harvest is repeated during winter between November to March or April. Collected Nori plants are processed usually into dry product. As for Wakame, full-grown weeds more than 1 m are harvested when the temperature goes below 15°C. The yield of Wakame varies between 5 kg and 10 kg/m rope. The harvested Wakame is processed by drying, raw pack, and salting. The cultured Konbu is harvested from July to August and dried as a product.

Production constraints. Seaweed culture is largely influenced by weather conditions and disease which in turn cause large fluctuations of annual yield. Technical development and genetic research are expected to solve these problems. Expansion and conservation of suitable farming grounds are needed to increase production. Deterioration of farming ground is usually found in areas of high density culture and where culture activity is maintained for a long time.

Table 13. Major shrimp and shellfish cultured by hatchery techniques and their production status

Species		Annual production (million)	Seed size (mm)
Kuruma prawn	*Penaeus japonicus*	715	10-60
Abalone	*Nordotis discus discus*	30	10-40
	Nordotis discus hannai		
	Nordotis madaka Habe		
	Nordotis gigantea		
Blood ark shell	*Scapharca broughtonii*	15	1-20
Pecten	*Pecten albicans*	3	5-40
Scallop	*Patinopecten yessoensis*	3	5-60
Noble scallop	*Chlamys nobilis*	4.5	10-30
Top shell	*Turbo (batillus) cornutus*	0.6	1-30

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