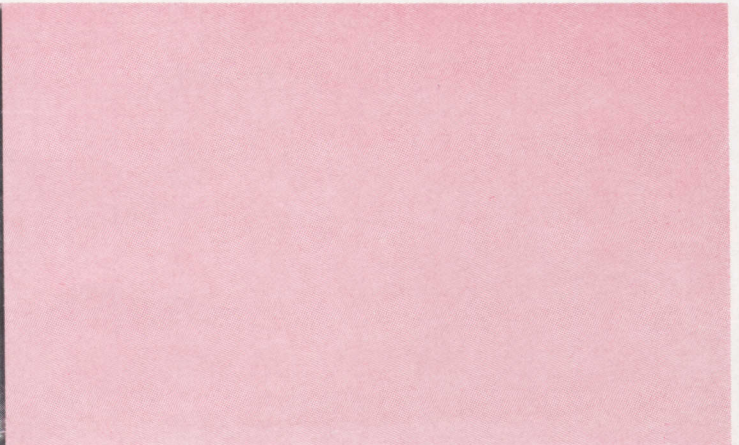


AQUACULTURAL SURVEY IN JAPAN

International Center for Aquaculture
Agricultural Experiment Station
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H. R. SCHMITTOU¹

INTRODUCTION

JAPAN has made important contributions to the field of aquaculture and has led the world in developing cultures of marine and brackishwater organisms. The country is limited in areas suitable for inland aquaculture, but its vast areas of protected shores, bays, and inland seas give it high potential for culturing marine and brackishwater animals and plants. Japan has taken good advantage of its potential for both inland and coastal aquaculture, especially for the latter. Examples are development of cultures for seaweeds, shrimp, oysters and other molluscs, eels, ayu, trout, and yellowtail. Last year Japanese research biologists were the first to artificially spawn and hatch yellowfin tuna. They have also collected fingerlings of yellowfin and bluefin tuna from the sea and raised them in net cages. In support of its aquacultural developments, Japan has many well-trained biologists and some of the best-equipped research stations and institutes in the world.

In May 1971, the author was able to tour various Japanese aquacultural facilities. The itinerary was developed by Dr. Clinton E. Atkinson, Fisheries Attache at the United States Embassy in Tokyo, and his assistant, Mr. Yoshio Nasaka, served as interpreter on the tour.

This report presents a summary of different types of aquaculture in Japan along with personal observations about these aquacultures. Also included is a summary for each of the various stations, laboratories, and private farms visited. The purpose was to assess the value of Japan's aquacultural methods in terms of possible direct or indirect application in other countries, and to evaluate the present and probable future status of aquacultures in Japan.

SELECTED AQUACULTURES OF JAPAN

Detailed descriptions and discussions on cultures of eel, ayu, yellowtail, oyster, and shrimp are presented in this section. Information on each culture was obtained through observations and interviews with research personnel or farmers and from reading published and unpublished literature.

Japanese Eel

The Japanese eel (*Anguilla japonica* Temminck and Schlegel) is one of the more important fishes being cultured in Japan. As with most of the fishes cultured in that country, those for stocking ponds must be taken from their natural environment since the eel has not been artificially propagated.

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Little is known about the spawning habits of the Japanese eel. It is definitely catadromous in habit. Probably its life cycle is similar to that of the Atlantic eel. It is believed the Japanese eel spawns somewhere south of Taiwan. The leptocephalus larvae then drift and swim with the Kuroshio Current to the shores of Japan and other countries where they metamorphose into elvers and ascend the streams. This occurs from January to April in Japan. During this period, commercial fishermen collect the young elvers to sell to eel farmers. Collecting is primarily at night during low tide with the aid of nets. Elvers are collected from both the streams and along the shores in and near the estuaries. The elvers do not migrate into the streams until stream temperatures are above 9° to 10° C.

Systems of culture vary. The most significant variations in cultural practices are the amount of water flowing through the culture area, stocking density, type of feed, frequency of feeding, number of harvests, and whether cultured alone or in combination with common carp.

Most farmers practice standing water culture, but some flow water through the culture area. Stocking density is, of course, influenced by which of the two systems is used. Density increases with increased flow. Also, stocking density is greater where the farmer periodically harvests the faster growing fish or removes part of the population after rate of growth declines and restocks them at lower density in other ponds.

Eel culture is carried out in two separate operations. The nursery operation consists of raising the elvers to suitable size for stocking into production ponds where they are grown to the desired marketable size.

The elvers, 50 to 70 millimeters long and up to 150 to 200 milligrams in weight, are stocked into nursery ponds at the rate of approximately 300,000/hectare during January to April. Generally, nursery ponds are about 150 square meters and seldom range over 200 square meters. Pond depth is usually about 1 meter. Feeding begins in April when water temperatures are about 10° to 13° C. By October the young eels range from 15 to 50 grams in weight. They are then ready for stocking into the production ponds for feeding out to market size.

Production ponds are stocked at varying rates of young eels per hectare. Most production ponds are less than 2 hectares in area with mean depth between 1.0 and 1.5 meters. Reliable figures on rates of survival and yield were not obtained, but maximum productions up to 2.5 kilograms/square meter/year (25,000 kilograms/hectare) were quoted for running water and up to 10,000 kilograms/hectare/year for standing water, with only occasional water exchange.

Feeds used by eel farmers were trash fish and artificial feeds. These were fed in combination or independently. When fish were the feed source, whole or ground fish were



FIG. 1. Eels yield up to 10,000 kg./ha. in pond culture and up to 25,000 kg./ha. in flowing water.

used depending on the farmer's preference. Trash fish were often mixed with approximately 10 per cent meal or flour before grinding. Whole fish were generally boiled to make them more palatable to the eels.

The boiled whole fish were strung together on a wire by passing the wire through the head of each fish. The strung fish were then suspended in the pond until all the flesh had been stripped away and consumed. Ground fish was rolled into a ball and placed into a wire-mesh tray suspended at the pond surface. The bottom of the tray was approximately 1/2 inch below the water surface. The most common fishes fed to eels were horse mackerel, mackerel, skipper, and anchovy. These trash fish were purchased for 30 yen/kilogram (\$0.04/pound when based on the exchange rate of 360 yen = \$1.00).

Artificial feeds varied in composition, but were consistently high in fish meal. The following are examples of some of the formulas of commercial feeds used by eel farmers:

Feed Ingredient	Formula	Formula	Formula
	1	2	3
	Pct.	Pct.	Pct.
Fish meal	60	65	72
Wheat or potato flour (alpha starch)	20	25	26
Soybean flour	10	---	---
Vitamin-mineral mix	10	10	2
Total	100	100	100

Formula 3 cost = 100 yen/kg (\$0.14/lb.).

Fish meal (cod) cost = 70 yen/kg (\$0.09/lb.).

The above feed mixes were each combined with enough water to form a dough. The dough was formed into a ball and fed by placing it into a wire-mesh tray as described above.

Conversions of artificial feeds were as low as 1.5 (1.5 kilograms of feed to produce 1.0 kilogram eel). On the all-fish diet, conversions ranged from 6 to 12, which is essentially a conversion of 2 to 4 with correction for moisture content.

The eels were fed at only one location in the pond. The feeding station was shaded by a canopy and was generally enclosed on one or more sides to form a shelter 0.5 to 1.5 meters high with an area of about 1 square meter. The sides extended only a short distance into the water, allowing the eels free passage into and out of the sheltered area.

On first observation, it appeared that the feeding basket was not large enough to accommodate the number of fish;

however, the feeding habit of eels is such that a large number can feed in a small area. When feeding, it appears that every eel in the pond congregates in a mass of tangled bodies beneath the feeding tray. Individual eels work their way to and even into the tray, take bites of feed and, within seconds, work their way back into the mass and sometimes back into the open pond.

Most farmers feed at least twice daily, but this is determined by water temperature and size of the eels. Optimum culture temperature is from 20° to 28° C. At temperatures below 10° C, the fish are not fed.

Not enough information was obtained on yields and other production parameters to adequately evaluate the economic aspects of eel culture. The following table gives costs and selling prices for feed and various sizes of eels:

Item	Cost/price Yen/kg
Feed	
Trash fish	30
Artificial feed	100
Eels	
Elvers (0.15 to 0.20 g)	100,000
Young eels (15.0 to 50.0 g)	3,000-5,000*
Food size (150.00 to 200.0 g)	1,200-1,500

* The stocking rate for production ponds is approximately 300 g/m².

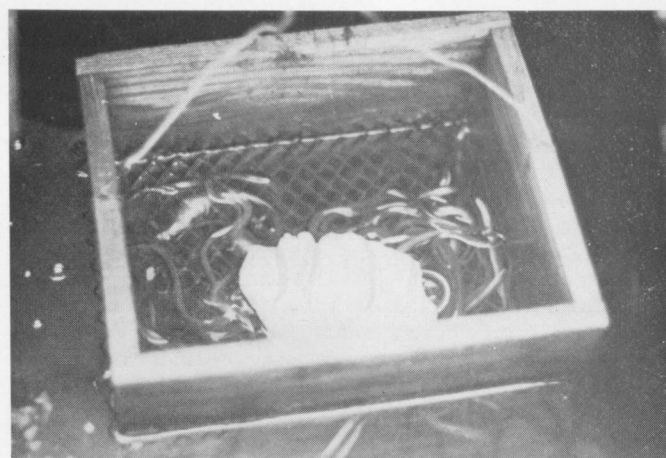


FIG. 2. Eels feeding on ball of freshly ground fish and flour in partially submerged feeding tray.

Japan is the world's largest producer, importer, and consumer of eels. All eels produced in Japan are consumed there and eels are imported to help meet the demand. Approximately 60 per cent of all eels on Japan's market (30,000 tons²/year) are produced in the Shizuoka Prefecture, where there are over 1,000 eel farms.

Japan buys elvers and market-size eels from Taiwan. Also, she imports elvers of the Japanese eel and European eel (*Anguilla anguilla*) from Korea and Europe, respectively. In 1970, Japanese eel farmers imported 10 tons of elvers from France, 5 tons from Taiwan, and 1 ton from Korea. The necessity for elver importation has developed within the past 5 years. Farmers need over 50 tons of elvers per year, but only 6 to 7 tons (less than 15 per cent of the demand) were collected from natural waters of Japan during the 1971 season. The demand for elvers has been steadily increasing

² All tons in this report are metric tons or 1,000 kg.

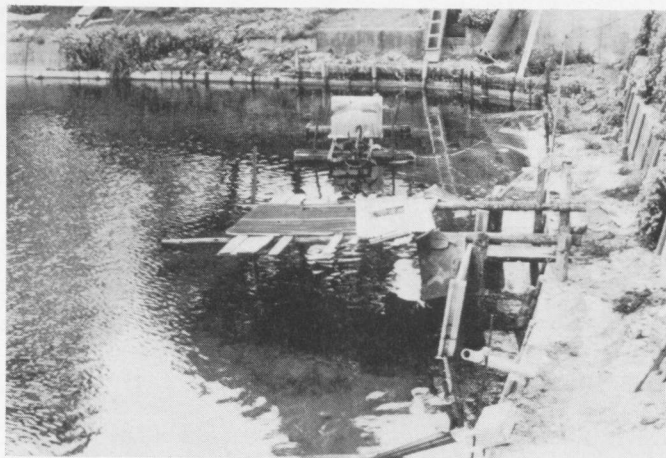


FIG. 3. Sheltered feeding station in eel culture pond.

while the catch has been decreasing over the past years.

Elvers are shipped from as far as Europe in plastic bags which contain about 1 kilogram of elvers and small amounts of water and oxygen. Ice is packed around the outside to keep their metabolic rate low. Expected mortality from Europe is about 10 per cent. Market-size eels are shipped locally for short distances in the same manner with up to 10 kilograms/bag.

There is a large number of significant problems associated with eel culture, some of which are certain to have a profound effect on the future of the industry. In the following paragraphs some of the more important problems are discussed.

Elver numbers are declining and they are already in short supply. Apparently no one knows the reasons for the decline. Researchers at Shizuoka Prefecture stated as possibilities: the effects of pollution; and the changing oceanic currents. Pollution in the rivers and estuaries is definitely a problem in Japan and is rapidly increasing. Obviously, pollution could decrease the elver supply, and it is also obvious that changing currents could be unfavorable to leptocephali drifting close to Japan's shores thus causing the supply to decrease. Perhaps other reasons for the decline may be increasing numbers of dams that prevent upstream migration of small eels and the tremendous harvest of all stages of eels over the years, causing fewer and fewer adults to return to the spawning grounds. These and other causes could be working independently or interacting to reduce the number of elvers migrating into collecting areas. At any rate, elver supply promises to limit and perhaps reduce this now important culture in Japan.

Eel culture is more difficult than that of carp, ayu, or trout because of disease; *Clostridium* is a particular problem. Also, a disease that is causing high mortality among the Japanese eels has apparently been introduced recently with eels imported from France.

Pollution was discussed earlier as a possible cause of the declining abundance of elvers. It also seriously affects use of water supplies for aquacultures, for the farmers must consider the various pollutants and their effects on fish and fish production.

Perhaps the most serious pollutant to the eel farmer is that developing within the culture pond from feed and biological wastes. The form in which feed is introduced does not lend itself to total consumption. As the fish feed, a cloud of

suspended particles develops in the feeding area that represents a substantial amount of organic pollution as well as a substantial loss in feed efficiency. This organic material requires a high percentage of dissolved oxygen in the water and reduces production potential.

Disease and poor growth are often effects of reduced oxygen levels. Kills due to low dissolved oxygen are not uncommon. The feed residue probably is partially, if not entirely, responsible for the large amounts of filamentous algae in practically all eel ponds observed. The algae reduces production potential, obstructs fish harvest, creates potential fish kills through oxygen depletion, and increases labor demand. Removal of filamentous algae by hand is a common and frequent chore in eel ponds.

Common carp (*Cyprinus carpio*) is sometimes stocked in combination with eels to help clean up the feed residue and resulting organic material. For some reason this practice is not popular. Common carp, because of its feeding habits, may not be the best species for this purpose. A mixed culture of several species of fishes, with eel being the primary one, might be more efficient and economical. However, pollution from the feed could be greatly reduced. A partial solution would be to feed only artificial feeds in cake or possibly pellet form, which would reduce the amount of feed loss.

Eel farmers must depend on nature to supply their stock, for the eel has not been spawned artificially. There are several reasons why artificial spawning of eels would be advantageous. Already mentioned are the problems of declining elver abundance and increasing pollution of rivers and estuaries which threaten the eel supply. However, ensuring an adequate eel supply is not the only need for artificial reproduction. Equally important is the need for genetic improvement of eels through selection. The only way that farmers can improve their eel stock for disease resistance, faster growth, and other desirable characteristics is through selective breeding. The reproductive habits of the eel suggest that it might be difficult to reproduce by artificial means. Even if that is achieved, there remains the problem of raising the leptocephalus larvae into elvers. This is likely to require much time and promises to be extremely difficult. A major difficulty in artificial spawning and larvae culture likely will be in creating a suitable environment.

Ayu

The ayu (*Plecoglossus altivelis* (Temminck and Schlegel)) makes up only about 1 per cent of the freshwater fish production in Japan. However, the fish does command a high, if not the highest, market price of any fish in Japan. The Japanese consider the fish a delicacy and serve it baked whole with head, skin, and viscera intact.

The ayu is an anadromous fish. The fingerlings spend the winter in the sea where they feed primarily on zooplankton. In March to May they ascend the rivers in schools feeding on diatoms and periphyton, including filamentous blue-green algae. The schools migrate into the stream headwaters from which they descend in August and September to the lower regions of the stream where they spawn. Spawning occurs from October to November, after which the adults die. The fry migrate to sea immediately after hatching and grow into fingerlings, thus completing the cycle.

A landlocked form called doayu, inhabiting Lake Biwa and other inland waters, is similar to the migrating ayu except that all life stages remain in freshwater.

Fingerlings were collected for culture by commercial fishermen as the fish ascended the streams. Both the migrating and the landlocked forms were used in culture, but were usually raised separately. Collectors that sell to culture farmers usually received 9 yen (\$0.02) per fingerling. Mean size of fingerlings for stocking was 0.2 gram and 7 centimeters.

Ayu were raised in ponds and more popularly in circular raceways. The following is information concerning a family-managed ayu culturing farm and processing facility near Hamamatsu, Shizuoka Prefecture.

The facility consisted of both ponds and pools with flowing water. The majority of production was in octagon-shaped pools with the double standpipe system for waste removal. They were constructed of concrete and contained 180 cubic meters of water. A continuous supply of water entering on opposite sides of each pool created a very obvious current estimated to be about 10 centimeters/second in the center. The bottom of the pool was sloped toward the center. Solid wastes driven by gravity and current were removed with the water overflow through the standpipe. Each pool was equipped with aeration.

The farmer had 8 such pools, all within a single building enclosed with corrugated fiberglass. The building and water-heating equipment permitted temperature control and, therefore, maintained year-round growing conditions in which four crops were produced annually. The total investment was 20 million yen (\$56,000) which included the building, raceways, and equipment.

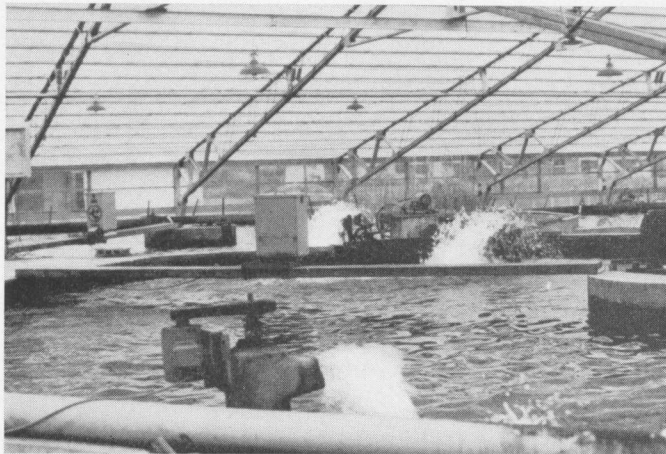


FIG. 4. Octagonal concrete raceways for ayu culture within fiberglass building. Note water inlets on sides and automatic feeder in center.

Stocking density per raceway was from 12,500 to 15,000 fingerlings. A crumble-type feed was fed by hand twice daily or more frequently by an automatic feeder. Feeding rate was not obtained. Feed conversion in growing the fish from 0.2 to 100 gram-size averaged about 2.0. The ayu is a very active fish and probably is not an efficient converter of feed. However, the formulation of the feed was not known, so there was no way to determine whether the relatively poor conversion reflected low efficiency or poor feed quality.

The culture period was approximately 90 days. In that period, the fish grew from 0.2 to between 60 and 100 grams with about 90 per cent survival. Culture temperature was maintained at approximately 18° C. Yields per pool ranged from 1 to 1.5 tons/crop, with four crops per year.

The owner processed his production by simply boxing and

icing whole fish. The iced fish were then shipped by train to markets in Osaka and Tokyo. The owner stated that he always received a premium price for his fish, which at that time was 3,000 yen/kilogram (\$4.00/lb). This was a high price, but production and marketing costs were very high also.

Yellowtail

The yellowtail (*Seriola quinquesadiata* (Temminck and Schlegel)) is by far the most important species of marine fish being cultured in Japan. The production of farm-raised marine fishes in Japan in 1967 amounted to 27,103 tons gross weight worth 8.7 billion yen (\$24.1 million). The production consisted of 98.6 per cent (26,712 tons) yellowtail; 0.25 per cent (53 tons) puffer (*Fugu rubripes rubripes*); and 1.2 per cent (338 tons) of other marine fishes including amber jack (*Seriola purpurascens*), striped jack (*Longirostrum delicatissimus*), red sea bream (*Pagrus major*), Japanese parrotfish (*Oplegnathus punctatus*), and others. The yellowtail produced in 1967 was valued at \$23.5 million.

Although culture of yellowtail dates back to at least 1928 on Shikoku Island, significant growth of the industry dates back to about 1960. In 1958 only 300 tons were produced nationally, in 1962 there were 1,521 tons, and in 1968 over 30,000 tons. The bulk of production, approximately 75 per cent of the total, is in the Seto Inland Sea region of southern Japan and along the southwest coast.

Much credit for the rapid growth of yellowtail culture can be attributed to the successful development of the cage culture system beginning in 1954. This method accounts for the larger part of the fish presently being cultured. The remainder are produced in ponds.

The yellowtail is a migratory fish that moves into the Okinawa area in March and northward to Kyushu Island, Japan, in April or early May. Spawning occurs offshore usually by early May.

Researchers have recently developed techniques for artificially spawning brood yellowtail taken from natural waters. Techniques for hatching and raising the progeny have also been developed. However, these methods at present are employed commercially on a very limited basis. The bulk of the fry is taken from natural waters. The fry are netted from the sea when approximately 25 millimeters and 0.3 gram in size. The fry are brought to the coast by the Kuroshio Current and are usually accompanied by floating seaweeds. Fry are netted by government-licensed collectors. Catch per collector is regulated to ensure against overfishing the natural stock. In 1967 total catch was limited to 17 billion fry.

Fry collectors sell to farmers who grade the fry into nursery cages approximately 2 x 1 x 1 meter. The cages are enclosed with fine mesh net. Grading into relative sizes of small, medium, and large is done to reduce cannibalism. A period of 4 to 6 weeks is required to raise the fry to fingerlings of approximately 8 to 10 centimeters and 25 to 50 grams size.

All cultures are in cages suspended in bays where salinity is 16 p.p.t. or higher. The fingerlings are restocked into net-enclosed cages usually about 6 x 6 x 6 meters. Stocking densities range from 40 to 70 fingerlings per cubic meter. Growth rate is rapid and fingerlings stocked in mid-June range from 200 to 700 grams by August; 600 to 1,600 grams by October; and 700 to 2,000 grams by the end of December. Harvest begins in September or October when a sufficient number of fish have reached the marketable size of

approximately 1.0 kilogram. It ends in December when growth becomes negligible. The smallest fish may be held over for the next growing season. This is a standard practice in south Japan where seasons are longest. At the end of the second year the fish are marketed at 4 to 5 kilograms each.

Production of yellowtail in cages in open water bays averaged about 40 kilograms/cubic meter (ranges from 10 to 80 kilograms) of culture area, or about 20 per cent of production attained with channel catfish in cages in closed ponds in the United States.

Rafts, generally constructed of bamboo and attached to floats forming a rectangular or circular frame, are essential for the floating net cages. The rafts may be divided into sections. The cages are usually composed of a single layer of mesh, but a second layer is sometimes included to ensure against fish loss from net damage. The rafts usually float, but the net cages, if properly covered, can be lowered to deeper water levels if desired. Surface areas of individual cages vary from 4 to 400 square meters and they range in depth from 2 to 15 meters. A common size used is 6 x 6 x 6 meters.

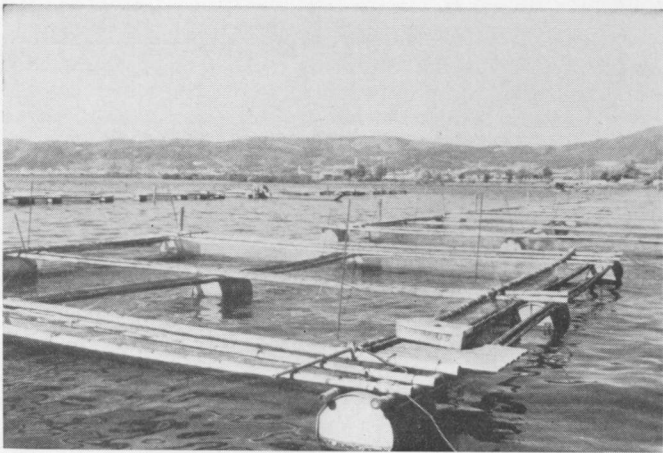


FIG. 5. Bamboo-framed raft for supporting net cages used in yellowtail culture. Production averaged 40 kg./m³ of cage.

Rafts of cages are restricted to specific areas in the bays. The restrictions are based on traffic and fishing rights. A farmer must obtain a special permit from the governmental division having jurisdiction over the area. Rent on the area normally is charged, except when the government is trying to promote fish culture and waives the rental fee. Also the farmer is obligated to pay fishermen having fishing rights in the area if so demanded.

As with most fishes cultured in Japan, the feed for yellowtail was fresh or fresh-frozen horse mackerel (*Trachurus japonicus*), anchovy (*Engraulis japonica*), sand eel (*Ammodytes personatus*), or other fishes.

An interesting fact concerning the feeding of fry was that high survival resulted by feeding crustaceans or minced white-meated fish. When only anchovy was fed, 100 per cent mortality occurred in 2 to 3 weeks. However, when fed with fish having white flesh, mortality was low, and it was even lower with crustaceans. Also interesting is that farmers attached lights above fry cages to attract zooplankton with positive phototropic behavior. This practice was not done exclusive of a feeding program but to supplement it.

The Hiroshima Prefecture Fisheries Experiment Station used freeze-dried shrimp to feed yellowtail fry. Fresh shrimp

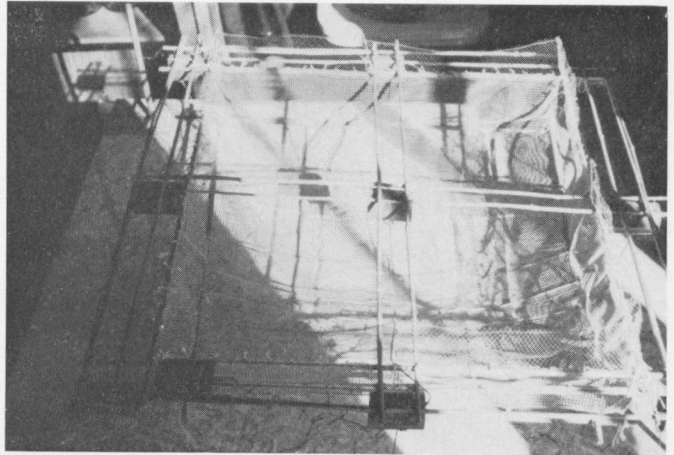


FIG. 6. Bamboo-framed raft with net cage.

were freeze-dried, ground, and then sieved to remove the shells. The resulting shrimp flour could be stored indefinitely at room temperature. When needed, it was mixed with an equal amount of water to form a paste which was spread on glass or plates as one would spread butter on bread. The glass with the attached shrimp paste was then suspended in the cage.

Fingerling and larger fish were fed whole or sliced, rather than minced, fish flesh. It had been demonstrated that feeding at approximately 75 to 80 per cent satiety, or roughly 10 per cent body weight (approximately 2.5 per cent dry weight per day) resulted in the most efficient growth. When this was divided into 2 meals per day for larger fish and 3 to 4 for fry, growth rate was satisfactory when fed at 5 per cent of body weight or less. When water temperatures were below 14° C, the fish were fed at 10 per cent one time every other day. Feed conversion was approximately 7 (2.1 dry) for fish up to 1.5 kilograms and 10 (3.0 dry) for fish up to 4 kilograms. The trash fishes used as feed cost the farmers about 30 yen/kilogram (\$0.04 pound) with a range of 25 to 60 yen/kilogram depending on supply. Thus, total feed costs were around 210 yen/kilogram (\$0.28/pound) for fish produced at a conversion of 7.0.

Artificial diets are not used at present although researchers were attempting to develop such feeds. It appeared from their work that the artificial diet would have to contain at least 70 per cent meal made from fish with white flesh. Whether total protein can be substituted in part by plant protein remains to be seen. Also, attempts thus far to get yellowtail to accept pelleted feed have not been successful.

Optimum water temperature for yellowtail growth ranges from 18° to 29° C. Fry grow best at a temperature range of 24° to 29° C, while larger fish grow better at a slightly lower range. Lethal temperatures are at 8° and 31° C for the low and high limits, respectively. Feeding ceases at around 14° C. Water temperatures on the farms ranged from highs of 25° to 31° C in summer to lows of 8° to 16° C in winter. The extremes of 8° and 31° C were generally for short duration and, therefore, were usually not lethal.

The minimum tolerance level for dissolved oxygen is 3 p.p.m. Salinity of the culture water should be maintained above 16 p.p.t.

Probably the most severe disease was that caused by the monogenetic trematode *Benedenia seriola*. *Axine heterocerca*, another monogenetic trematode, was also a problem.

Both of these species attain an adult size of 1 centimeter or larger. The recommended treatment for both was a fresh-water dip for 5 to 10 minutes, the duration depending on water temperature.

Few reliable figures on production economics were available. Market prices obtained by the farmers were generally from 400 to 450 yen/kilogram (\$0.50 to 0.56/pound), but ranged from 330 to 520 yen/kilogram (\$0.42 to 0.68/pound). Cost of production ranged from 270 to 350 yen/kilogram (\$0.35 to 0.45/pound). The margin of profit, therefore, fluctuated greatly. Farming operations were usually by family units. A family-size operation may produce in one season about 10 tons of yellowtail. At a market price of 425 yen/kilogram (\$0.54/pound) and production cost of 300 yen/kilogram (\$0.38/pound), the family would realize profits of 125 yen/kilogram or 1.25 million yen (\$3,472) for the total 10-ton production.

The following is an example of one farmer's breakdown of relative production expenses:

Item	Relative per cent
Feed.....	49.4
Labor.....	11.2
Fingerlings.....	10.1
Management.....	10.0
Facility.....	8.8
Maintenance.....	5.1
Miscellaneous.....	5.4

A large number of problems threaten the yellowtail industry in Japan. These problems, individually or collectively, are certain to limit future growth of the industry and could result in decreased production.

Degradation of water quality from the various pollutant sources is progressively becoming more serious to yellowtail culture in Japan. At present, the farmers are able to culture in areas where pollution from external sources is not a major problem; however, such areas are becoming more scarce while the demand for suitable areas is increasing.

The feeds used in yellowtail culture are trash fishes harvested especially for feeding cultured fishes. Other cultures besides that of yellowtail also utilize trash fishes. These cultures are also increasing in magnitude and, therefore, the demand for feed fish is increasing proportionately. Hence, it can be expected that there will be an insufficient supply of trash fishes to meet future aquacultural demands in Japan.

To overcome this problem, artificial feeds must be developed. However, present indications are that yellowtail may require a feed containing approximately 70 per cent white-colored fish meal. Costs must be considered and at present such fish meal sells for 70 yen/kilogram (\$0.09/pound).

A problem with disease, perhaps unnecessary, is that of disease-contaminated feed. The practice of feeding raw fish has contributed greatly to the disease incidence in cultured yellowtail. The fungus, *Ichthyosporidium*, is definitely a disease transmitted to yellowtail through infected fish used as feed. *Vibrio*, a serious bacterial disease, is probably also transmitted in this manner. Both of these diseases effect significant losses on the yellowtail industry each year. The practice of feeding untreated raw fish put many trout farmers out of business in Europe and in the United States before it was stopped.

The present practice of depending on the natural production of yellowtail for fry for stocking purposes has a number of disadvantages. However, fry can now be produced artificially from adults taken from natural waters. This is a posi-

tive accomplishment, although not a completely satisfactory development since parental stock have to be obtained from natural populations.

Japanese Oyster

Japan is the world's leading oyster producing country. Their total production in 1970 was 45,000 tons of shucked meat. The area around Hiroshima in the Seto Inland Sea produced almost 70 per cent of that total and should be classified as the oyster producing center of the world. Oyster culture originated here in the 17th century when fishermen began setting rocks and bamboo in shallow water for oyster attachment. Japan is not alone in the oyster farming industry, for culturists in many other countries are culturing oysters. Over the world there are many species of oysters being cultured with a variety of techniques or systems. Almost all oysters of commercial importance belong to two artificial groups: the flat oysters, represented by two species of the genus *Ostrea*; and the cup-shaped oysters, represented by four species belonging to the genus *Crassostrea*. The *Ostrea* possess two flat shells while *Crassostrea* possess a dorsal flat shell and a ventral (attaching) cupped shell.

All the oysters cultured in Japan for food are the Japanese or Pacific oyster (*Crassostrea gigas*). About 1 billion seed oysters of *C. gigas* are exported to the United States each year. This, plus the production of seed oysters for domestic use and almost 50,000 tons of food oysters per year, places the culture of *C. gigas* at the top in world importance.

The spawning for *C. gigas* is from May to August with definite peak spawns occurring during the period. Spawning normally begins in May when water temperatures have warmed to about 20° C. Optimum temperature for spawning and young development is between 23° and 28° C, while minimum and maximum limits for larval development are 15° and 30° C, respectively. Optimum salinity for oyster production is between 23 and 28 p.p.t. Highest setting of spat larvae is usually in water of about 15 to 18 p.p.t. salinity.

In spawning, the eggs (½ to 1 million per oyster) and spermatozoa are released directly into the water, where fertilization occurs. The zygotes develop into swimming planktonic larvae in about 20 hours. The larvae feed on small plankton and suspended organic matter. After 10 to 14 days in the swimming stage, the larvae settle and subsequently attach on a clean, hard substrate which is usually shells or rocks. After attachment, the young oysters develop new shells and take on the characteristics of adult oysters.

The attached larval oysters, called spat, are the stage obtained for culture to food size by oyster farmers. "Collectors" of various hard materials are placed in the sea to collect the setting spat for commercial culture. Collecting materials used almost exclusively in Japan were scallop (pecten) shells and plastic plates. The shells or plates (collectors), 10 to 15 centimeters in diameter, were pierced in the center for stringing on a galvanized wire (No. 16 gauge). The wire was usually 2 meters in length and contained about 100 collectors separated by 2-centimeter spacers. The wire with collectors, called a "ren," is draped across a horizontal bamboo frame which is attached to vertical bamboo posts that anchor the frame to the bottom. The ren is suspended with the center across the frame while both free ends drape vertically. For spat collecting, the rens were usually placed below low water level so they would not be exposed to the air.

The time and location for placing the collectors is important. Placing them too soon will result in attachment of

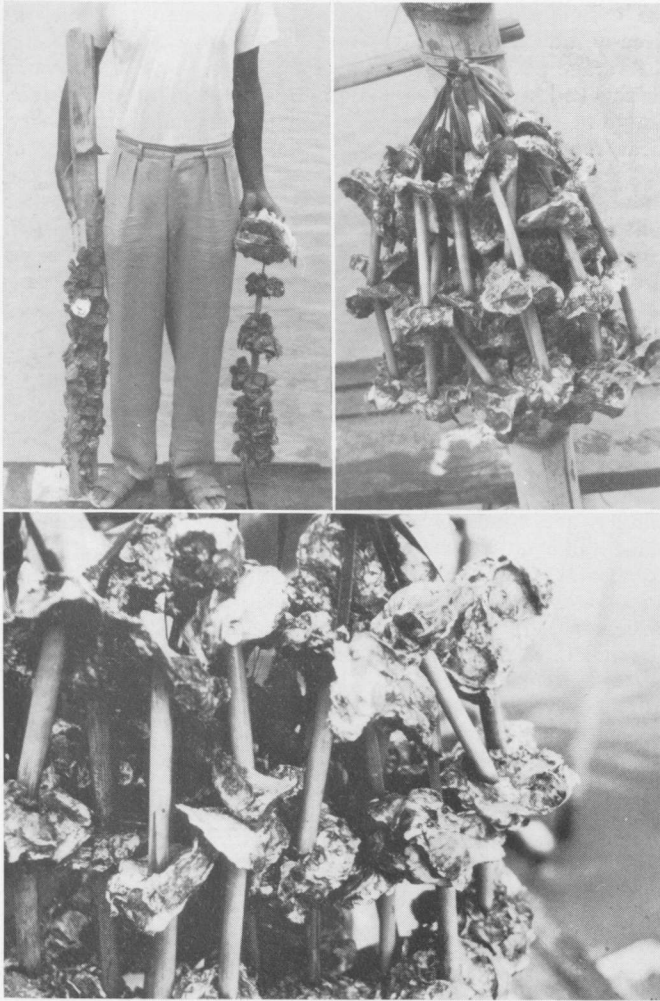


FIG. 7. Various views of oyster rens. Average production is 4.5 kg. per meter of ren with shells or 0.4 kg. of shucked oysters.

barnacles and other organisms and leave little or no space for spat attachment. Collecting was conducted throughout the spawning period from May through August, but most farmers preferred August collecting for there were fewer fouling organisms at that time and better survival was obtained.

In 4 to 5 weeks after setting, the young oysters have grown to about 10 millimeters and are ready to transfer to another stage of culture. The next stage may be for production of marketable food oysters, or it may be a "hardening" stage during which time the oyster is conditioned to adverse environmental conditions. If the young oysters are going directly to production, the rens are removed from the racks and the collectors are unstrung from the wires, cleaned of debris, fouling organisms, and silt, and then restrung on new wires. If the young oysters are going to be hardened, the rens are removed from the racks, but the collectors are cleaned without being unstrung. After cleaning, the rens are placed horizontally on racks where they will be exposed to the air for 4 to 5 hours during each tidal cycle. This is the hardening process.

Seed oysters destined for export to the United States are collected on oyster shells (70 to 80 per ren) rather than scallop shells, because oyster shells make better substrate for

bottom cultures practiced in the United States. The seed oysters must be hardened before shipping to the United States or they would not survive the trip. The hardening period usually lasts from September until June, when the seed are about 15 millimeters in size. They are then ready for exporting. Mortality during the period from spat to seed (time of setting until oysters are about 15 millimeters in size) without the hardening process averages about 80 per cent. After the hardening process, beginning when the young oysters are about 10 millimeters, subsequent mortality is decreased to about 40 per cent. The average shell produces about 15 seed oysters. In preparation for production culture, collectors containing seed oysters are restrung on wires of No. 13 gauge 10 to 15 meters long with plastic or bamboo spacers separating individual collectors. The seed oysters on rens consisting of 50 to 75 collectors are ready for production.

Oyster farmers in Japan employ three different production methods for growing seed oysters to food size; namely the raft, long-line, and rack methods. All three types are methods where the oyster is suspended in the water and is never in contact with the bay or sea bottom. Details of each method are in the following paragraphs.

Raft Method. This method is by far the most important. It is practiced almost exclusively in the Seto Inland Sea. The rafts consist of 20-meter-long spliced bamboo or wood poles about 10 centimeters in diameter placed parallel to each other with about 45 centimeters spacing. These poles are attached to 10-meter-long poles placed at right angles to the 20 meter poles forming a rectangular frame 20 x 10 meters. The frame is supported by styrofoam cylinders (approximately 0.8 x 1.2 meters) enclosed in protective polyethylene bags.

Each raft generally contains 800 to 900 rens. Usually the rafts are tied together in series of 10 or more, spaced about 10 meters apart. The rafts are left in the water between cultures, and with proper maintenance, are expected to last for 5 years.

Long-Line Method. This method is commonly used in northern Japan because it is more resistant to rough water than the other methods.

The long-line structure consists of a series of tar-coated wooden barrels or metal drums used as floats. The floats are positioned about 7 to 8 meters apart and connected by two parallel lines of tarred rice-fiber ropes 6 centimeters in diameter. The two lines are positioned about 60 centimeters apart. The total structure is about 80 meters long, and is supported by 10 to 12 barrels. Anchors are positioned at each end and in the center of the structure. Wire rens or rice ropes containing collectors are suspended vertically about 30 centimeters apart from the parallel lines connecting the barrel floats. The collector-containing lines hang 7 to 10 meters deep. The ropes containing collectors are of rice-fiber, 4 centimeters in diameter, and are tar covered. They are not as strong and durable as wire. Collectors are tied on the ropes at spacings of 30 centimeters.

Several long-line units are positioned parallel to each other at about 10 meters distance. Lines connect several individual units to give added stability in rough waters.

Rack Method. This is the method best suited for culture in shallow waters. The racks are rectangular structures usually about 1 to 1.5 meters wide and 8 to 12 meters long. The top of the rack is in a fixed position about halfway between high and low tides. The racks consist of vertical poles (bamboo usually) driven into the bottom soil and long hori-



FIG. 8. Oyster racks submerged at high tide.

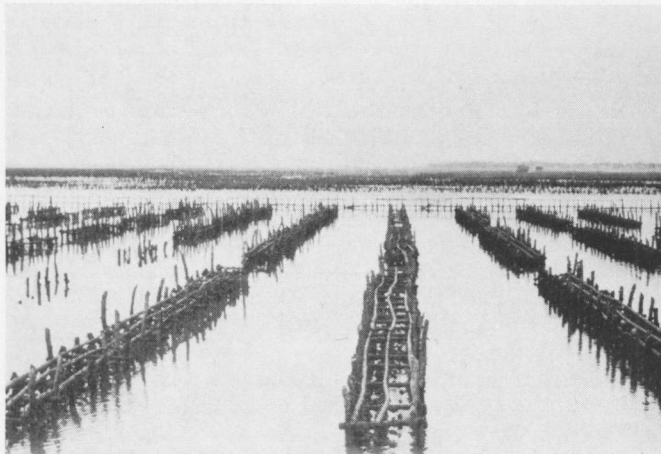


FIG. 9. Oyster racks exposed at low tide. Tide fluctuation facilitates stocking and harvest operations and allows use of the intertidal zone for culture.

zontal poles connecting the vertical poles. Short horizontal poles connect the vertical poles at right angles to the long poles. Wire rens are suspended from the long horizontal poles. Water depth influences length of the ren; the rens do not touch bottom.

The rack method is employed primarily in the seed oyster production and hardening process.

Harvestable oysters are produced by two systems: 1-year and 2-year cultures. In 1-year culture, seed oysters are transferred directly to production rafts in about 4 weeks after collecting. The young oysters are not subjected to the hardening process. Seed oysters used in this system must be on production rafts by early August for them to reach harvestable size of 5 to 10 grams shucked weight in that year. Harvest begins in late December or early January for 1-year production.

In 2-year culture, seed oysters are transferred from collecting racks to hardening racks where they will remain for 8 to 10 months, until June or July of the following year. They are then transferred to the production raft for growing to food size of 10 to 30 grams shucked weight. Harvest season begins in November.

The major difference between 1-year culture and 2-year culture is the hardening process employed by the latter. Little growth is realized during the hardening, but exposing

the oysters to the process reduces subsequent mortality as already indicated.

Average production per 10 meter ren is about 4 kilograms of shucked meat or 45 kilograms total weight of oysters. Range of production is from 2.5 to 10 kilograms for shucked meat/ren (30 to 110 kilograms total weight/ren). A raft of 850 rens will have productions of shucked meats averaging about 3.4 tons and ranging from 2.5 to 5 tons. About 90 per cent of Japan's oyster production is for home consumption. Most of the remainder is canned before exporting. All sizes of oysters are utilized. The smallest are smoked before canning and exporting.

Farmers can expect to sell their oysters for about 550 yen/kilogram (\$0.70/pound) shucked weight. This is about 1.9 million yen/raft (\$5,277). Costs of production are relatively high. A large amount of labor is necessary in the cultural practices.

Environmental conditions adversely affecting oyster culture are extreme temperatures, silted water, rapid change in salinity, and wind. Oysters on racks are more susceptible to unfavorable environments than those on rafts or long-lines, because the racks are always employed in shallow water. Racks and rafts are often positioned near the mouths of freshwater streams which, during floods, may be subjected to water of low salinity and laden with silt. Wind does considerable damage to rafts and racks; long-lines are specifically designed to resist wind and its effects. Typhoons may cause adverse environmental conditions. Temperatures influence growth, and a slightly better growth rate is experienced in southern Japan than in northern Japan.

Parasites and diseases are apparently not considered serious problems by the oyster farmers. However, parasites and diseases probably contribute significantly to the high mortality among cultured oysters, especially those in seed production.

Red tides caused by *Gymnodinium* dinoflagellates are considered serious problems in the culture areas, especially in spring and fall months when the waters are least turbulent.

Predators do not affect oyster production in Japan nearly as much as in countries where the hanging methods are not used. The two major predators are starfish and oyster drills. Little damage from these animals can occur in the long-line and raft methods because they cannot reach the oysters. However, oysters cultured on racks are more susceptible to the predators since the racks are anchored by posts driven into the soil.

Perhaps more serious than predators are the competitors — the organisms which attach to the rens and oysters and compete for space, food, and oxygen. Sponges, barnacles, tunicates, and seaweeds are examples of competitive organisms.

Probably the two most important problems in oyster farming in Japan are increasing labor costs and pollution. The greatest cost associated with oyster farming is that for manual labor. The United States does not employ the hanging methods practiced in Japan because of the scarcity and high cost of labor. Pollution is becoming a serious threat to all aquacultures in Japan including that of oysters. Since oysters feed on naturally-produced food organisms, the best culture areas are estuaries where adequate nutrients are available. These areas are also the areas of greatest pollution.

Japanese or Kuruma Shrimp

Shrimp culture is probably receiving more attention at present than all other aquacultures in the world. Much of this attention can be attributed to the successes achieved in

Japan with the Kuruma shrimp (*Penaeus japonicus* Bate). Those successes, in turn, can be attributed to Dr. Motosaku Fujinaga more than any other single individual. Fujinaga is credited with culturing the first penaeid shrimp from egg to adult in an artificial environment. He is credited with the development of the system now often termed the "Fujinaga System," for raising post-larval shrimp from the egg on a commercial basis.

Production of Post-Larval Shrimp. Fujinaga succeeded in 1933 in artificially spawning and hatching a penaeid shrimp for the first time. Few of these shrimp survived through the zoeal stage because of lack of suitable food. In 1941, Fujinaga began feeding the diatom (*Skeletonema costatum*) and found it to be a suitable food for zoeal shrimp³. In 1956 he began using nauplii of brine shrimp (*Artemia*) to feed mysis larvae. In 1958 he produced food-size shrimp from artificially spawned eggs. No one had ever accomplished this previously. This accomplishment set the stage for commercial culture. The limitations on shrimp culture at the commercial level include low yields per area, poor feed conversion, high cost of feeds, lack of success in the developing of acceptable artificial feeds, low survival rate, and high cost of labor.

Researchers in Japan and other areas of the world are actively trying to make shrimp culture feasible on a commercial scale. Japan is one of the few countries of the world where commercial shrimp culture is feasible at present. It is possible there only because of the high market price the product commands. The farmer can get as high as 2,500 to 11,000 yen/kilogram (\$3.16 to \$14.00/pound) for live, cultured, food-size Kuruma shrimp. Even at these selling prices, there are not many farmers getting into the business. In 1969, there were only 14 shrimp farms in Japan collectively totaling about 100 hectares. Harvest from these farms totaled an estimated 200 tons.

In its natural environment, the Kuruma shrimp spawns from mid-May to late September. Copulation takes place in the open sea. Sperm are encapsulated in spermatophores and are inserted by the male into a special seminal receptacle of the female. When spawning occurs, which may be many days after mating, the viable sperm in the seminal receptacles are released simultaneously with the eggs and fertilization occurs. The eggs are shed loose into the water and both eggs and larvae of all stages are planktonic. The eggs hatch into nauplii larvae, and through successive molts, the nauplii develop into zoea and then to mysis larvae. The mysis larvae develop into post larvae, which relinquish the planktonic habitat for a benthic one. The post larvae develop through a series of molts into juvenile shrimp having adult characteristics.

Farmers that artificially spawn Kuruma shrimp obtain their brooders from commercial shrimpers. Since the gravid female is capable of fertilizing the eggs as she releases them, there is no need for collecting male shrimp for spawning purposes. Brooder shrimp are collected by commercial shrimpers in the open coastal waters from late March through October. The shrimpers, trawling at night, separate out the gravid females and hold them in specifically constructed live wells beneath the boat deck. Upon arrival at port in early morning, the females are transferred to hauling facilities for transport to the nursery. Transport may be either in a tank of aerated sea water, in a plastic bag filled with

20 per cent sea water and 80 per cent pure oxygen, or in a container in cool, dry, coarse sawdust. The plastic bag method is the best method of the three and the sawdust method is the poorest.

Fujinaga was using the sawdust method. The containers used were corrugated cardboard boxes with 31 x 27 x 15-centimeter dimensions. About 30 shrimp were contained in each box. Plastic bags containing ice were packed on top of the sawdust before sealing and shipping. The adult shrimp to be shipped to Fujinaga's farm were packed and shipped from Nagoya in the early morning; they arrived at the farm by mid-afternoon.

Gravid females were readily detected by the gray-green ovaries showing in the dorsal portion of the body; especially, at the hinge between carapace and abdomen. The thicker, more defined the ovaries, the more likely the female was to spawn readily.

Prior to receiving gravid females, the spawning nursery tanks were partially filled with sea water filtered through cloth of approximately 96 x 76 threads/inch. Gravid shrimp were stocked during the daylight period at varying densities ranging from 0.5 to 1.5 shrimp per cubic meter depending on such factors as type and size of tanks, temperature, condition of the shrimp, and others. Fujinaga stocked up to 100 females per tank (10 x 10 meters) in sea water to a depth of 0.7 meter (70 cubic meters). Facilities for spawning and raising larval shrimp have varied in shape, size, and material. In the past, structures for spawning and rearing were separate. However, facilities have become more standardized, with the same facility serving both spawning and nursery functions.

The standard nursery facility was a square concrete tank 5 x 5 x 2 meters or 10 x 10 x 2 meters, with water capacity of 50 to 200 cubic meters. The tank floor was sloped to one corner at a rate of 3:100 to permit total draining of water. A plastic drain pipe, equipped with control valve, led from the tank into a chamber in the drainage canal whose floor was approximately 0.5 meter below the outside end of the drain. Water depth in the chamber could be maintained at approximately 0.4 meter. The function of the chamber was to facilitate harvest from the tank.

Water in the spawning-nursery tanks normally ranged from 21 to 23 p.p.t. salinity. Optimum water temperature for spawning was 28° C. Fujinaga stocked brooder shrimp in controlled temperature of 23° C and began increasing the temperature to 28° C immediately following stocking. Temperature of the natural waters in April is about 15° C but the shrimp can be acclimated rapidly to 28° C. Temperature control was managed by a combination of methods: heating water; constructing the culture tanks below ground level to conserve heat and prevent rapid fluctuations of temperature; and enclosing the tank area with a translucent, corrugated fiberglass, greenhouse-type structure. Heating the water was not necessary from July to October.

Spawning nursery-tanks were aerated vigorously through airstones positioned about 10 centimeters from the tank floor. Each airstone was connected by a plastic or rubber hose which led to pipes from a compressor or blower. One airstone for each 3 square meters of tank floor was considered adequate and an even greater area was covered by one stone if air pressure was great enough to furnish a high volume flow. The effect desired was to have water moving in all areas of the tanks, with the surface giving the appearance of boiling water.

The average body weight of gravid females was approxi-

³ M. Johnson and J. R. Fielding (Tulane Stud. Zool. 4(6):175-190; 1956) succeeded in the United States in 1955 and 1956 in spawning the white shrimp (*Penaeus setiferus*) and rearing them to harvestable size with net production of 806.7 kg./ha.

mately 100 grams and ranged from about 65 to 140 grams. Size of collected females decreased as the season progressed; in April average size may have been 120 grams, but by September average may have decreased to only 80 grams.

Approximately 50 per cent of females placed in tanks actually spawned. Spawning was influenced by a number of factors including physical condition of females, state of egg development, and others. Spawning occurred at night, which was one reason the culturists wished to stock females during the daylight hours. The spawning act generally becomes later at night as the season progresses. In May the spawning peak occurred between 8 and 10 p.m.; in July between midnight and 2 a.m.; and in September between 2 and 4 a.m. Spawning was readily evidenced by foam appearing on the water surface and the water becoming pinkish in color. The eggs were released directly into the water.

The number of eggs discharged per female averaged about 300,000 and ranged to over 1 million per female depending on body size. Egg number increased with body size. Hatching occurred 14 hours after spawning in water temperature of 28° C. (First cleavage occurs 15 minutes after spawning; eye formation develops in 11 hours.) Approximately 50 per cent of spawned eggs actually hatched. Fujinaga expected hatchability to be only 5 per cent in April and May; 10 to 20 per cent in June; and 80 per cent from July through September or until the end of the season. Adult shrimp were removed from the tank with scoop nets after 2 days or after the first nauplii have been observed. Dead shrimp were removed when they were detected.

Hatching into the first larval stage (the nauplius) occurred 14 to 16 hours after spawning. The nauplius was about 0.3 millimeter in length and was planktonic in habit. Nutrition was furnished by self-contained yolk; larvae in this stage do not take food. The larvae remained in nauplius stage through 5 molts, which required about 35 to 36 hours at 28° C. Survival was usually 95 per cent during this stage provided water quality was high. Estimating numbers of nauplii and other larvae was easily accomplished by taking 1-liter samples of water at random, combining the samples, counting the larvae, and expanding the consolidated number of larvae on the basis of total water volume. The nauplii metamorphosed into zoea on the 6th molt as a nauplius. This occurred about the 36th hour of the nauplius stage, or on the 4th day after stocking the gravid females. The larvae were about 0.9 millimeter total length at this stage. In the first stage as a zoea, the remaining yolk was totally absorbed and the larvae began taking diatoms as food. The zoea, still planktonic in habit, were unable to actively seek food, so diatom density must be great enough that the larvae come into contact with diatom cells at sufficient intervals. A fertilization program was begun while the larvae were in the nauplius stage. Usually it was initiated on the morning following hatch of the first nauplii. Chemical fertilizers were used. The object of fertilization was to induce mixed diatom growth to provide food for larvae in the zoeal stage. Pure cultures of *Skeletonema costatum* are no longer necessary as in earlier methods of culture. Chemicals and concentrations commonly used per 70 cubic meters of water per day were: potassium nitrate (KNO₃) at 100 grams; sodium phosphate (Na₂HPO₄) at 100 grams; potassium silicate solution⁴ (K₂Si₂O₅) at 5 cubic centimeters. Application of the chemicals was practiced daily for about 10 days. After a few days,

⁴ Commercially known also as "water glass" containing about 25 per cent potassium silicate.

the amount of chemical used was adjusted downward, when and how much depending on the density of diatom growth. Diatom density was indicated by depth visibility and the brownish color of the water. When for some reason diatom density was not sufficient, finely ground soybean meal was added as a supplementary feed for the larvae. As a standard practice, Fujinaga introduced *Artemia* to the culture tank at a rate of 500 grams *Artemia* eggs per day per million larvae. At 28° C *Artemia* eggs hatch in about 24 hours. Hatchability was usually between 40 and 50 per cent.

The zoeal stage in larval development is probably the most critical and it is influenced by water quality and food availability. Fujinaga expected to get about 80 per cent survival in the zoeal stage. This stage is characterized by 3 molts requiring 4 days (8 days since stocking brooders) at 28° C to complete. In the third molt, the zoea metamorphose into mysis larvae.

The mysis larvae appear as minute adult shrimp, but are planktonic and swim backward, anterior end down, in a vertical position. Peripods function as appendages for swimming. These larvae are omnivorous and actively feed on the small *Artemia* nauplii introduced as eggs in preceding days. Survival in this stage was about 95 per cent. The mysis larvae go through two growth molts before a third metamorphosing molt that occurs after 4 days (12 days from spawning) in that stage. This is the last molt while the shrimp are in the larval stages; they emerge from this metamorphosing molt as post larvae.

Beginning at the first mysis stage, filtered sea water was added daily over a 6- to 8-day period until the tank was at maximum level of 2 meters.

The post larvae (P) are characterized by 5 pairs of pleopods that function as appendages for swimming. The peripods that served as swimming appendages in the mysis now serve as grasping and walking appendages. The shrimp in early stage become carnivorous and depend on *Artemia* nauplii and minced clam meat for food. *Artemia* eggs were added at 500 to 1,000 grams/day/million P by Fujinaga. A generalized feeding rate for minced clam meat is as follows:

Stage of P	Weight of meat per day per million P
P ₁ -P ₆	3 kg
P ₇ -P ₉	6 kg
P ₁₀ -P ₁₂	9 kg
P ₁₃ -P ₁₆	12 kg
P ₁₇ -Harvest.....	16 kg

Fujinaga stated that the amount of clam fed in his larval production operations was less than half that given above. The cost of *Artemia* eggs was 40,000 yen/kilogram (\$50.00/pound) and for clam meat 20 yen/kilogram (\$0.03/pound). It has been found that P in early stages each devour 46 to 84 *Artemia* nauplii in a 24-hour period. Body color of P₁ (P₁ are 1st day post larvae; P₂₃ would be 23rd day post larvae) is colorless to whitish, but as *Artemia* are fed upon, body color becomes red-orange, the color of *Artemia* nauplii.

Fujinaga expected 85 per cent survival of P shrimp from P₁ to harvest at P₂₀-P₂₅. Sea water was added daily during the three mysis stages and up to the fourth day of the post-larval stage to fill the tank from 0.7 meter to maximum depth of 2 meters. From this point until shrimp were harvested, sea water was added at a replacement rate of from 0.20 to 0.33 total volume/day. P₁ shrimp are benthic, the first stage to be so; therefore, until this stage is reached, replacing water would result in loss of shrimp. Water temperature

from P₁ stage onward was maintained at approximately 25° C. Generally, the P were harvested when they attained an average of 0.01 to 0.02 gram and 15 to 20 millimeters length. This was usually about P₂₀ to P₂₅ or 35 to 40 days after stocking the brooders.

Harvest was not as difficult as it might appear. The collecting facility on the outside end of the drain pipe was important in facilitating harvest. The contour of the tank floor, permitting total drain of the tank, was also important. To harvest, the first step was to drain the water level down to about 0.4 meter. Fine mesh screens at the mouth of the drain prevented loss of shrimp. Next, a plankton net about 2 meters long was affixed to the outside end of the drain. The free end of the net was equipped with a draw string to facilitate emptying collected shrimp. The screens on the inside were removed and shrimp were allowed to pass through the drain to be collected in the plankton net. Rate of flow was controlled to prevent injury to shrimp. Also, the collecting portion of the net was kept under water at all times to prevent injury and stress. Shrimp collected in the net were transferred to buckets as necessary.

The standard method for transporting and shipping P shrimp was in polyethylene bags containing oxygen and sea water. The number P per bag depended, of course, on size of bag, period of time required in bag, and method of transport (temperature control). An example would be to place 5,000 P in a 20-liter bag containing 8 liters of sea water; add 10 liters of oxygen; place bag in metal or wood box; add ice to top or place in a refrigerated hauling facility; transport at approximately 12° C. Fujinaga shipped P₁₀ to France by air in this manner. Transport time was about 96 hours with only 10 per cent mortality.

Temperature acclimation is necessary but it evidently is not as critical with shrimp as with fishes. Fujinaga sometimes acclimated P from 25° to 12° C in only 10 minutes.

Yields of P larvae are influenced by many factors, but expectations of 25,000 per female or 5,000/cubic meter of tank are realistic. Fujinaga averaged about 1 million per 200-cubic meter tank or 5,000/cubic meter.

Fujinaga expected to produce 60 million juvenile shrimp per year with a total labor force of 5 people. He had the capability of that production, but markets for P shrimp were limited. Markets and outlets for P shrimp included private shrimp farms, limited markets in other countries, and the natural waters of Japan. Private shrimp farms in Japan total about 100 hectares. At stocking densities of 250,000 to 350,000 P/hectare (25 to 35 P/square meter) there is need for only 25 to 35 million P to satisfy the demand for farm culture. Some farmers of food-size shrimp produce their own P for stocking. Foreign markets must necessarily be very small due to the cost and problems in shipping. By far the major outlet for shrimp is in the natural waters. An example of this is that 5 propagation centers of the Nansei Regional Fisheries Laboratory plan to release a collective total of 140 million shrimp into the Seto Inland Sea this year. Other government-financed stations and cooperatives have similar programs.

Production of Food Shrimp. The raising of food-size shrimp from juveniles is not a large practice by any means. The largest of the 14 food shrimp farms in Japan had 6 ponds totaling 20 hectares. Two major factors limiting growth are limited technology and profit risks. These and other problems in shrimp farming will be discussed in detail at the end of this report.

Culture ponds have for the most part been converted from

abandoned salt fields where salt was obtained from sun- evaporated sea water. Pond sizes ranged from less than 1 hectare up to 10 hectares. A convenient size was about 3 hectares with depths fluctuating between 1.0 and 1.5 meters between low and high tides. Changing tides were utilized to exchange water in the ponds. Gates with screens to restrict wild fish entry and shrimp escape were most frequently used, but siphons emptying into screened boxes were also used. Pond bottoms of sand were preferred, partially to accommodate the burrowing habit of shrimp. Inside slopes of dykes were usually lined with concrete. Suspended net cages were being used experimentally to raise food shrimp. Results thus far indicate that this may be a feasible method.

Preparation of the culture pond was necessary before stocking. The pond was drained and dried, and any potholes remaining were poisoned with rotenone or tea-seed cake to eradicate any fish that might be there. The bottom sand was plowed at least once and new sand added if necessary. Any necessary repairs were made on the facility before filling with sea water. The pond should be prepared for stocking by late April. Shrimp P may be stocked in a nursery pond to raise them to juvenile stage before stocking into production ponds for growing to food size. However, the nursery is not necessary and P may be stocked directly into production ponds. The latter alternative will be emphasized here.

The generalized system of raising food shrimp was stocking ponds in May; feeding daily; and harvesting in October. The P were stocked into production ponds from early May to mid-June. Mean water temperature during this period was about 15° C. Care was taken to stock the total number of P so as to get even dispersal over the pond. Stocking density was approximately 30 to 35 P/square meter of water. Expected mortality was about 40 per cent during the culture period, so with the above density about 20 shrimp/square meter were expected at harvest. Mortalities result from predation, disease, poor water quality, cannibalism, and other causes; therefore, predicting a given per cent mortality is hardly realistic. Quality management was probably reflected more here than with most aquacultures. As a general rule, the larger the shrimp when stocked the better the survival, regardless of the duration of the culture.

The feeds used for shrimp culture were primarily clams (i.e., *Venerupis philippinarum* and *Mytilus edulis*), shrimp, fish (sand eel and horse mackerel), and occasionally squid and flesh of other animals. The feeds were usually minced or ground in preparation for feeding. Clams presented a problem in that their flesh was difficult to obtain efficiently and economically without some shell contamination. Continuous feeding of minced clam contaminated with bits of shells resulted in undesirable hardening of the pond bottom.

The following table is an example of a feeding program for shrimp being raised in production ponds from 0.1 gram to food size (20 to 25 grams):

Shrimp size Grams	Feeding rate		Type of feed
	Pct. body wt.	Times/day	
0.1-0.5.....	50	2 to 3	minced clam, shrimp minced clam, shrimp ground clam, fish, small shrimp
0.5-1.0.....	35	1 to 2	
1.0-5.0.....	25	1	ground clam, fish, small shrimp
5.0-15.0.....	15	1	
15.0-25.0.....	5	1	ground clam, fish, small shrimp

The S conversion (kilograms of feed required to produce 1 kilogram of shrimp under pond conditions) usually was

from 10 to 15 following the above program. This is about twice the conversion rate expected for most fish; however, the loss of energy and protein in the molting (ecdysis) process of shrimp should alone account for a significant portion of the differential in S between shrimp and fish.

The shrimp should be fed in late afternoon or early evening. After they are about 0.1 gram in size, they feed only at night. Movement of shrimp during daylight periods is indicative of insufficient food or a stress condition. Cannibalism is also indicative of inadequate food quality or quantity.

The most rapid growth of shrimp in ponds is from July through September when water temperatures range from 23° to 28° C. Optimum temperature for growth is considered to be about 25° C. At temperatures below 10° C shrimp will not take feed.

Maintaining suitable water quality is a greater problem in shrimp ponds than in fish culture ponds because of the higher oxygen requirement of the shrimp. The exclusive daily feeding of ground or minced animal flesh tends to pollute and lower water quality. However, the partial water exchange in the ponds by tidal activity flushes much of the pollution out of the ponds, thus tending to improve water quality. Kuruma shrimp by nature inhabit the pond bottom, which is most likely to have water of poorest quality. To maintain a high dissolved oxygen level at all depths of water, paddle-wheel agitators were often employed.

Predatory and competitive fishes contaminate most culture ponds, but apparently no attempts were made to eradicate them. The practice of using tea-seed cake as a selective piscicide was not used in Japan (tea-seed cake at 2.5 to 10.0 p.p.m. was used in Taiwan to selectively eradicate fish without harm to shrimp; tolerance for the toxin was 50 times greater in shrimp than in fish). Rotenone and RADA (rosinamine-D-acetate) have potential use as selective piscicides; however, these materials are toxic to shrimp at lower concentrations and the margin of safety is not as great as with tea-seed cake.

Disease was apparently not as serious a problem in Kuruma shrimp culture as it was with most fish cultures. Shrimp are cannibalistic, which becomes a significant factor as density is increased; however, cannibalism is not considered a serious problem when the shrimp are being fed properly. Cannibalism occurs when shrimp are molting, at which time they are soft and vulnerable to other shrimp, and probably also when shrimp are sick.

The standard harvest methods required two kinds of gear: pound nets and drag nets equipped with pumps. The pound net was normally used in October and November, and the continued harvest was by drag net.

The pound net, illustrated in Figure 10, is most effective at night when the shrimp are active. However, catch with this gear decreases with decreasing temperature because shrimp become less active. It is then necessary to change to the pump-drag net gear. The pump-drag net, Figure 11, is operated during the day. The drag net is towed along the pond bottom behind a boat. A pump in the boat forces water through a hose to a pipe positioned at the mouth of the drag net. The water escapes downward from a series of outlets in the pipe. The velocity of escaping water stirs the sand, dislodging and frightening the shrimp to where they can be collected in the trailing drag net.

Harvested shrimp must be kept alive and were immediately transferred to holding tanks equipped with aerators and cooling coils. Water temperature was lowered to 12° to

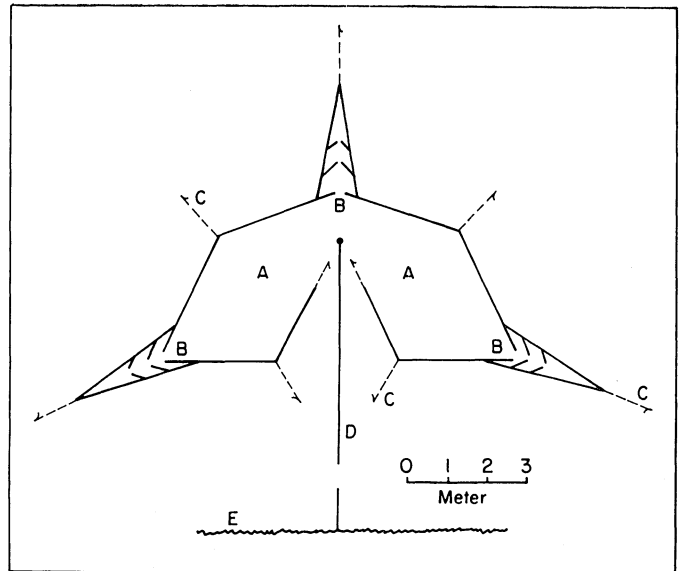


FIG. 10. Pound net used to harvest cultured shrimp. A—body of net; B—funnel traps; C—anchor lines; D—wing net; and E—pond dike.

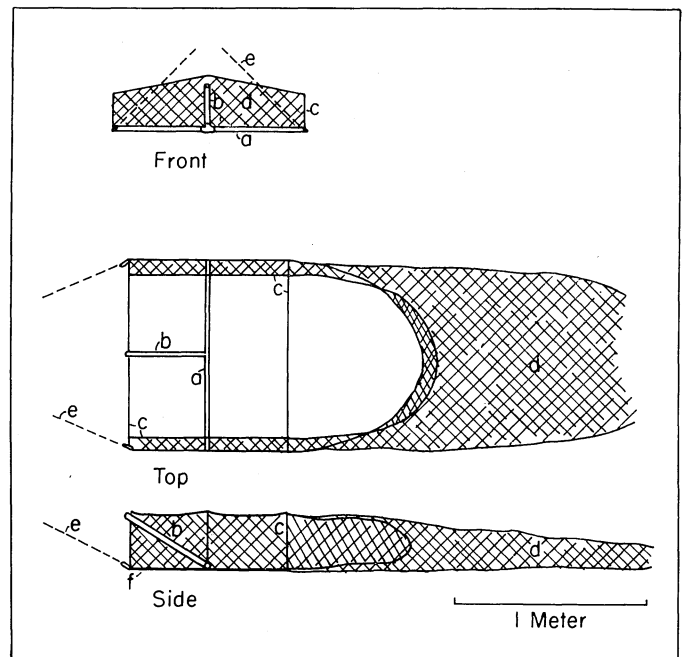


FIG. 11. Pump-drag net. a—perforated pipe; b—pipe hose leading to pump in boat; c—frame; d—drag net bag; e—tow lines; and f—frame skids.

14° C if it was not already that low. The low temperature served three purposes: 1) prevented molting and subsequent cannibalism; 2) reduced shrimp metabolic rate; and, 3) caused a reddish tinge on appendages and other portions of the shrimp desired for marketing. Shrimp were held in this manner for at least 8 hours before being packed for shipping. For shipping the shrimp were packed in boxes containing dry sawdust. The packing was done in a cold-room. A sawdust of coarse texture was used for packing. Corrugated cardboard boxes with 31 x 27 x 15-centimeter dimensions received a layer of sawdust followed by a layer of shrimp, and so on until full. About 2.5 kilograms of

shrimp graded to size were packed per box in warm weather and 3.0 kilograms/box in winter. The shrimp had to be alive when they reached their destination in Tokyo, Osaka, or other cities.

The price for live shrimp at the Tokyo Central Fish Market fluctuated according to availability from 2,500 to 11,000 yen/kilogram (\$3.16 to \$14.00/pound) with an annual average of about 3,500 to 4,000 yen/kilogram (\$5.00/pound). The highest paid price of 11,000 yen/kilogram was realized only in April when shrimp were scarce.

At present it appears that the average price will steadily increase in the next few years since the supply of naturally produced shrimp has declined in recent years and is expected to continue to do so.

Production costs were considered to average about 2,500 yen/kilogram (\$3.16/pound) excluding depreciation on ponds and other facilities. The following is a breakdown on cost by item per kilogram of shrimp produced:

Cost Item	Cost/kg	
	Yen	Dollars
Labor.....	540	1.5
Feed.....	1,080	3.0
Packing/shipping.....	540	1.5
Supplies, etc.....	180	0.5
Interest.....	180	0.5
Totals.....	2,520	7.0

Problems Associated with Shrimp Culture. The following paragraphs contain personal observations and comments concerning the problems associated with the culture of penaeid shrimp in general and *P. japonicus* in particular. The discussion is concerned primarily on how these problems will likely influence the future of shrimp culture in Japan and the world. Discussion covers both the post larval and food production phase of shrimp farming.

The high cost of production is perhaps the most significant of all the problems associated with shrimp farming. Farm-raised shrimp are definitely in the luxury food class. Obviously, the product must bring a premium price to be an economical venture for the farmers. The decline in supply of naturally-produced shrimp is likely to increase the demand and price of the cultured product.

As this occurs and profits increase accordingly, farming operations may expand and new ones originate. However, present cultural techniques limit expansion. For instance, one feed item is fishes, which themselves are limited in supply, and shrimp farmers must compete with eel farmers and farmers of other fishes for trash fish for feed. The catch per unit effort of trash fish is declining so it appears that with the increasing demand and decreasing supply of these fishes, production costs of farm-raised shrimp will necessarily increase.

It is not conceivable that intensive monoculture shrimp farming can be practiced on a profitable scale outside Japan using present techniques with the resulting high cost of production. For example, consider the possibilities of commercial food shrimp culture in the United States using techniques employed in Japan for Kuruma shrimp culture. Labor, land, and construction cost would be more costly also. Suitable topography, soil, tidal fluctuations, and climate are limited to very few areas of the United States. Nevertheless, the principal limiting factor would be a low market price as the United States shrimp farmer probably could not sell his product for much over \$1.50/pound.

The cost of production exceeds the market price in most

areas of the world where live shrimp do not command a premium price. Cost of production in terms of protein prohibits such an enterprise in most developing countries, where it would be difficult to justify S conversions of 10 to 15 when feeding animal meat exclusively.

Many of the problems indicated above center around the use of animal flesh as feed. There are many obvious advantages of artificial pelleted feeds over raw flesh; the most important of which is simply that pelleted feeds are generally cheaper and much more practical. Although research is in progress on this problem, artificial feeds have not yet been developed that are acceptable to the Kuruma shrimp, either in the larval or adult stage. Even on highly fortified pelleted feed, shrimp will probably not be as efficient in conversion as most fish species. A great deal of energy and protein are lost by shrimp when molting and in production of its chitinous exoskeleton.

Production potential in shrimp culture ponds with tidal water exchanges was reported to be not above 2.5 tons/hectare (2,300 pounds/acre) with the present techniques. The factor limiting production is poor water quality resulting primarily from residues from the ground flesh feed. Pollution could be reduced through use of artificial feeds which would have the effect of increasing production potential. The methods of harvesting Kuruma shrimp now employed are slow, laborious, and expensive. Harvest is complicated by the habit of the shrimp to burrow. There is definite need for improved harvesting techniques.

DISCUSSION

It appears Japan is faced with some serious problems in most of its aquacultures. Few of the many methods of culture developed there have application in other countries. If present methods are continued in Japan, many cultures will have limited growth and some may actually decline.

Perhaps the most serious of all the problems, and perhaps the ultimate limiting factor in the healthy growth of most aquacultures in Japan, is the cost of production. It is now the factor restricting many cultural practices to Japan. An example of higher cost culture is that of the Kuruma shrimp. The average cost to produce a kilogram of food size shrimp is \$7.00, or about \$3.20/pound. This is acceptable in Japan where the market prices for live cultured shrimp range from \$7.00 to \$30.00/kilogram (\$3.16 to \$14.00/pound). Shrimp farming at production costs of \$3.50/pound has practically no application outside of Japan.

The two primary cost items of all cultures are feed and labor. Problems of labor scarcity and high labor costs are being felt in Japan now and are expected to increase in the future. Feed costs are expected to increase also, especially for those cultures requiring fresh meat as feed. The supply of trash fish, the primary meat source, is decreasing while the demand increases — a healthy situation only for the feed supplier. The cost for trash fish was 30 yen/kilogram (\$0.04/pound), while S conversions ranged from about 6 to 15. This represents a feed cost ranging from 180 to 450 yen/kilogram (\$0.23 to \$0.57/pound).

The costs of feed could be reduced in some cultures if artificial feeds could be used, but many of the cultured animals are strict carnivores and attempts to feed artificial feeds have met with little or no success.⁵ One researcher con-

⁵ However, in the United States piscivorous species such as the largemouth bass have been reared on pelleted feeds after subjecting the fish to a training period.

cluded that if yellowtail could be fed an artificial diet, at least 70 per cent of the feed would have to consist of fish meal. This requirement would preclude the development of cheaper feeds.

Production has been considered from a monetary standpoint, but production from a protein-efficiency standpoint is also very important. It would be difficult in most countries to justify such inefficient conversions of animal protein ($S = 6$ to 15 using animal flesh). Solutions may be difficult to find. The cultured animals must give efficient conversions on prepared feeds that derive a large portion of their protein from plants. Otherwise, these animals may become too costly in terms of money and/or protein to culture on a commercial basis.

Pollution is a problem of significance facing aquaculture in Japan. The natural waters in many areas, especially around large cities, are highly polluted. This is affecting culturists in at least three ways. First, it restricts the use of that water for filling ponds or for suspending culture cages or rafts. Second, it is reducing the availability of young animals for stocking because many must be obtained from natural populations. Third, most culturists depend on trash fish for feed and pollution is reducing local stocks, resulting in less catch per unit of effort to the fishermen who must increase effort or fish farther away from port.

Pollution results from an aquaculture system, especially one under intensive feeding. Pollution is a much greater problem when ground trash fish are used rather than pelleted artificial feeds. The major results of pollution are increased incidence of disease, lower carrying capacities of the culture environment, and fish kills.

Still a major problem with many aquacultures in Japan, as well as elsewhere, is that of having to depend on natural populations for young animals for stocking. For some cultures, the adults are collected from natural populations, while spawning, hatching, and raising of young to a stockable size are done artificially. For others, such as eel and oyster, the young are collected directly from natural waters. Obviously, no genetic improvement of the cultured animals is possible under either of these conditions.

Another consideration is the decline in abundance of brood or young in the natural populations. As an example, the abundance of eel elvers for stocking has declined steadily over the past few years. As a result, eel farmers are importing elvers from countries such as Taiwan and France. From the latter, elvers of different species have been imported, and apparently have brought with them at least one disease to which the Japanese eel is susceptible.

A potential disease problem innate in Japanese methods of aquaculture results from the feeding of uncooked or otherwise untreated trash fish. The transfer of disease organisms through the feeding of raw fish has caused such severe disease problems in trout that many farmers in the United States and Europe were forced out of production. This problem has manifested itself in yellowtail culture.

Stocking programs, whereby young organisms are stocked in natural waters to replenish natural stocks, are practiced in Japan on a very large scale by various governmental agencies and fisheries cooperatives. As an example, Nansei Regional Fisheries Laboratory plans to release 140 million young shrimp into the Seto Inland Sea this year from its five propagational centers. Other organizations have similar plans. Each prefecture receives a quota of young shrimp and has responsibility for the actual release. This stocking program has been in operation for a number of years, but no

studies have been made to determine its effectiveness.

Currently, much effort, facility, and money are being put forth to artificially reproduce yellowfin and other tuna for release into the Pacific Ocean. The objective is to replenish the declining fishery. One researcher concluded that for good survival the young fish should be at least 20 centimeters total length before stocking. This would suggest that if this species can be efficiently raised to 20 centimeters, the tuna should not be released but processed for food directly or cultured to a larger size before processing. It is difficult to comprehend a facility of the size necessary to produce enough tuna 20 centimeters long to stock into the Pacific Ocean to significantly affect the number of harvestable size tuna. The actual cost of culture would be phenomenal since trash fish would probably be the feed material. This would further increase the competition for trash fish.

Experiences by various state and federal agencies in the United States have demonstrated that replenishing breeding populations of fishes in inland waters is a costly waste of time and effort. Also, fishery biologists have learned that fecundity in general varies inversely with the number of parents. If this is the case in Pacific tuna, then the declining adult population should be producing a greater than normal number of offspring and replenishing may be unnecessary.

FACILITIES VISITED

Those places visited during this survey and general information on each are presented below in sequence visited. The location of each is shown in Figure 12 and is indicated by the corresponding brackets-enclosed numbers.

(1) Freshwater Fisheries Research Laboratory, Dr. J. Yamakaya, Director, Hino-shi, Tokyo, (May 17)

This is the only national institute engaged in research on the culture of freshwater fishes. The institute is, however, tri-divided with Hino serving as headquarters; one branch is at Nikko, and the other at Ueda. Total area of research ponds at all three locations is 14,750 square meters. Research interest includes fish breeding, culture of exotic fishes, nutritional requirements, feed production and testing, production of forage organisms, and diseases. Fishes being studied include eel, ayu, rainbow trout, common carp, and tilapias (*T. mossambica* and *T. nilotica*). The station also produces fish fry for sale to fish farmers.

(2) Kanagawa Prefecture Fisheries Experimental Station, Mr. Masaaki Inoue, Chief, Culture Division, Misaki, Miura, (May 18)

Primary functions of this station are research and extension in offshore fisheries. The station has seven divisions, namely: 1) Culture (Propagation); 2) Offshore Coastal Resource (Population Dynamics); 3) Fish Management; 4) Commercial Gear; 5) Oceanography; 6) Fry Production; and, 7) Extension. Each division has six scientists. Also, there are two branch stations each with 12 scientists. This is a large, well-equipped and well-staffed station.

Culture animals being studied include sea bream, flatfish, abalone, and top-shell crab.

(3) Fujinaga Shrimp Farm, Mr. Isamu Ando, Chief Biologist, Yoshiki-gun, Yamaguchi-ken, (May 19)

This farm is located on Aiu Bay. The hatchery consists

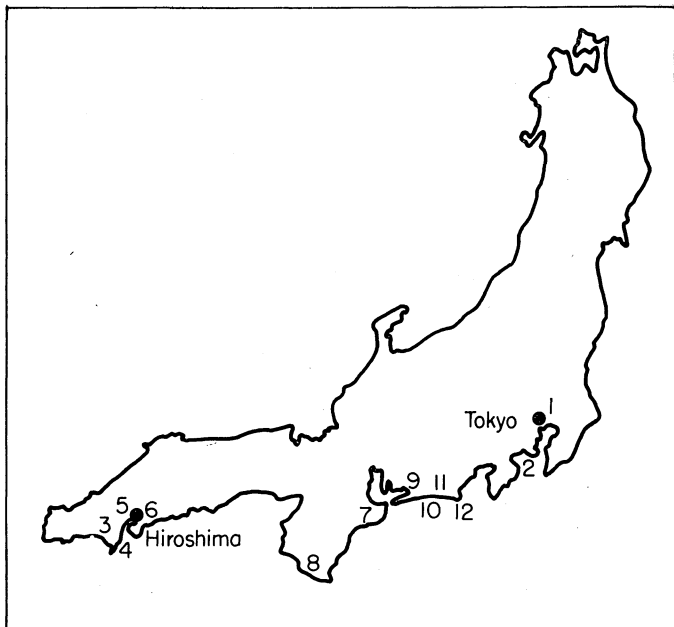


FIG. 12. Map of Honshu Island, Japan, showing aquacultural facilities visited.

of 12 concrete tanks enclosed inside a large corrugated fiberglass building. The tanks are each 2 meters deep and 10 meters square. They are used for hatching and raising shrimp to the post larval or stocking stage. Production potential is 1 million post larvae/tank/40 to 50-day period. Some research is also conducted at this facility. Individual air and water supplies service each tank. The water is heated when necessary. To preserve heat, the tanks were constructed below ground level. The farm also includes ponds and fenced-in areas of the bay that serve as production ponds for raising post larval shrimp to marketable food shrimp. The discussion of shrimp culture in this report covers the system used at this farm.

**(4) Yamaguchi Prefecture Culture Center,
Yoshiki-gun, Yamaguchi-ken, (May 19)**

This station on Aiu Bay consists of 11 hectares of ponds. Research interest is centered around shrimp, ayu, fungus, and nori algae. Shrimp are reproduced here using the "Fujinaga System," but in much smaller tanks than at the Fujinaga Farm. Typical of the stations responsible for marine and brackishwater organisms, this station is well equipped and all facilities are modern and well kept.

**(5) Nansei Regional Fisheries Laboratory,
Mr. S. Ota, Director,
Ohno-cho, Hiroshima-ken, (May 20)**

This station has divisions of: 1) Research Planning and Coordination; 2) Inland Sea Fisheries Resources Research; 3) Offshore Fisheries Resources Research; 4) Oceanographic Research; 5) Aquaculture Research. The latter division consists of four laboratories, namely: 1) Breeding Research; 2) Nutritional and Physiological Research; 3) Pathological Research; and, 4) Environmental Research. This division is responsible for "restocking" the Seto Inland Sea fish populations. An example of the restocking program is that of the shrimp releasing program. Under this program, five propagation centers are expected to release 140 million post larvae shrimp into the Seto Inland Sea this year. No studies were

made prior to or after the initiation of the program a number of years ago to measure effects of the releases. The first releases were made directly into the sea but recent releases have been into "naturalization" (conditioning) pens positioned in the sea. The young shrimp stay in the pens for 2 to 8 weeks before being finally released into the open sea. Mortality here has been from 20 to 40 per cent. Other cultures of interest here are those of porgy and oyster.

**(6) Nichiro Gyogyo Oyster Plant,
Hiroshima-shi, (May 20)**

This is the largest oyster plant in Japan and possibly the world. Production of canned smoked oysters amounts to 20 million cans per year. All of these are exported. The *Geisha* brand, familiar in the United States, is a product of Nichiro. Most of these oysters are from raft cultures. In the Hiroshima area, approximately 30,000 tons of oyster meats are produced per year in raft cultures.

**(7) Pearl Research Laboratory,
Kashikojima, (May 22)**

This station is totally engaged in support of the cultured pearl industry. Their 11 research scientists are involved in research to improve cultural methods, disease control, breeding, physiology, mineralogy, and other aspects of the industry.

At present, there are 4,700 individual managements of pearl culture that utilize 255,000 rafts. The annual value of exported cultured pearls is in excess of \$50 million.

**(8) Fisheries Laboratory of Kinki University,
Dr. Teruo Harada, Professor,
Shirahama, (May 23)**

This station is working with a large number of finfish and oyster cultures. Dr. Harada began using floating net cages in 1954 for raising yellowtail. The primary interest of this station at present is tuna reproduction. Last year they were successful in artificially spawning two female yellowfin, but were unable to keep fry alive longer than 20 days.

Net cages are utilized for most work here with finfish. Primary interest is on yellowtail and other *Seriola* sp., yellowfin and bluefin tuna, oysters, and other fishes.

**(9) Shizuoka Prefecture Fisheries Experimental Station,
Mr. Tsunogai, Director,
Hammatsu, (May 24)**

This station is located adjacent to a laboratory of Tokyo University. Research here covers both brackish and freshwater cultures. Oysters and nori are the primary brackish-water cultures; eel, ayu, and carp are the freshwater species. Eel, however, receives the major emphasis.

**(10) Privately Owned Eel and Ayu Culturing Farms near
Hammatsu, (May 24)**

Two farms were visited where the owners were engaged in the monoculturing of eel. Both farmers were using the standard cultural methods discussed in this report. Both farms were family operations which is apparently the case with most eel farms.

A family-managed ayu culturing farm was also visited. The elaborate facility and management techniques are discussed in this report under ayu culture. The owner of this farm also processed and shipped his production.

**(11) Eel Processing Plant near
Hammatsu, (May 24)**

A plant engaged in processing and shipping eel was visited.

Both live and canned eel were shipped. The live eel were shipped in oxygen-water filled plastic bags with approximately 10 kilograms of eel per bag. Markets for live eel were primarily Osaka and Tokyo. Canned eel were in the form of skinned, eviscerated sections approximately 4 inches long, broiled and canned in soy sauce.

**(12) Far Seas Fisheries Laboratory,
Dr. Yabuta, Director, Tokai University,
Shizuoka, (May 25)**

This laboratory is concerned with pelagic fishes and off-shore fish populations in general. The only culture in which this station is interested is that of tuna, on which they are cooperating with the Fisheries Laboratory of Kinki University. Their intention is to artificially reproduce species of tuna for replenishing the natural ocean stocks.

