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AYU SWEETFISH CULTURE

Propagation within an ecosystem

Every spring in March, ayu fishery begins around the shores of Lake Biwa and the rivers that flow into it. Since olden times scenes of fishermen using various methods such as weir fish traps, chase scoop nets and 4-armed scoop nets to catch ayu along the shores of Lake Biwa have been a popular seasonal fixture from spring into summer. The ayu of Lake Biwa are called koayu, meaning small ayu, and have long been used in fresh fish dishes or as the material for processed foods. Today these ayu are valued as seed fish for release in rivers or for aquaculture, with about 300 million fish being shipped annually around the country as "ayu seeds". Today Lake Biwa is the hub of Japan's ayu fishery industry.

Ayu sweetfish, *Plecoglossus altivelis* is a species distributed at latitudes up to 42° N in the Far East countries of *Japan, Taiwan, China, and Korea*. In 1989, the Japanese production of ayu sweetfish included 16,900 tons caught in rivers and lakes and 13,400 tons produced by aquaculture in manmade ponds, for a total of 30,300 tons. Among fresh water fishes, this production is second only to the 41,000 tons of eel produced in Japan. During the period of industrial growth following World War II, a number of species of fish disappeared from Japan's rivers and lakes. And while the aquaculture production of the two fish species which, like ayu sweetfish, have been a popular food for the Japanese since olden times, namely carp and eel has been large, their natural catch has reduced drastically. This has been due to factors such as the severing of rivers due to dam or dike construction, etc., the deterioration of water quality due to industrial wastes or sewage and excessive fishing by inland fisheries. In the case of ayu, too, the life environment has by no means improved. However, in the case of this fish species, the nationwide catch in lakes like Lake Biwa and other rivers and lakes has not decreased noticeably over the last dozen or so years.

What is the reason for this? It is because for many years efforts have been continued in Japan to maintain the natural production of its rivers through the transplant and release of young, as well as efforts by the culture centers to maintain the growth environment. Presently, large numbers of artificially hatched young are released in rivers throughout the country, an increasing number of which naturally hatched young are unable to ascend now due to the construction of dams, etc.

Ayu has long been a favorite fish of the Japanese. With its well-loved taste and aroma, it is considered the king of river fish from a culinary standpoint. Ayu is also characterized by the fact that a long familiarity with its mode of life and habits has led to the development of numerous fishing methods. In other words, the Japanese are as fond of catching ayu as they are of eating it.

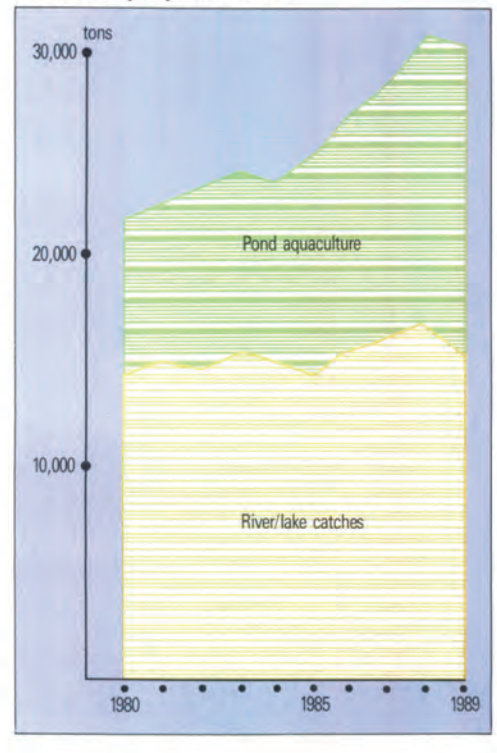
Ayu is a one-year fish with a life cycle that basically ends within one year. Mature fish have a body length of 25 ~ 30cm. They are born in the fall, grow to maturity in the middle stretches of rivers during the following summer and descend the rivers in the fall to lay their eggs in the sandy bottoms at the river mouth. The eggs hatch in the river waters and float with the flow out into the sea, where they spend the winter in the coastal waters. After being raised in the sea with its abundant food supply, the young begin to ascend rivers in the spring when the water becomes warmer. Almost all the parent fish die after spawning.

It should also be noted that there are inland groups of ayu that do not go down to the sea for spawning, but rather spend their entire life in lake waters. The koayu of Lake Biwa are a representative group of this inland type which only reaches a body length of 5 ~ 9cm. In the past it was believed by not only fishermen but by fishery biologists too, that the lake koayu were a different species from river ayu. In 1913, however, zoologist Chiyomatsu Ishikawa proved that the two were the same species by means of an experiment in which koayu from Lake Biwa were transplanted to the Tama River in the Kanto region and found to grow there to the same size as river ayu. Today, the koayu which grow every year in large numbers in Lake Biwa are an important resource used for both release-purpose and aquaculture-purpose fish seeds.

The case of ayu in Japan makes for a good example demonstrating the importance of maintaining production by means of resource propagation that suits the fish's mode of life and life environment.

In this issue we will introduce the overall structure of ayu fishery in Japan, and how its various parts are integrated into the whole.

FIG. 1: Ayu production



Traditional value and adaptability to the environment

According to the theory of specialists in the area, the ayu has probably evolved in the following way. During the geological period about 10 million years ago, the fish that was the evolutional predecessor to the smelt, *Osmerus eperlanus*, was living in the coastal waters or adjacent offshore waters of the northern Pacific. Entering the age of the recession of ice age glaciers, this fish began to extend its habitat along the shores of both the Asian and North American continents, repeating north-south migrations in accordance with warmings and coolings of the climate and, in the process, diversified into a number of varieties including shishamo smelt, *Srrinchus lanceolatus*, and pond smelt, *Hypomesus transpacificus*. Among these, the variety that demonstrated the greatest change through the evolutional process was the ayu sweetfish. The ayu left the open sea areas in favor of a closed river environment where they developed the habit of feeding on small algae growing on rocks in the riverbed and acquired a mode of life by which they laid their eggs on river conglomerates. Furthermore, they acquired a migration pattern, irrespective of the reproduction process, from a river out to the sea and then back to the river again.

Ayu sweetfish grow to a body length of 25～30cm (body weight: 75～90g) within 10～11 months, and reach sexual maturity at this time. After hatching, the fry enter sea waters where they feed primarily on *Copepoda* type zooplanktons, at times eating the larva of squids and bivalves, as well. By the time they approach the coasts to prepare for river ascent, their diet becomes more diverse, including attached algae and midges along with zooplanktons. By the time they begin their river ascent, they have also developed comb-like teeth on both their upper and lower jaws that enable them to pull out and eat algae such as *Cyanophyta* and *Bacillariophyceae* attached to the rocks on the river bottom. It is said that for normal growth, a young ayu with a body length of about 15cm needs to consume 20g of algae (wet weight) a day.

As an eater of algae, ayu occupies its own unique ecological niche in the lake/river food chain different from other fish feeding on aquatic insects. The reproductive capacity of ayu resources in rivers and lakes depends on the algae production capacity of the bottoms of the rivers and lakes. In other words, the systems which promote or inhibit the growth of these algae are the factors which determine ayu proliferation.

River ayu

Ayu make their habitat in both the rapids and pools of rivers. While rapids tend to be good for algae growth, they are not good as hiding or resting places. On the other hand, pools offer the ayu good protection from predators and good resting spots, but algae growth tends to be inferior. Therefore, the middle section of rivers, where wide sections of rapids alterate with deep pools make the best habitat for ayu.

Among freshwater fishes, ayu has an exceptionally good reproductive capacity. The reproductive capacity of a species can be expressed in terms of the total amount of growth that occurs for a group of that species over a given period of time (including losses through mortality or capture), and with fishes, a productivity rate of 100g/1 sq meter/year is rare. In the case of ayu it has been shown that the productivity rate in natural conditions ranges from a low of 10g/1 sq meter/year to a high of 400g/1 sq meter/year. [Based on the findings of Prof. Hiroya Kawanabe] It is understood that this outstanding growth capacity is due to the ayu's mode of life by which it feeds on the abundant nutrients of the sea environment in the fry stage and then ascends rivers at the season when productivity of the river algae reaches its height from spring into summer.

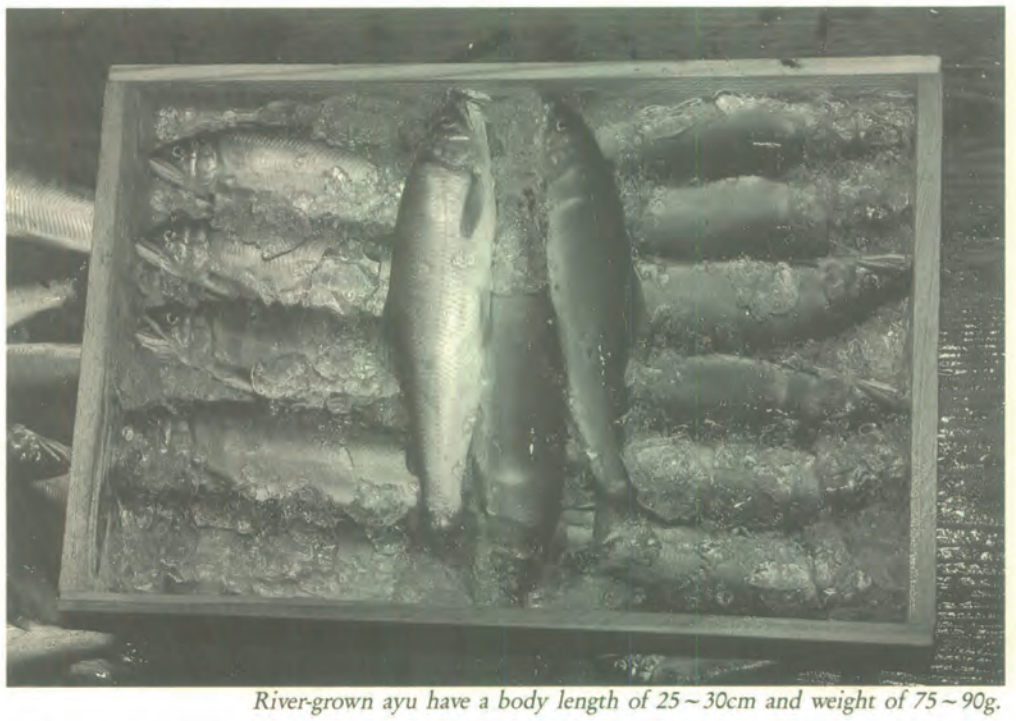
Because the ayu does not lose the abovementioned genetic qualities when it is the object of aquaculture in closed ponds, its productivity in terms of surface area far exceeds that of eel, rainbow trout or carp aquaculture. **(TABLE 1)**

River ayu are known for the fact that individuals defend a "territory" of their own. An individual will occupy a territory of about 1 sq. m. in a section of rapids and feed on the algae in that area, and will immediately attack any other individual that enters its territory.

Note: Japanese fishermen have developed a unique fishing method that makes use of this trait. A live ayu is attached to the fishing line and allowed to swim in the rapids. When another ayu attacks the bait ayu, it becomes caught on a hook attached to the tail part of the bait ayu. Every year some four to five million sport fishermen use this method, called "tomozuri" (decoy angling), to enjoy ayu fishing in the country's rivers.

TABLE 1: A comparison of aquaculture productivity (1989)

Species and culture type	Total area of culture facilities (1,000 m^2)	Annual production (tons)	Yield per 1 m^2 (kg)	Culture period (year)
■ Ayu	403	11,288	28.0	0.5
■ Trouts	1,266	15,804	12.5	1
■ Carps				
Flow-through pond type	383	1,893	4.9	1.5
Reservoir type	8,966	5,127	0.6	1.5
Net cage type	129	7,764	60.2	1.5
■ Eels				
Flow-through pond type	38	464	12.2	1～2
Still water pond type	9,119	33,835	3.7	1～2



River-grown ayu have a body length of 25～30cm and weight of 75～90g.

The density at which a given species of plant or animal inhabits a given area is closely related to that species' growth rate. How many ayu can inhabit a given river? Calculating the number of ayu that a given natural water area can support is very important for determining standards for the number of seed fish that should be released. The animal ecologist Denzaburo Miyaji spent three to four years studying the living conditions of ayu in several rivers in a certain region back in the mid 1950s. Based on the results of these field surveys, he came up with the following interesting deductions:

1) In cases where the population density is extremely low, all the ayu are found to be defending a territory of their own in the rapids and all the individuals are found to grow at the same rate. Since the algae growing on the rocks of one square meter of river bed are believed to be sufficient to support the growth of five ayu, the territory which a single individual defends represents a considerable "safety buffer".

2) When the population density increases and all potential area for territories in the rapids is taken, one sees the emergence of individuals without their own territory. These individuals are then chased out into the still pool areas of the river where they are able to get enough algae to support their growth by feeding over a larger area. In this case, as well, the individuals are all observed to show the same growth rate.

3) When the density increases further, a situation is observed in which some ayu have their own territories and some do not, and a corresponding difference in growth rate emerges. The resulting overpopulation of the schools of ayu gathered in the pools leads to an insufficient food supply. This causes the growth rate of the weaker ayu to deteriorate and the productivity of the population as a whole to decrease.

4) However, if the density increases even further, the territorial habit of the ayu collapses altogether. In other words, the constant invasion of the defended territories by the schools of unterritoried ayu puts so much pressure on the defenders that they quit the behavioral habit of defending a territory altogether and are absorbed into the schools. When the rapids are thus freed of territorial barriers, the ayu population is then able to take advantage of the full algae resources of the river as feed and, as a result, a rise in the average growth rate is observed once again. In such a case, the productive capacity of the river returns to the level of case 2.

The territorial habit observed in river ayu seems to be a rather unstable one in which no clear order exists among the individuals and there are often exchanges of roles between territory defenders and school members. Thus, it appears correct to believe that ayu possess two behavioral patterns, and that their "social structure" changes according to the population density.

Lake ayu

Ayu that spend their entire lives in lakes or reservoirs and do not migrate down to the sea are referred to as lake ayu. Like salmon and trout (*Salmonidae*) family fishes, ayu are a cyclical migrating fish, but changes in geographical features or other events that have served to cut them off from their routes to the sea, has led to the evolution of a landlocked fish character. Lake ayu exhibit several differences in transformation, growth and spawning characteristics compared to river ayu. Furthermore, lake ayu can be divided into several groups based on their habitat, river ascent and feeding characteristics. Generally speaking, they can be divided into two types; one that ascend the rivers running into the lake for a period and then return to the lake for spawning; and one that spawns near the lake shores and then, after hatching, heads out into the offshore waters of the lake where they migrate in search of food in the surface waters and grow up feeding on water flea and other zooplanktons. While the former group will grow to a body length of 25～30cm, the later will reach sexual maturity and spawn at a body length of 5～9cm.

* * *

River and lake ayu exhibit various differences in form and mode of life depending on their habitat. These differences represent the results of adaptations to environmental factors within their life history, and, taken as a whole, constitutes a history of the genealogical evolution of the species. The fish farming and aquaculture activities which humans undertake, represent attempts to enter the ayu's life environment and draw the maximum output from the productive capacity of the ayu as regulated by the life environment and the characteristics of the species. In undertaking such a task, it is the job of man to achieve both preservation of the natural environment and maintenance of a favorable breed.

(Note) This treatise is based on reference to the writings of Professors Denzaburo Miyaji and Hiroya Kawanabe.

The structure of ayu fishery in Japan

In Japan, inland fisheries on rivers and lakes are conducted on the basis of fishing rights granted by the prefectural governors to cooperative organizations such as fishery cooperatives for the purpose of conducting commercial fishery. In particular, Japanese national law provides that the govenors should grant such rights in the case of water areas especially suited to the proliferation of fishery objects, or to fishery cooperatives that promise to ensure the proliferation of the aquatic plants or animals that are the subject of their fishery. Furthermore, each prefecture and municipality has an inland fishery management committee that makes regular plans for the control of fish farming and catching activities.

The system by which Japanese ayu fishery operates is shown in **FIG. 2** and **FIG. 3**. In Japan, transplant release has made an important contribution to the maintenance of ayu resources. While this is of course true for rivers, there are also numerous cases in which eggs or fry transplanted to lakes and reservoirs have resulted in the successful propagation of koayu. Due to the deterioration of water quality in river mouth areas that are the spawning ground for ayu and the severing of rivers by dam construction, transplant release has become an essential method for maintaining ayu resources. There are three types of seed fish used in resource propagation and pond aquaculture; (1) lake-born ayu, (2) sea-born ayu, and (3) artificially hatched seeds.

Lake-born ayu: The use of lake-born ayu as seeds spread to the various regions of Japan beginning about the year 1921. Land locked type ayu are distributed in natural and artificial lakes throughout Japan, but by far the largest resources and the largest volume of seeds gathered are those of Lake Biwa. The ayu seeds harvested from Lake Biwa are supplied to cities throughout the country. Lake ayu from other lakes around the country are used as seeds for local consumption.

Sea-born ayu: In the spring, when the ayu fry approach the coast or inner bay areas, they are caught with boat seine. Or, as they begin to ascend the rivers they are caught at the river mouth by means of weir fish traps or set net. In recent years, the annual catch of sea-born ayu is about 29 million fish, with Shizuoka, Wakayama, Tokushima and Miyazaki being the primary producing prefectures.

FIG. 2: River ayu and lake ayu

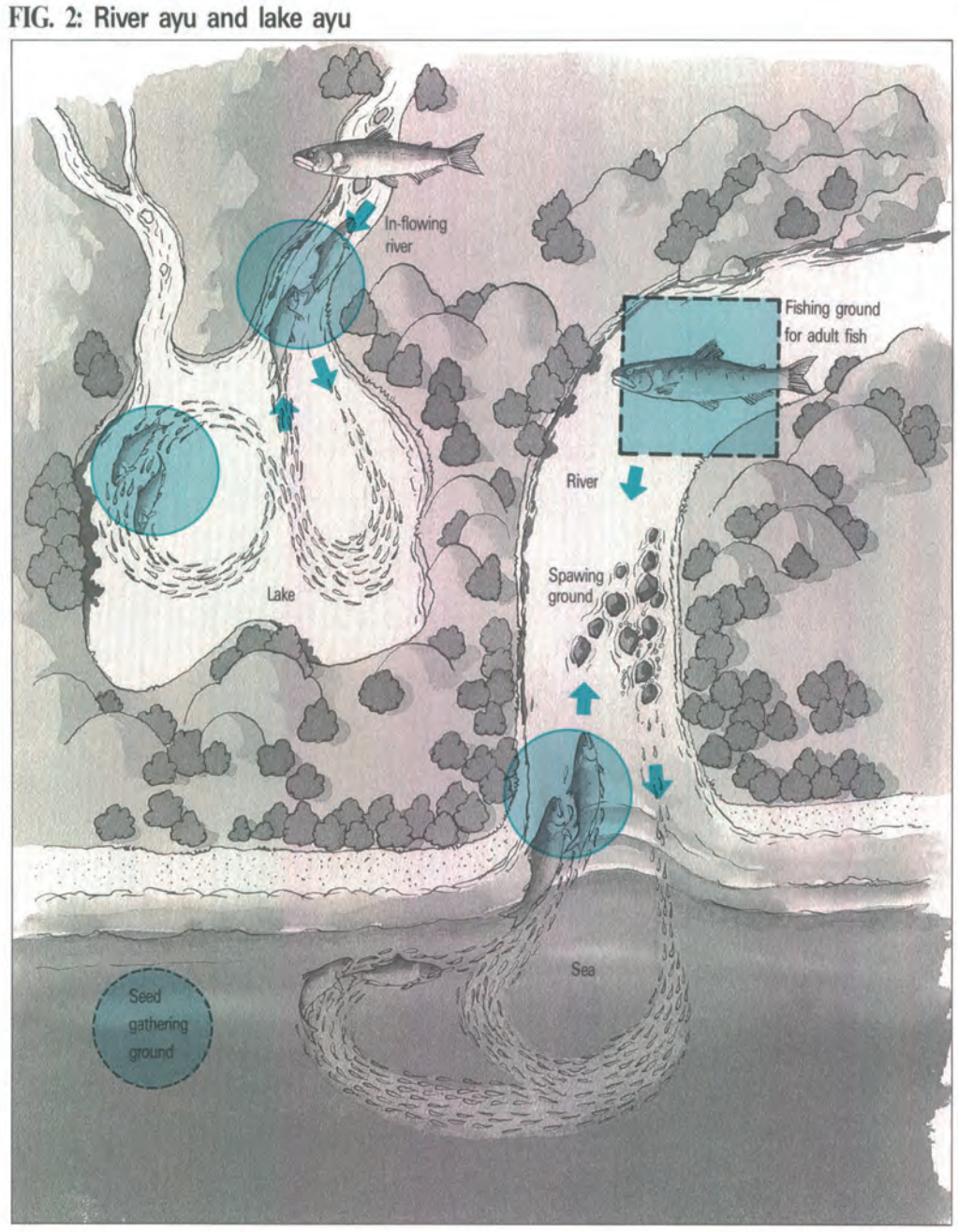
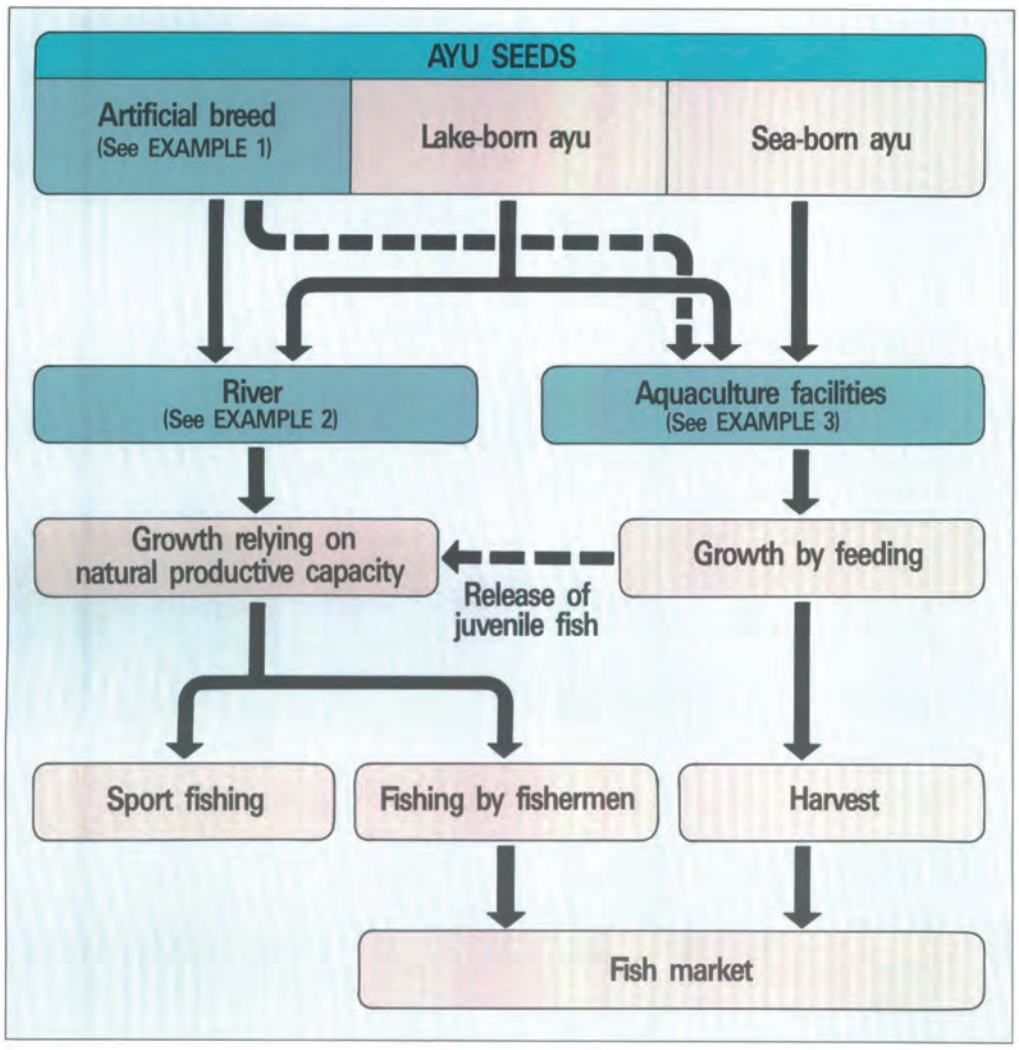


FIG. 3: The structure of ayu fishery in Japan



See fish being released in a river.

Artificially hatched seeds: Artificial hatching of ayu was first attempted by a number of fishery researchers around 1920. However, it wasn't until after World War II that the techniques for seed production became fully established. The three basic conditions that must be met for successful artificial hatching of eggs and rearing of the young include: (i) securing parent fish from which fully mature eggs can be obtained, (ii) development of suitable feeds for the fry stage, (iii) maintaining a culture pond with suitable water temperature and water quality. From the 1950's into the 1960's, solutions were found for these different problems at the various research laboratories, making it possible for full scale seed production to get under way. In particular, Professor Takashi Ito of Mie University proved that the small zooplanktons "tsubowamushi" were the best suited feed and proceeded to develop both the techniques for raising them and proper feeding methods. These developments subsequently led to a dramatic increase in seed production.

Fishery production for ayu is divided into two branches, one which depends on the natural productive capacity of the rivers and another supported by feeding-type aquaculture in culture ponds. With regard to the former, sport fishermen have accounted for a considerable percentage of the total catch in recent years. The catch by commercial fishermen specializing in ayu is becoming limited to a few specific rivers such as the Nagara River (Gifu Pref.) and the Shimanto River (Kochi Pref). At present there are no official statistics regarding the division of river ayu catch between sport fishermen and commercial fishermen. A part of the catch by sport fishermen is brought up by middlemen called "Yoseya" who, in turn, ship the catch to market. The majority, however, goes for the fishermen's own home consumption. Market shipments of ayu by commercial fishery come as two types of products; those caught by commercial fishery and those produced by the ayu aquaculture industry.

The number of sport fishermen fishing on Japan's rivers is presently estimated to stand at about 10 million. The primary fish caught by these fishermen is ayu, and a fishery census in 1988 concluded that ayu fishermen account for 47% of all sport fishermen, or a total of about 5.17 million. This figure is followed by 1.56 million (14%) fishermen fishing for carp, 1.48 million (13%) crucian carp and 1.43 million (13%) trout. Ayu fishing is exceptionally popular and it is characterized by a solid following of devout "tomozuri" enthusiasts.

The river fishery cooperative associations which hold the fishing rights for the various regional rivers, release seed fish into the rivers at their own expense and, in turn, charge sport fishermen a fishing fee which then becomes income for the cooperatives. The cooperatives set regulations on fishing season, fishing gear and methods, etc., and in general take responsibility for maintenance and supervision of the fishing grounds.

The number of seeds to be released is decided through experience each year, with consideration for the previous year's catch and the increase or decrease in the number of sport fishermen. As ayu fishery gains popularity each year as an outdoor sport in which people can enjoy the natural river setting, the number of seeds being released annually also continues to increase. In 1988, a total of 250 million seed fish were released nationwide. And, besides this initial release, additional releases of juvenile ayu reared in aquaculture facilities are also made in the summer to meet demand from sport fishermen.

Because sport fishing in inland water areas is considered to be not only a leisure industry that contributes to the economies of mountain areas but is also actively promoted as a means of environmental preservation through the maintenance of fish resources, it is likely that sport fishing will continue to be an important aspect of inland water fishery policy. And, as a result, we are likely to see the role of the river fishery cooperative associations shift more and more from that of fishery producers to that of managers of fishing rights, maintainers of fishery resources and to the social role of instructors in the rules of good sportsmanship in river fishing.

EXAMPLE 1

Lake Biwa (Shiga Prefecture)

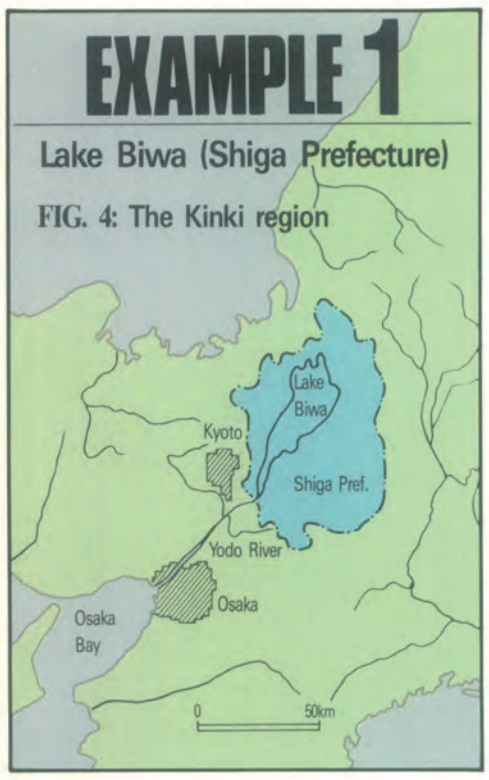


FIG. 4: The Kinki region

Making the lake a 'resource cultivation pool' by means of artificial rivers

Lying roughly in the center of the Japanese archipelago, Lake Biwa is the country's largest freshwater lake. Having a surface area of 674 square kilometers, a circumference of 235 km, a maximum depth of 104 meters and a water volume of about 27.5 billion tons, an annual volume of some 5.3 billion tons flows out of the lake via the Yodo River to empty into Osaka Bay.

It is estimated that Lake Biwa was formed between 4.5 and 5 million years ago, making it the third oldest lake in the world after Lake Baikal and the Caspian Sea. It contains a variety of natural environments and life forms. A survey in 1973 identified 52 species of fish, 43 species of shellfish and five species of crustaceans living in the lake. Among these, some 30 species are caught as fishery products.

Since ancient times, Lake Biwa has benefitted man in a number of different ways. First of all, Lake Biwa and the rivers flowing into it have supported the growth of fishery, with fan-shaped areas and triangular-shaped deltas around the lake shores. Furthermore, in modern times it has come to serve as the urban water supply for the downstream cities of Kyoto (pop: 1.47 million) and Osaka (pop: 2.55 million).

Since 1972, a government program has made the lake the object of an ongoing Lake Biwa Consolidated Development Project, aimed at environmental preservation, river improvement and water resource development. After almost 20 years, the project is nearing completion. The results of the project will include an estimated 1.5 meter drop in the lake's water level that is expected to cause changes in the lake's fishery resources. The use of artificial rivers to promote resource propagation for ayu that we will introduce here, is one of the measures intended to deal with these changes in the lake environment.

Lake Biwa fisheries

Fisheries developed for the various marine animals on the waters of Lake Biwa and the rivers flowing into it. These fisheries are characterized by the fact that small quantities of the different aquatic products are produced in the respective seasons and the small scale of the fishery operations. The representative fishing techniques include large-scale brush weir fish traps called 'eri' set in the lake's surface waters and small weir traps called 'yana' set in the mouths of the rivers. In addition, gill net and boat seine are also used. The mid-1960s also saw the emergence of increasingly larger motorized FRP fishing boats and a subsequent shift to mechanized boat seine fishing techniques.

Furthermore, lake water or subterranean water supplies are used in certain parts of the lake for the aquaculture of ayu, trout, carp and freshwater pearl or mother oysters for pearl culture.

The fisheries of Lake Biwa can be divided roughly into ① lake surface fishery, ② river fishery. ③ aquaculture of fishes and ④ culture of pearls or mother oysters for pearling, and the product value of these fisheries by category for the year 1988 are shown in **FIG. 5**. And, the catches of these different fisheries are marketed as the following types of products.

1) Common consumption fish ... sold primarily within the prefecture as household dishes (koayu, cruscian carp, goby. willow gudgeon, carp, etc.)

2) Quality fish ... sold widely to the markets of Kyoto, Osaka, Kobe, etc. (ayu, shrimp, trout, etc.)

3) Fish for processed foods ... products processed locally into tsukudani, nare sushi, etc. are marketed over a large area

4) Ayu seed fish ... seeds for release or use as aquaculture seeds are sold nationwide

5) Export products ... pearls

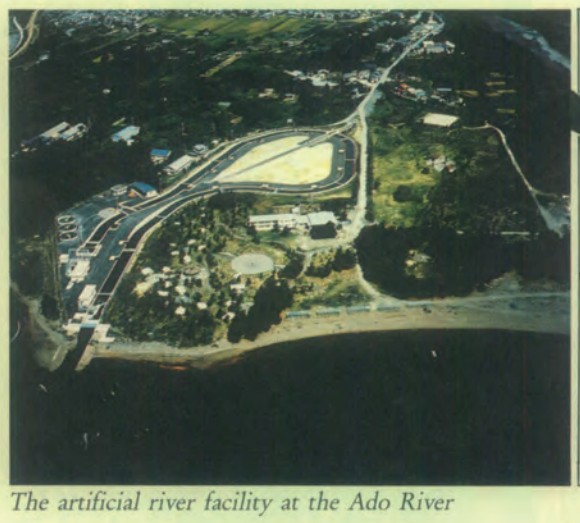
Traditionally, fish and shellfish from the lake have been processed into a variety of processed aquatic products unique to the Lake Biwa area, and these products have constituted a significant local industry contributing to the prefectural economy. However, in recent years, sales of ayu seed fish and fresh adult fish have become the leading products of the lake's fishery industry. In 1988 the total production of ayu from the lake waters, rivers and aquaculture farms was 2,996 tons, with a market value of 3.8 billion yen. This represents 50% of the total fishery production from Lake Biwa in terms of volume and 58% in terms of market value. **(TABLE 2)**

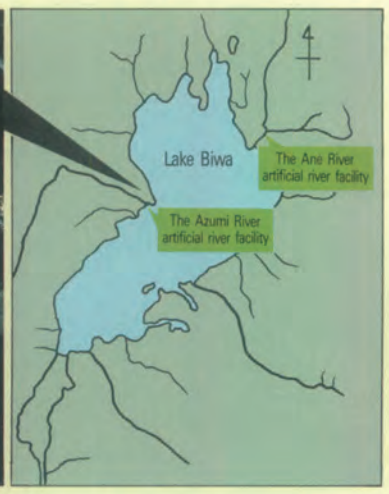
TABLE 2: Shiga Prefecture ayu fishery production in 1988

Fishery	Product	Catch (in tons)	Value (in ¥mil.)
Lake fisheries	hiuo & koayu	1,065	373
Lake fisheries	ayu seeds	733	2,118
River fisheries	ayu (fresh)	258	90
Aquaculture	ayu (fresh)	940	1,253
Subtotal (A)		2,996	3,834
Total fishery production (B)		5,973	6,600
A/B×100		50%	58%

Ayu fish farming

Up until now, several programs have been attempted to promote the propagation of ayu resources in Lake Biwa. These have included prohibiting fishing during the spawning season, release of eggs and fry and also the cultivating of natural spawning grounds. Cultivating means in fact the preservation of spawning grounds. When spawning grounds are left as they are for long periods of time, fine sands fill in the spaces between the pebbles on the bottom and a layer of silt forms over this bed, which can cause moss to grow in profusion.





The artificial river facility at the Ado River

Parent fish culture ponds. Light poles surround each pond for nighttime lighting.

A water supply mixing trough

A spawning bed

A screen

Fry that have hatched and descended the river (specimen preserved in formalin)

A weir trap

A dead fish removal device

Lake side view

AYU SWEETFISH CULTURE IN JAPAN

Tilling the lake bottom with an agricultural cultivator exposes the pebbles once again and returns the bottom to a condition favorable as a spawning environment.
In conjunction with the Lake Biwa Consolidated Development Project, a large-scale ayu fish farming project was undertaken in 1981. This project involved the construction of artificial rivers for the purpose of resource propagation. Today, this method constitutes the nucleus of resource propagation activities for ayu in Lake Biwa. Here we will introduce the details of this method.
Because it was forecast that water resource development in the lake would lower the water level and cause changes in the lake and a drying out of the shore areas that would interfere with the ayu's ability to ascend its native rivers, in 1973 the Shiga Prefectural Fisheries Experimental Station undertook the construction of an artificial river and commenced research and experimentation concerning ayu river ascent. From this research the following facts were revealed:
•By running water into the lake through an artificial river, parent ayu in the lake can be induced to ascend the river.
•The parent fish that ascend the artificial river can be caught and introduced to a culture pond where their sexual maturity can be controlled by the nighttime use of electric lighting.
•A production rate of 1 million eggs per square meter, or ten times that of a natural river, can be expected from the artificial river spawning ground.
•The hatching rate of eggs in the artificial river is about 90%, making it considerably higher than the 60% rate in natural rivers.
•By planning the spawning period of the parent fish, three spawnings and hatchings can be achieved a year.
In the years 1979 ~ 1980, two artificial rivers were built by the prefecture; one at the mouth of the Ane River and the other at the mouth of the Ado River. Operations were then begun at these facilities in 1981. The rivers are built in a closed "U" shape with the following dimensions:
Ane River facility: 7.7 meters in width, 653 meters in length
Ado River facility: 4.5 meters in width, 230 meters in length
The artificial rivers consist of **1)** a water supply pipeline, **2)** a mixing trough for the water supply, **3)** a spawning bed, **4)** an ascent waterway and **5)** a weir trap, plus support facilities that include **6)** a pumping station, **7)** a rearing pond for parent fish, **8)** a screen, **9)** a device for retrieving dead fish and **10)** a fish return.
1) Water supply pipeline ... In order to enable an intake of precise amounts of cold and warm water, the pipeline is built with two intakes; one at a depth of 20 meters and the other at 5 meters.
2) Mixing trough ... Here, the water from the two intakes is mixed to the ideal temperature for ayu spawning activities, 18°C.
3) Spawning bed ... The bed is spread with a 20cm layer of 5 ~ 25mm diameter pebbles and covered with water to a depth of 20cm. The water flow across the bed is maintained at 50cm/sec. Also, a net is strung across the bed to prevent birds from feeding on the eggs.
4) Ascent waterway ... Water is flushed down the graded waterway to induce parent fish to ascend.
5) Weir trap ... This trap is used for catching the fish that ascend the waterway. Selection also takes place here, with sexually mature fish being moved to the spawning bed and semi-mature fish to the parent rearing pond.
6) Pump station ... Five pumps are used in sequence to pump up 0.8 tons of water per second.
7) Parent fish rearing pond ... To control sexual maturation, the pond is lighted at night.
8) Screen ... To prevent overcrowding, the spawning bed is divided into several sections by means of screens.
9) Dead fish removal device ... The fish that die after spawning float down to a net where they are scooped up automatically and sent to the drying facility to be made into fish meal.
10) Fish return ... A water cut-off mechanism is included to prevent fish that would feed on the ayu eggs from ascending to the spawning bed.

Beginning in August, water is run down the artificial river three times.
Each spawning and subsequent hatching requires 10 ~ 20 days, after which the fry ride naturally down the current when water is flushed down the river and out into the lake where they find food and commence growth. At present, two artificial rivers on the lake produce an annual total of seven billion fish (equivalent to 300 tons at the time of seed gathering).
This constitutes some 70% of the nationwide demand for ayu seed fish.
The project facilities were built with funds provided by the prefecture.
Management is carried out by a joint enterprize of the prefecture's Federation of Fishery Cooperatives and the prefecture's Federation of Ayu Seed Fisheries. The cost of running the release enterprize is paid for by the members of the respective fishery cooperatives who profit from the catch of seeds.

The ayu catch

Every year in Nov. ~ Dec. the fishermen of Lake Biwa catch young 'hiuo' ayu with a body length of 2 ~ 3cm. Then, from Mar. to Jul. they catch 'koayu' with a body length of 5 ~ 9cm. Both of these catches are used either as (1) fresh fish or material for processed foods, or (2) shipped live as seed fish. Since the market value of the latter is higher, a larger percentage of the catch is being used as seed fish in recent years.
The ayu are caught by traditional methods that include weir trap, four-armed dip-net, "eri" fish trap or chase-in scoop net. Also, since ten years ago, boat seine operations

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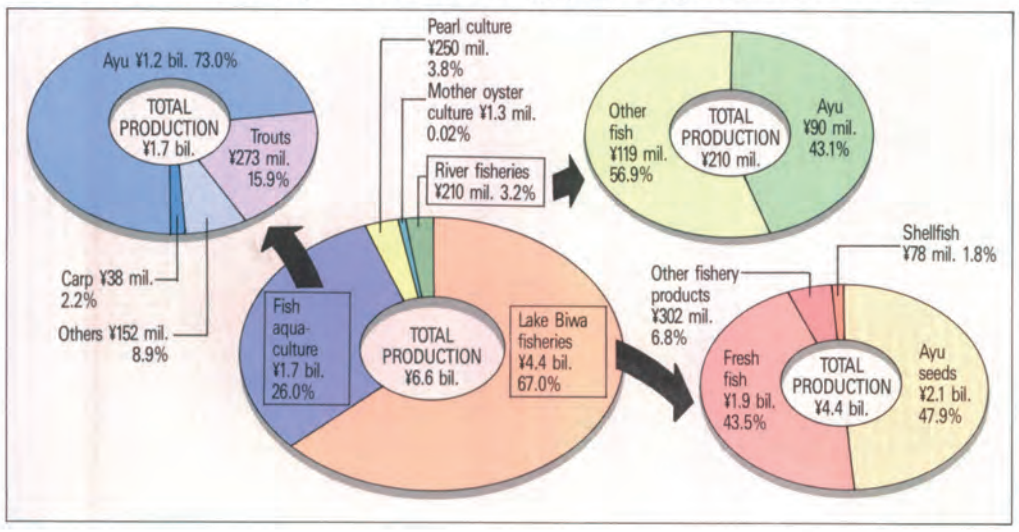
FIG. 5: Value of fishery production by category for Shiga Prefecture in 1988



FISHING METHODS FOR CATCHING AYU

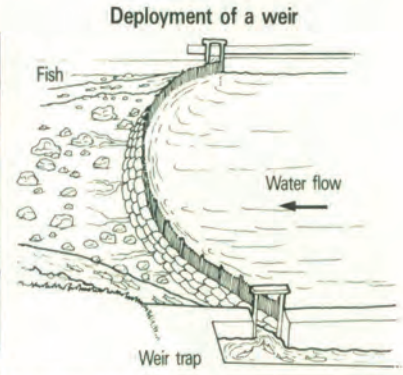
1. WEIR TRAP

There are two types of weir net; one for catching fish as they descend a river, and the other for catching ascending fish. In the case of ayu, the later type is used. Various different configurations have been devised for weir traps but basically they all consist of a wall to cut off the river and a trap section where the fish are forced together and caught in a concentrated area.

Weir trap device (A)

Weir trap device (B)

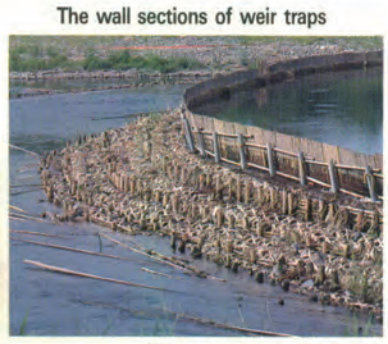
Deployment of a weir



Correcting fish at a trap

The wall sections of weir traps

Over view



Weir part

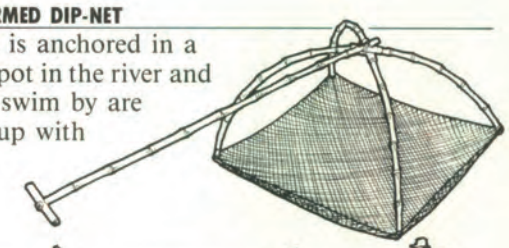
Weir part

2. ERI (BRUSH WEIR) FISH TRAP

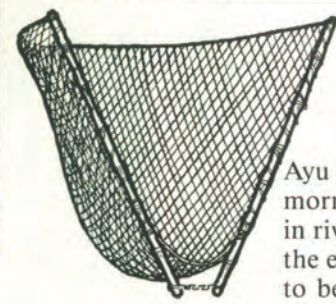
A leader fence cuts off the migrating route of the fish along the lake shore and leads them into the body fence. The fish are then forced into the bag nets at either end and caught. In the past these traps were built of bamboo and bamboo branches, but in about 1970 the introduction of new materials including FRP support poles with vinyl chloride draining board or synthetic fiber netting made it possible to expand fishing grounds to rougher waters or deeper sections of shore.

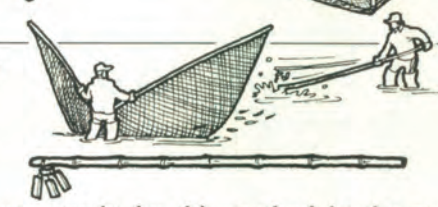
3. FOUR-ARMED DIP-NET

The boat is anchored in a shallow spot in the river and fish that swim by are scooped up with the net.



4. CHASE-IN SCOOP NET





Ayu are caught by this method in the early morning in shallow areas along lake shores or in rivers. A pole with bird feathers attached to the end is used to score the fish toward the net to be scooped up.

Continued from previous pages

using motorized boats have been allowed during the month of February.
Up until the 1970s, only koayu were caught for use as seed fish. But, when the artificial rivers went into operation in the 1980s, guaranteeing a stable supply of seed fish, catches of early hiuo began to be made as well. As diversification emerged in the seed fish supply, systems of planned seed production involving selection, holding and feeding began to take shape. Today, the ayu seed fish supplied from Lake Biwa can be divided into the three following types:
1) Seeds placed in a holding pond for 2~3 days after catching and shipped after selection.
2) Seeds kept in the holding pond for about 10 days after catching and then shipped.
3) Seeds put in a holding pond after catching and fed there for an intermediate rearing period of 1~2 months before being shipped.

Fishery development policy for the future

At present, the fisheries of Lake Biwa are showing a stable production, with ayu as their main product. However, allowing the production of a certain fish to become disproportionately large can threaten the structure of the ecosystem of the lake environment and, at the same time, can also invite a collapse in market price for that fish. In light of these factors, the fishery agencies of Shiga Prefecture have made the propagation of resources of other species besides ayu an important item in their fishery development policies for the future. In particular, species inherent to Lake Biwa like willow gudgeon, *Gnathopogon elongatus,* Cursian carp, *Carassius auratus grandoculis* and a freshwater clam, *Corbicula sandai* are among the candidates being considered. All of these are important products for consumption as fresh fish or as material for processed foods, and all used to be caught here in large quantities. However, all have suffered the same relentless decrease in abundance as a result of landfill projects along the lake shores and other types of development.
When utilizing the natural productive capacity of a lake to increase fishery resources, it is important to tackle the problem of environmental preservation from an ecological standpoint. As a part of these efforts, fishery researchers and fishery agency officials are planning the construction and restoration of reed beds along the lake shores. In the past, plants like reeds, water oats and cattails, grew in the marshy areas along the lake shores in stands that covered large areas. These stands served not only as the spawning grounds and infant rearing grounds for fishes, but also the place where the organisms they fed on proliferated and a place to hide from predators. Furthermore, they functioned as a filtering system that helped maintain the lake's water quality. Fishery authorities here on Lake Biwa believe that future promotion of fisheries must be based on integrated programs for the use and control of fishery resources within the context of overall environmental preservation.

EXAMPLE 2

Nagara River (Gifu Prefecture)

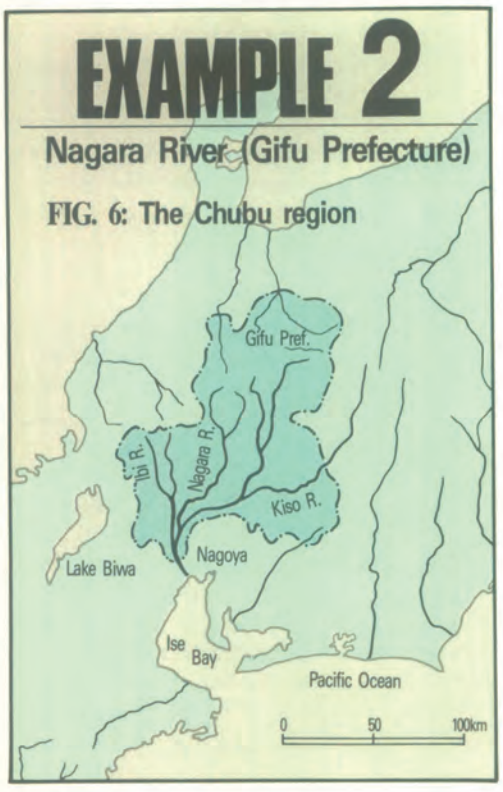


FIG. 6: The Chubu region

River productivity and the popularity of sport fishing support the 'prefectural fish'

The Gifu Prefectural Fishery Development Department conducts ongoing surveys of the growth conditions of bottom algae at specified points along the Nagara River.

TABLE 3 : Changes in numbers of sport fishing licenses sold unit: one license

year	ayu		assorted fishes		total	
	season license	day license	season license	day license	season license	day license
1975	25,411	66,826	13,323	49,955	38,734	116,781
1980	31,753	88,167	14,851	74,278	46,604	162,445
1985	39,706	110,902	16,148	81,299	55,854	192,201
1986	38,459	107,777	18,455	82,942	56,914	190,719
1987	41,518	122,135	19,170	69,683	60,688	191,818
1988	42,958	114,227	19,608	64,362	62,566	178,589
'88/'75	1.71	1.71	1.44	1.29	1.62	1.53
'88/'80	1.35	1.30	1.32	0.87	1.34	1.10

Source: Study of River Fishery Movements (Gifu Prefectural Bureau of Agriculture and Fishery, Fishery Development Section)

Gifu is a landlocked prefecture with forest land accounting for 82% of its total area. A chain of high mountains runs through the northern and eastern parts of the prefecture, while the southern part spreads out into a wide plain. An abundant water supply from the mountains feeds six river systems, three of which flow to the Japan Sea and three to the Pacific Ocean.
Various types of traditional fisheries have been conducted in these rivers since olden times, the main objects of which are ayu, dwarf nill trout, landlocked salmon, carp and crucian carp. Of these, ayu accounts for the largest annual catch for any prefecture, with 1,607 tons in 1988, representing 9.2% of the national total of 17,388 tons. The rivers with the highest productivity are the Nagara River with 960 tons, the Kiso River with 305 tons and the Ibi River with 196 tons. All three of these rivers empty into the Ise Bay on the Pacific Ocean side. In terms of volume, ayu accounts for 40% of the catch for river fisheries in Gifu Prefecture, while in terms of market value ayu accounts for 70%, making it the single most important fish.
In Gifu, the ayu has been given official status as the "prefectural fish". This fact is not only a recognition of the economic contribution of ayu fishery in the prefecture, but also a recognition of the ayu's importance as a valuable tourism resource that attracts large numbers of tourists and sport fishermen to the prefecture's rivers. On the lower stretches of the Nagara River there is a type of fishery in which boats go out on the river at night with a fire grate out over the bow to light the water and cormorants on lines are used to catch ayu. This is a traditional fishery that was introduced from China about 1,000 years ago, and today is performed primarily as a show for tourists. Here in Gifu it has become a nationally famous tourist attraction that draws about 250,000 tourists a year.
In Gifu Prefecture today, there are 63,000 members registered with the 33 local river fishery cooperatives, but most of them are only part-time fishermen who do not depend on fishery as their primary source of income. Only a few hundred actually make fishing their profession. On the other hand, the prefecture's sport fisherman population is estimated to be about 820,000. The overall number of sport fishermen is on the increase, especially the number of ayu fishermen, which presently stands at about 470,000. The local fishery cooperatives sell fishing licenses to these sport fishermen, and the numbers of licenses sold are shown in **TABLE 3**.
Every year the prefecture releases seed fish of the 14 major species, including ayu, drawf nill trout, mountain trout, carp and crucian carp. The cost of these release operations totaled ¥577 million for the year 1988. By species, the volume of seeds released was 116 tons for ayu, 38 tons for carp, 11 tons for crucian carp, 4.38 million fish for dwarf nill trout and landlocked salmon and 540,000 fish for mountain trout. The present trend is toward an increase in the number of seeds released for all species, but with the exception of ayu the increases are slight. The limited nature of these increases can be explained by a de-

A scene along the lower stretches of the Nagara River. Tourist hotels line the far shore of the river, and in the foreground are seen river boats that take tourists out to watch the cormorant fishing.

terioration of the natural environment and an overall lack of interest in increasing fishery production on the part of both the professional and the sport fishermen. In the case of ayu, however, the high reproductive capacity of the species itself and its strong popularity as a catch have supported a state of continued growth.

The Nagara River, Kiso River and Ibi River are three important rivers that account for 90% of the prefecture's ayu catch. Due to the construction of dams, however, an increasing portion of these rivers can no longer be ascended by the ayu. The following table shows the present status of these rivers:

TABLE 4 : Natural ayu ascent

	lower stretches	middle stretches	upper stretches
Nagara River	passable	passable	passable
Kiso River	passable	not passable	not passable
Ibi River	passable	passable	not passable

Even in the case of the last natural river, the Nagara River, there are plans to build a breakwall at the river mouth by 1995 that is expected to have a big effect on the ascent of natural ayu. In 1965, between 10 and 20 million ayu (60-120 tons) ascended the rivers of Gifu Prefecture. Today, the equivalent of that number, some 60～120 tons of seed fish are released in the rivers annually. Twenty percent of this seed demand is supplied by the Gifu Prefectural Fish Seed Center. For the remaining 80%, the prefecture relies on lake ayu from Lake Biwa. Since about 1980, the supply from the Center has been stable, in terms of both quality and quantity.

The ayu production of the Nagara and other rivers in Gifu Prefecture remains stable at present. However, according to the observations of professional ayu fishermen who have fished the Nagara River for many years, the ayu up until about ten years ago tended to have a round trunk and an average length of 30～35cm, while today's ayu seem to have a flatter trunk and a shorter body length. Whether this change is a result of crossbreeding between natural river ayu and lake ayu or a result of changes in population density due to release practices, remains a question for future research.

Professional fishermen catch ayu primarily with gillnet. The nets come in two types; bottom gillnet and floating drift-gillnet. The photo shows the operation of a bottom gillnet performed at night. The net is strung out perpendicular to the current and while shining a light on the water surface the fish are chased into the net by beating on the side of the boat with a pole.

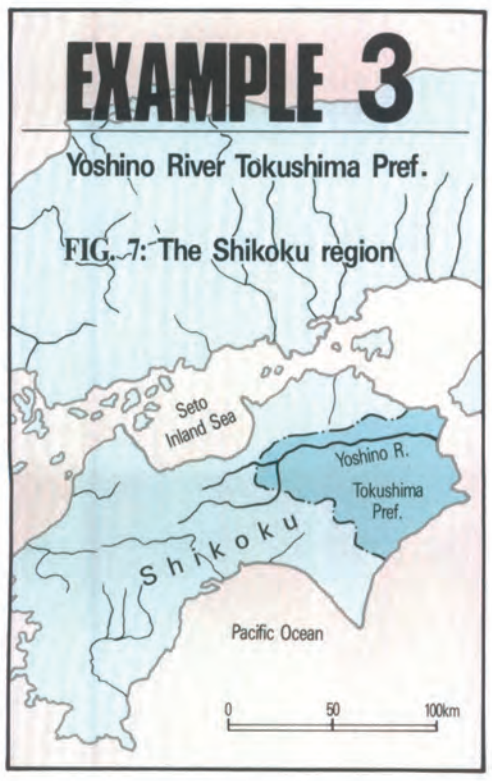


FIG. 7: The Shikoku region

Pond aquaculture approaching maturity as an industry

Pond aquaculture of ayu is a fishery that has a long history. But, it was not until the 1960s that, spurred by the high national economic growth rate, it began to develop toward a mass-production industry. The percentage of Japan's national ayu production made up by cultured ayu grew suddenly from a mere 2% in 1960 to 35% in 1980 and 44% in 1989.

Ayu aquaculture is conducted in virtually all parts of Japan with the exception of Hokkaido and Okinawa, the country's northernmost and southernmost islands respectively. The main producing prefectures are Tokushima, Wakayama, Shizuoka, Shiga and Tochigi. Among these, Tokushima boasts the most active industry, shipping a total of 5,079 tons in 1989 to account for 38% of the national culture production.

At first, cultured ayu were considered no more than a substitute product to fill in for shortages in the natural ayu production. But, with improvements in aquaculture technology, the product value has gradually improved to the point where, now, it seems to have established a product category all its own. Also, as the production volume has increased, a larger portion of the production is being freeze-processed, making it a product that can be kept for long periods of time. As a result, ayu is beginning to emerge from under its image as a seasonal fish to one that can be supplied yearround. Here, let us examine the present status of ayu aquaculture in the prefecture with the largest production, Tokushima.

The background behind development as an industry

Ayu aquaculture got its start in Tokushima Prefecture in about 1963, when a few fishermen from the Naka River valley of central Tokushima acquired sea-born ayu seeds to make an attempt at ayu aquaculture. As their efforts began to prove successful, they were imitated by another group of operators on the Yoshino River in the northern part of the prefecture. This group consisted not of fishermen, but of farmers who converted portions of their rice paddy fields into aquaculture ponds. The Yoshino River flows through a fan-shaped valley bordered on two sides by high ranges of mountains. It has the largest valley in the prefecture and is blessed with an abundant supply of river area and vadose waters.

Furthermore, it has a relatively warm water supply that ranges between 18～23°C for almost the entire year.

Thanks to the large amounts of land owned by these operators and the abundant water supply available, ayu aquaculture was able to develop very rapidly here. Of the roughly 60 ayu aquaculture operations in Tokushima, 20 operate in the Yoshino River valley, and their production accounts for roughly half of that for the entire prefecture.

Although Tokushima was rather late in entering the ayu aquaculture industry, in order to overcome the handicap of having only sea-route access to Osaka, the largest consumer market in Western Japan, it was one of the first to organize cooperatives of culture operators for the purpose of making joint shipments of their goods to market. This enabled the members to create a system capable of standardizing its products and planning its shipments advantageously, making early shipments at times of high market price. This organization enabled them also to expand their sales routes as they became the first to make shipments to Tokyo, Japan's largest market, as early as 1965.

Seed fish

In the early stages of their development, operations here in Tokushima used ayu seeds caught at the mouth of the Naka River, but as the scale of culture production grew, an increasingly large portion of the seed demand was filled with Lake Biwa ayu. In recent years seeds from the prefectural fish seed center are also being used.

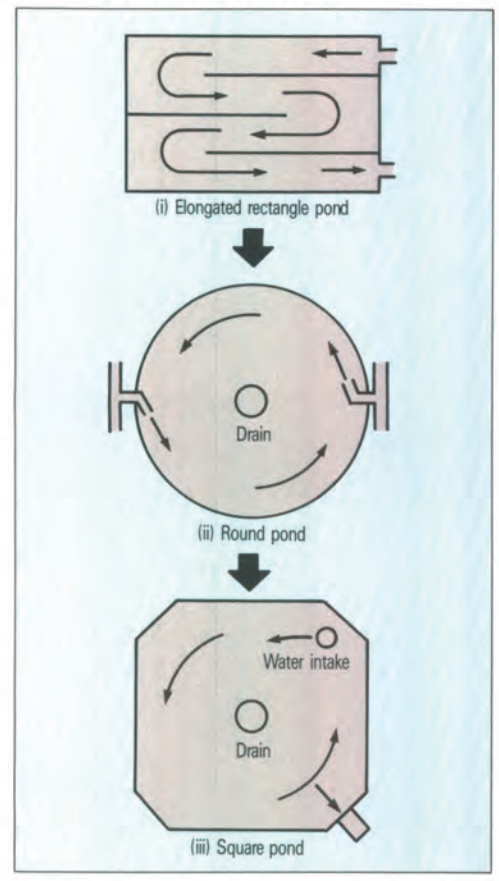
At present, 90% of the ayu seeds come from Lake Biwa, 5% from catches of sea-born ayu and 5% are artificially hatched seeds.

The water and the ponds

Ayu are reared in flowing water. Three types of water are used; river water, lake water and underground water. Generally, in order to control water temperature and also ensure a sufficient volume of water, the water supply is made up of a combination of either underground water and river water or underground water and lake water.

The water temperature range at which ayu culture is possible is 13～30°, but the preferred range is 15～25°. And, considering the fact that ayu feed most actively and grow fastest at a temperature range of 20～25°, it is preferable that the pond water temperature climb above 20 ° in the summer months. In order to maintain water quality and ensure a sufficient supply of suspended oxygen, it is necessary to supply enough water for a complete exchange of the pond water once or twice every hour. Normally, the used water is filtered and then recirculated through the pond, and aeration is performed by means of water wheels in the ponds.

FIG. 8: Development of ayu aquaculture pond shapes (Tokushima)



The shape of a culture pond is a problem closely related to the way the water is used. In Tokushima, the shape of the culture ponds has evolved through the progession shown in **FIG. 8**. The elongated rectangle shape (i) proved infeasible because leftover feed and other debris tend to accumulate in the corners where the water flow stagnates. The round-shaped pond (ii), with the water supply introduced at an angle to create a circular flow to match the shape of the pond, eliminated the areas of stagnation and increased productivity by making effective use of 100% of the pond area. Also, the fact that the water is always flowing, forces the fish to swim, thus stimulating their feeding instinct and increasing growth rate. However, there is one serious disadvantage to the round-shaped pond: when a large number of round ponds are laid out in rows on a limited area of land, a lot of unused space is created. In other words, it makes for inefficient land use.

For this reason, operators today have adopted a format in which square-shaped ponds are built in closely grouped rows **(FIG. 9)**. The four corners of the square are cut off to eliminate stagnant areas while creating eddies which give the fish a place to rest. The ponds are built 1~1.2 meters deep and are filled with 70~80cm of water. Both the bottom and sides of the ponds are lined with concrete, and the bottom is given an inward slope of about 3/100 in order to draw debris and leftover feed toward the central drain. **(FIG. 10)**

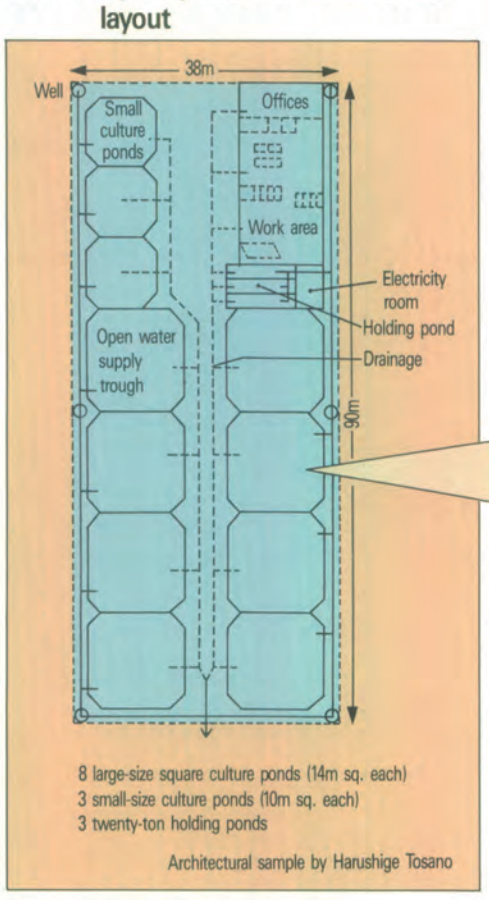
Feed

As we have seen earlier, during their life history natural ayu progress from feeding on animals to herbivorous feeding. However, Lake Biwa ayu are known for the fact that throughout their life they feed on both zoo- and phyto-planktons. This implies that ayu is a species with a high degree of environmental adaptability and the ability to adjust to a wide range of foods.

In the early stages of ayu aquaculture in the 1960s, fresh minced meat of fish like horse mackerel, sardine and sand launce was mixed with flour of wheat or other grains and fed to the fish. Later, however, composite feeds with fish meal and flour as their main ingredients were developed. These composite feeds now come in a variety of sizes of crumble which are fed to the culture stock by means of automatic feeders. In the case of high intensity pond aquaculture, overfeeding or underfeeding can lead to outbreaks of fish disease or poor growth development. At the beginning of culture, operators base their daily feed allotments on a standard of 10% of the seed fish's body weight. As the fish grow, the ratio is gradually decreased until it reaches a ratio of about 2% of body weight daily for adult fish. To ensure that the whole stock is fed evenly, the feed is given out little by little with care over a period of time.

As natural ayu feeding on algae grow, they take on an olive coloring with bluish markings and their meat acquires a special fragrance similar to smelts. As a measure to preserve this special character of natural ayu in their cultured fish, aquaculture operators have made quite successful use of a phyto-plankton, *Spirulina* as an additive food during the later stages of the culture process.

FIG. 9: Ayu aquaculture farm facility layout



The culture process

As can be seen from the yearly culture schedule shown in **FIG. 11**, the culture operation is divided into a first and second culture group. The first group is made up of Lake Biwa ayu that spawn about one month earlier than sea-born ayu. The products of this group are shipped to market as fresh fish from spring into summer. The second group utilizes all the different types of seeds, which are introduced to the culture ponds at intervals that enable shipments to commence in September after the end of the group one shipments. The production ratio of group one and group two is about half and half.

The fishing season for natural ayu is summer and, for the Japanese, ayu carries a strong seasonal image as a summer fish. So, in spite of the development of ayu aquaculture, market demand tends to remain concentrated in the summer months. Therefore, culture operators are focusing their promotional activities on creating yearround demand as a means to expand the ayu market. At the same time, efforts are being made to build long-term storage systems using freeze-processing. Frozen ayu are sold mainly to the major food manufacturers which, in turn, watch the ayu market in order to strategically time their market shipments in such a way as to create a viable retail market for frozen ayu. In this way a yearround marketing system for ayu has been established.

FIG. 10: A large-size culture pond

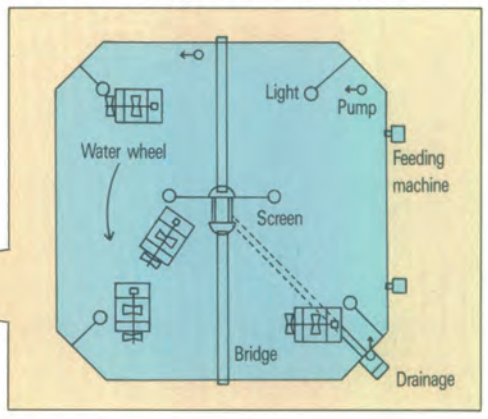


FIG. 11: An ayu culture schedule

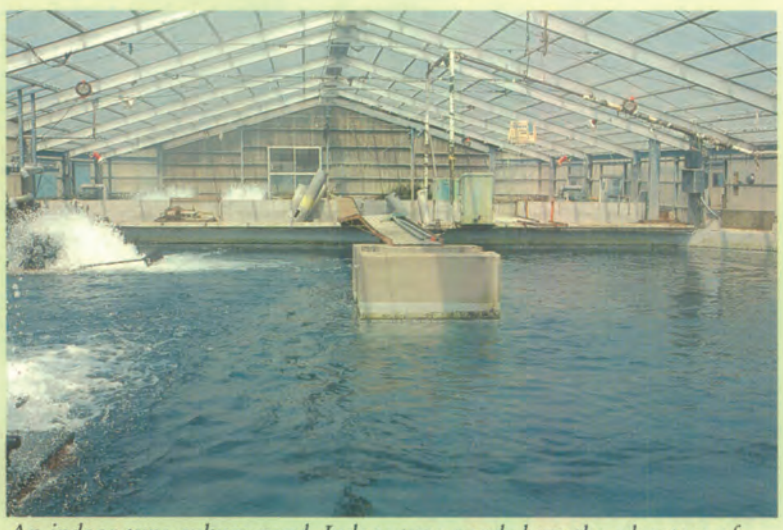
	12	1	2	3	4	5	6	7	8	9	10	11	12	
1st group	Release				Shipment									Fresh fish shipments
2nd group					Release						Shipment			Freeze-processed

Culture management

Ayu is subject to drastic seasonal fluctuations in market price. At the time the river ayu fishing season opens in June, the producer's price for ayu is at a high ¥2,000 per kilogram. After that, as the season progresses, the price gradually drops until it reaches about ¥1,000 per kilo in late August. Shipments of frozen ayu made during the off-season sell for prices in the range of ¥800~650.

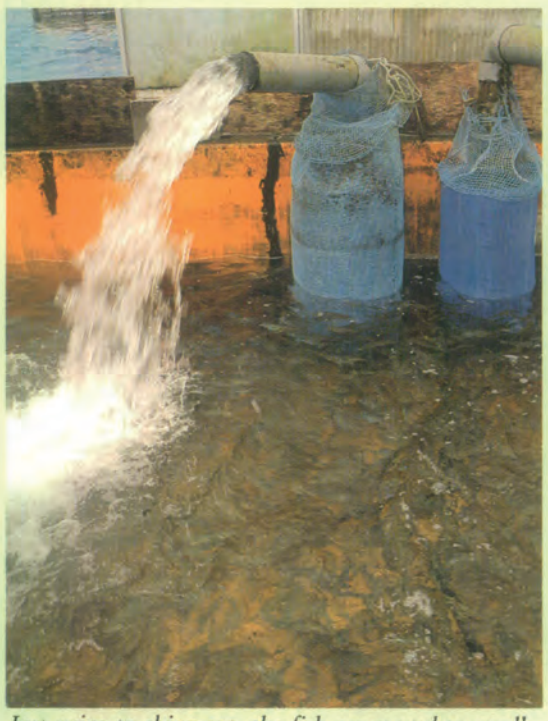
Speaking of production costs, according to the estimate of one operator, it requires a feed cost of ¥380, an electricity cost (running cost for pumps) of ¥110, a seed cost of ¥180, for a total of ¥670 to raise one kilogram of ayu. To these direct costs must also be added mangement costs such as labor and facility depreciation.

At present, it appears that the ayu aquaculture industry is in a stable condition, supported by a strong market demand for ayu as a high-class fish product. However, since all the culture operators increased their production at once during the 1970s and '80s, in the future it will be necessary for them to deal with two problems: the creation of new ayu products and the expansion of sales routes, and the perfection of favorable aquaculture technology that maintains high growth rate and is efficient at the same time, thus reducing production costs. The ayu culture industry has now entered a mature stage in which success will depend on the quality of each operator's management skills.



An indoor type culture pond. Indoor type ponds have the advantage of temperature control, but they entail greater construction cost. In Japan, outdoor type ponds are most common.

Shipping ayu. Because the fish are to be shipped fresh, they are placed in crushed ice containers for transport to the shipping facility.



Just prior to shipment, the fish are moved to small holding tanks and feeding is stopped for two days to empty their stomachs.

For shipment, ayu are sorted by size and placed in styrofoam boxes containing one kilo each. Then crushed ice is added and the boxes sealed.