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JAPANESE EEL AQUA-CULTURE

Internationalization comes to the Japanese eel industry

The large majority of Japanese eel culture operations are run with family labor. Because of this, efforts are made to mechanize and economize the day-to-day work as much as possible. Shown in the photo is the work of harvesting the culture stock for shipment to market. This is the one job that requires 5~10 laborers, and the operators help each other out at this stage by offering their own labor and transport vehicles.

Japanese eel, *Anguilla japonica*, is an important fish in Japan, where it is the object of the largest production of any freshwater fish.

Although the annual production of natural eel in Japan is only one thousand and a few hundred tons, there is a large aquaculture production that ranged between 34,000~39,000 tons annually during the 1980s. Eel aquaculture became a prosperous industry in Japan about one hundred years ago, and today its production far exceeds that of the other leading freshwater fish, including carp (approx. 17,000 tons), rainbow trout (approx. 15,000 tons) and sweetfish (approx. 13,000 tons).

Since olden times, the Japanese have had a strong preference for eating eel. This is because they believed the sweet taste of its meat and high fat content made it a food of high nutritional value. But, it was around the middle of the Edo Period (17th~19th centuries), with the development of a cooking method called "kaba-yaki," that eel truly became a part of the Japanese diet. This dish, prepared by splitting the eel open along the dorsal fin or the stomach and grilling it skewered out flat while basting it with a sauce, became popular as a high-nutrition food supposedly good for keeping up one's strength in the hot summer months. With the progress of nutritional research in modern times, the fact has been stressed that eel has a high content of vitamin A. One skewer of "kaba-yaki" (60~100g) contains 2,000IU of vitamin A, enough to satisfy the recommended daily adult requirement of 2,000~6,000IU. By comparison, 100g of beef or pork contains 50IU.

In the past 20 years there have been two major milestones in the eel aquaculture industry.

1) Until the 1960s, the three prefectures of the Pacific side of central Japan, namely Shizuoka, Aichi and Mie, constituted the major producing areas, with more than 90% of the total national production. Beginning about the year 1970, however, the prefectures of Tokushima, Kochi, Miyazaki and Kagoshima emerged as prosperous new producing areas, and eel aquaculture began to spread throughout the country.

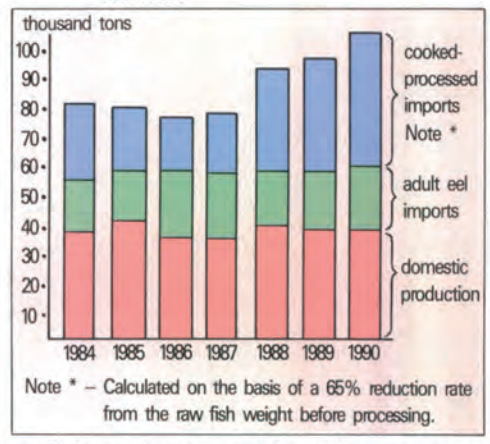
2) Beginning about 1985, there was a sharp increase in exports of eel to Japan from the neighboring countries of Taiwan, Hong Kong and China. An especially large portion of these imports are ready-cooked processed foods in the form of "kaba-yaki" and "shiro-yaki" (a partially prepared version of kaba-yaki) from Taiwan.

One of the background factors influencing these two developments was the fact that, as the production of the established producing areas of central Japan grew and producers became more dependent on sources from other prefectures or overseas for culture seeds, the culture operators had to travel outside their prefectures more and more to purchase "shirasu" (elver) as culture seeds in years of poor local production. The result was that people in these shirasu producing areas began to recognize the profitability of eel aquaculture and venture into the business of raising adult eel themselves.

At present, annual eel supply/demand in Japan averages between 95,000~100,000 tons, and it is commonly believed that eel culture will continue as a 100,000-ton industry. The breakdown of eel supply for 1990 was 39,900 tons of domestically produced natural and cultured eel, as opposed to 20,300 tons of frozen eel imports and 28,800 tons of imported cooked-processed eel products. Considering the fact that the raw material for these cooked-processed products constitutes about 44,000 tons of eel, the total supply of domestic and imported eel can be said to be about 104,000 tons. **(FIG. 1)**

On the demand side there have also been major developments. In the case of kaba-yaki, one of the important characteristics of the dish is the special taste that derives from the outer membrane of the eel when cooked. Because of the fact that this membrane begins to peel away a few hours after death, there is a need to keep the eel alive until just prior to cooking. The process of cutting open the live eel along the back or stomach, skewering it and grilling it properly, is considered a task too difficult for the average housewife. So, traditionally, the job of preparing kaba-yaki for the consumer has been performed either by specialized retailers at their own shops or by the cooks of specialty restaurants.

FIG. 1: Eel supply in the Japanese market



However, beginning about 1965, eel culture operators of the Yoshida district of Shizuoka Prefecture began partially processing a portion of their adult eel production fresh out of the pond at a processing plant run by their own cooperative and storing them as frozen products as a means of regulating market shipments in times of over-production. Then, in 1973, a major super-market chain began to import eel processed as shiro-yaki from Taiwan for the first time. After this, processing of eel production in the producing areas became a full-fledged industry in both Japan and Taiwan, with the processed goods developing from shiro-yaki to kaba-yaki. Now it has become common practice for shipments from any given producing area to include both live eel intended for specialty retailers and restaurants and frozen kaba-yaki processed and individually packaged locally in the producing area. Household consumers prepare these frozen products by thawing them out and serving them warmed, to be eaten with a specially prepared sauce. The ease with which this dish can be prepared in the home and the satisfaction it brings to amateur gourmets, led to the growth of demand for this product.

In Japan today, two types of eel products, (i) live eel for specialty retailers and restaurants and (ii) processed eel for the general consumer market, mainly via supermarkets, are distributed on the market. In this issue we will be concerned with the now internationalized eel industry. We will introduce the present conditions of the domestic aquaculture industry and the measures being taken to deal with the recent internationalization of the eel industry, as well as the expansion into the mass consumer market due to the importation of frozen products.

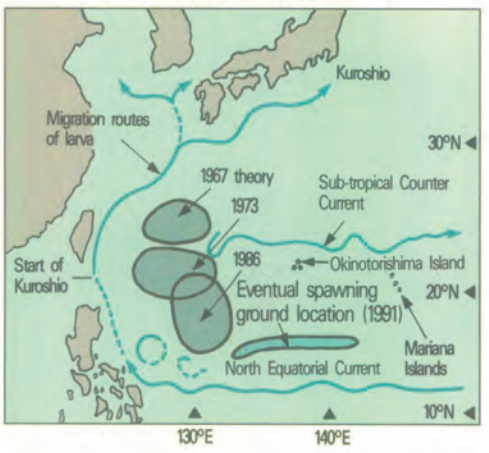
The eel's life history and mode of life

There are 19 genera of eel in the world. (16 species, 3 subspecies) Of these, only two species are found distributed on the European and American sides of the Atlantic Ocean. All of the remaining 17 are distributed around the Indian and Pacific Oceans. In the Atlantic region, eel are found only in the northern hemisphere, whereas in the Indian and Pacific Oceans they are distributed across both hemispheres, with an especially large number of species being concentrated in the tropical waters on both sides of the equator. Eel make their spawning grounds in middle layer waters with a high water temperature and high salinity at depths from 200～500 meters. The young that hatch in these waters immediately rise to the surface layer, where they are distributed over a wide area by the ocean currents. Within ten days of hatching, the eel young grow to a body length of about 10mm with a leaf-like body shape. At this stage they are referred to as *Leptocephalus*. The *Leptocephalus* migrate by riding the ocean currents, and by the time they approach the coastal waters they have undergone metamorphosis to the elver stage. It is at this stage that they begin river ascent. Unlike salmon and sweetfish, eel do not have the homing instinct to their mother river. Rather, it is believed that they use their sense of smell to detect freshwater and thus find a river to ascend in whatever coastal region their migrations happen to bring them to. Eel resources are, thereby, closely related to the interrelationship between ocean currents and the coastal water systems.

The eel that commence river ascent, eventually find a place along the river or one of its related lakes or marshes with a suitable life environment and take up habitation there. The males will reach a body length of about 22cm in the first year, 30cm by their second year, and eventually reach a length of 50cm within 5～6 years. Females will grow at a rate that is a few centimeters faster than the males at each stage. When the eel reach maturity after 5～10 years of growth in the freshwater environment, both the males and females descend the rivers to the sea. It is believed that the eel reaches genital maturity between the time it descends to the sea and the time it reaches its spawning grounds, but the actual process remains unknown.

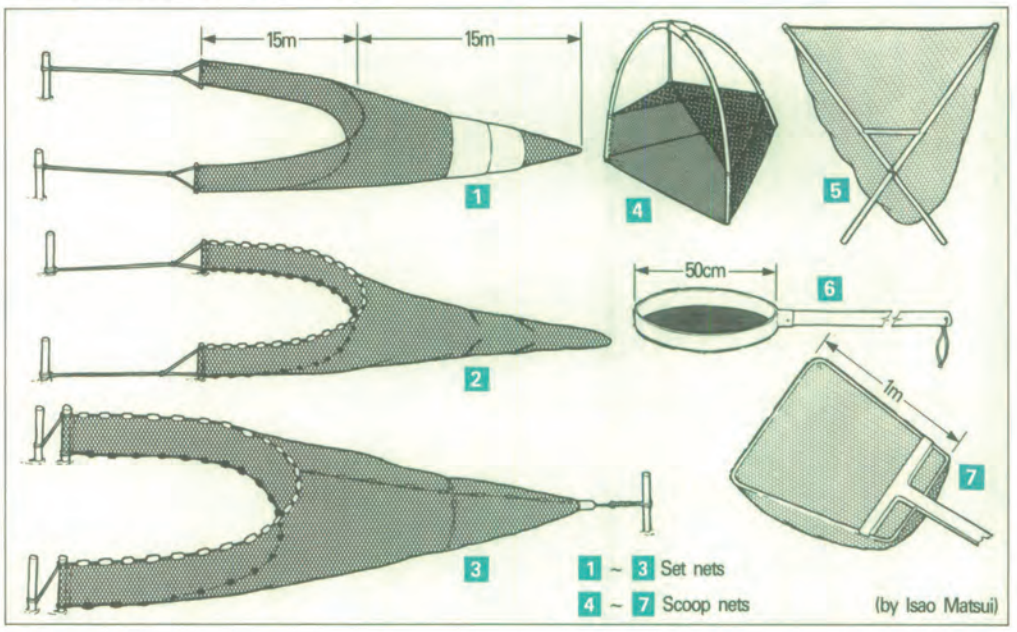
Japanese eel, *Anguilla japonica*, is distributed widely in all the waters of Japan, plus the west coast of the Korean Peninsula and the coasts of China, Vietnam, Taiwan and Luzon Island of the Philippines. Until recently, it was believed that the spawning grounds for Japanese eel lay between 20°～28°N in the waters stretching from the east coasts of Taiwan and Okinawa into the Ryukyu Sea area. However, in 1991 the Oceanography Research Department of Tokyo University conducted a survey consisting of some 262 nettings for eel larva by the research boat "Hakuohmaru" between longitudes 131°～155°E and latitudes 10°～22°N during the peak spawning period from June to July. From the results of this survey, Assistant Professor Katsumi Tsukamoto determined that the spawning grounds for *Anguilla japonica* lie in the waters between 14～16°N and 134°～143°E. **(FIG. 2)**

FIG. 2: Changes in the supposed location of eel spawning grounds



The ocean currents that play a role in the distribution of eel resources for Japan are the Kuroshio, the Tsushima Warm Current and the coastal currents. Among these it is the Kuroshio that has the largest effect. The largest catch of natural eel is concentrated around the rivers of the Pacific coast, particularly in areas south of the Kanto region. Resources along the Japan Sea coast are much smaller than those of the Pacific side.

FIG. 3: Shirasu eel fishing gear



Catching shirasu eel by scoop net.

Since olden times, eel have been caught in Japan by means of a variety of implements, including hooks, weir traps, pots, etc. Even today, a number of distinct local fishing methods continue to be found in the different regions of the country. However, with the flourishing of eel aquaculture, the catching of shirasu in coastal waters and river mouths has became more important than the catching of adult eel. This is because of the fact that, in eel culture the techniques of artificial hatching have not yet been established, and the culture industry thus depends completely on natural shirasu as culture seeds.

Compared to *Anguilla anguilla* of Europe, which spends three years migrating in the sea after hatching before approaching the coasts of the European Continent, Japanese eel approach the coast within about one year of hatching and commence river ascent. Since the eel waits for the rise in the river water temperature to reduce the gap between river water and sea water temperatures, the peak ascent season falls between January and March. However, this season is subject to annual and regional variations. In years when the river water temperature is high or resources are particularly large, the peak season may begin in December.

Because eel is nocturnal by nature, river ascent by the shirasu occurs only at night, commencing at sunset. Also, the amount of shirasu ascending the river will be greatest at spring tide, while at the neap tide the amount will be little or none. And, at the time of high tide river ascent will reach its peak. The shirasu are caught either by means of a scoop net in coastal waters near a river mouth or by means of a small set net in the mouth area. **(FIG. 3)**

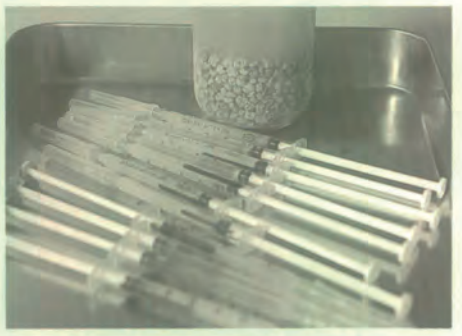
Feeding habits: Eel fry feed on zooplanktons. During metamorphosis, they cease feeding altogether. But when they begin river ascent they begin to feed on detritus, after which they eat zooplanktons and, after growing further, progress to crustaceans, aquatic insects, small fish and a wide variety of other aquatic animals.

Water temperature: Eel cease to feed at temperatures below 10°C. Feeding activity begins at the 10°～13°C range, becoming more active as the temperature rises, until it reaches its peak at about 25°C. When the temperature rises above 28°C, their appetite begins to decrease.

Research concerning the inducement of spawning activities and artificial hatching have been carried on in Japan since the early 1960s at the Marine Experimental Laboratory of Tokyo University, the Shizuoka Prefectural Fisheries Experimental Station, the Chiba Prefectural Fisheries Experimental Station, Hokkaido University and Kochi University.

In order to induce spawning and sexual maturity in males, a method of regular injections of a stimulant hormone for the genital gland is used.

Up until now there have been several successful cases of artificial insemination with mature eggs that have hatched into larva, but the longest that the resulting fry have been kept alive is 17 days. All attempts to surpass this record have failed. The focuses of present research are the problems of the high death rate of parent fish during experimentation and finding a suitable feed for the larva stage. Up until now natural eel have been used as parent fish in experiments, but in November of 1991 the Aichi Prefectural Fisheries Experimental Station succeeded in getting eggs to hatch from cultured eel after inducing spawning with hormone injections. However, the larvae lived at the longest for only 45 hours.



The hormone used to stimulate the genital gland in female eel is a hormone obtained from the pituitary gland of Oncorhynchus keta, and for male it is a placental genital gland stimulant hormone available on the market. (Shizuoka Prefectural Fisheries Experimental Station)

Prospering through more productive use of land

-Development and regional specialization in the eel aquaculture industry-

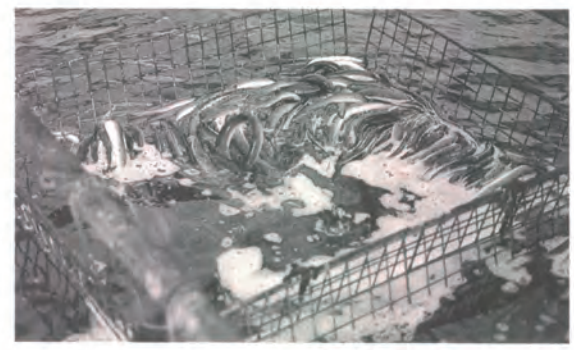
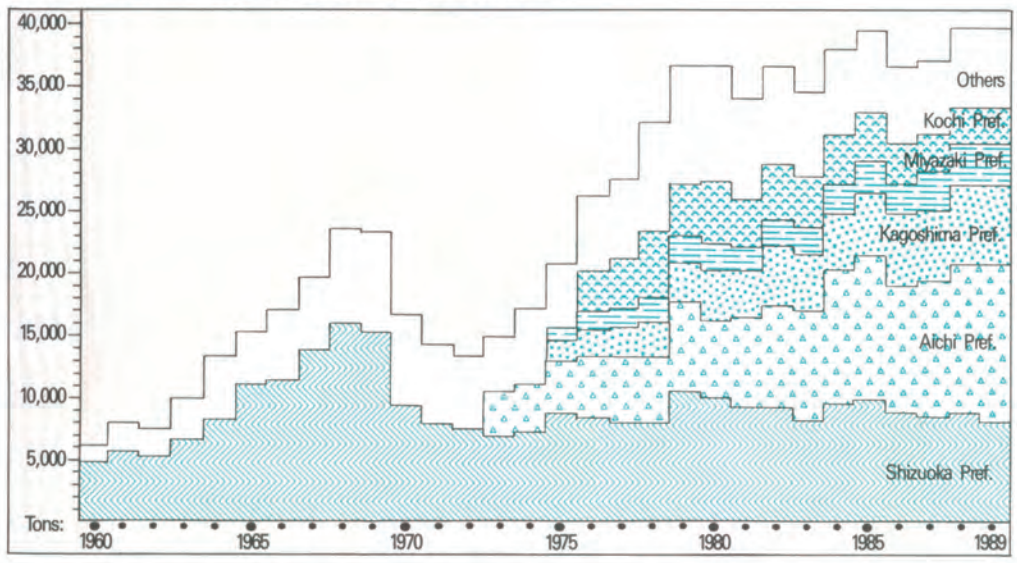


FIG. 4: Eel culture production by prefecture



The founders of the eel aquaculture industry in Japan were four pioneering men who undertook eel aquaculture independently in Tokyo, Shizuoka, Aichi and Mie Prefectures at roughly the same time between the years 1879 and 1899. And it was during this period that the techniques of Japanese eel aquaculture took shape. From this time until the late 1960s, eel culture developed as a localized industry in the three Pacific coast prefectures of Japan's Tokai region, namely Shizuoka, Aichi and Mie.

Around the year 1960, Shizuoka Prefecture boasted some 70% of the total national eel culture production, while the three Tokai prefectures together accounted for 94% of that total. Entering the 1970s, however, raising adult eel also became a prospering industry in the Shikoku prefectures of Kochi and Tokushima and the Kyushu prefectures of Kagoshima and Miyazaki, all of which had previously been suppliers of "shirasu" (elver) as seed fish for the established eel culture industry in the Tokai prefectures. During the '70s and '80s, the industry in these new producing prefectures grew at a rapid rate; and by 1989, the production from these Shikoku and Kyushu prefectures accounted for 36% of the national total. The Tokai region also saw changes, with Aichi Prefecture undergoing a sudden growth and surpassing Shizuoka as the leading producer by the year 1983. Amid these changes, Shizuoka's share of the national production had shrunken to 21% as of 1989. **(FIG. 4)**

Then, around 1970, the culture of eel to adulthood became a substantial industry in Taiwan and exports to Japan were soon begun. Today, China is pursuing the same course. As a result of these developments, roughly half of the 95,000 ~ 100,000 tons of eel supplied to the Japanese market are foreign products. In the following sections let us introduce some of the background conditions that led to these developments, along with an exploration of the present status of the eel industry in Japan.

1. The composition of a special producing area centered in Shizuoka

Lake Hamana in Shizuoka Prefecture has been known since olden times as a producing area for natural eel, and catching eel was long one of the major forms of fishery here. The presence of this natural eel habitat provided the basis on which the eel aquaculture industry here was to prosper. Around the middle of the 19th century, operators of culture ponds for carp and snapping turtle on the shores of the Lake noticed the presence of eel fry and made attempts at raising them through feeding. However, their growth proved to be insufficient and the desired results could not be achieved. Later, in the year 1900, an aquaculturist by the name of Kurajiro Hattori came to this area and was lent an eight hectare pond to begin eel culture. In preparing his pond, he gave consideration to water supply and drainage and encouraged the growth of phytoplanktons as measures to prevent eel mortality from oxygen defficiency. As feed, he first used freshwater shrimp, mud snail, mysid and the like, but a later attempt at using live silk worm pupa produced in large quantities as a by-product of the neighboring silk industry proved to be a big success.

It is said that Hattori was the first to perfect a workable method for eel culture. Silk worm culture operators were naturally pleased to learn that their pupa were highly valued as a feed for eel culture, and they welcomed the spread of eel aquaculture as an industry. There were even some cases in which silk thread industry investors also invested capital for the creation of new culture ponds.

The fact that eel fry could be caught along the shores of the lake, the local climate and the warm water temperature suitable for eel culture, were the major reasons eel aquaculture developed successfully in the Lake Hamana area. In addition to these factors, was the fact that the area is a lowland with a large amount of marshland unsuitable for the traditional Japanese two-crop farming method (ie. the method in which successive plantings and harvests of two different crops such as rice and barley or rice and soy beans are conducted in the course of one year). This made it possible to commit land to a specialized industry like eel culture.

Around the turn of the century, the cultured eel producing areas in Shizuoka Prefecture were concentrated around the shores of Lake Hamana or the alluvial plain at the mouth of the Tenryu River. A little later, beginning about 1922, eel culture spread to the Haibara and Shita districts along the lower stretches of the Ohi River. This area also happened to be unsuitable for rice production due to the makeup of the Ohi River watershed, which is characterized by the presence of cold water springs throughout its area. In either case, abandoning rice farming in favor of eel culture led to a more productive use of the areas' abundant water resources.

Furthermore, the following social factors contributed to the establishment of the eel culture industry here in Shizuoka.

1) In 1909, the prefecture's eel culture operators joined together to form a culture fishery cooperative union that, through activities such as communal buying of feed, helped bring a sense of solidarity to its members and contribute to stable growth in the industry.

2) In 1919 a reclamation aid law was passed by the national government, and in 1921 another law was passed permitting landfill projects on public water areas. These laws were intended to encourage the development of new agricultural land, and government funding was made available for such projects. Furthermore, in the case of lake areas, licensed developers were granted ownership rights for any landfill area they created.

2. Progress in techniques and expansion of producing areas

Water, seed fish and feed are the three basic elements that influence production in fish aquaculture.

In the early days of eel culture, fry with a body weight of 10 ~ 20g called "yochu" were caught for use as seed fish. However, as the eel culture industry grew, increasingly smaller fry came to be used. Entering the second decade of the 20th century, experimental raising of shirasu (elver) eel was undertaken for the first time. Once this transfer to shirasu became successfully established, an industry specializing in the raising of shirasu for supply to culture operators as seeds developed.

Culture operators have come to distinguish between the various growth stages of eel, as shown in **TABLE 1**, according to how they are used or their status as market products. During the primary development stage of the eel culture industry in the 1920s and '30s and just after World War II, separate industries developed regionally for 1) catching natural eel fry, 2) rearing natural fry to the biri or yochu stage and 3) obtaining supplies of natural or cultured seed fish and rearing them to adult eel. Within this regional differentiation, Shizuoka Prefecture became the region where eel were reared to adulthood, and this period saw this branch of eel aquaculture develop into a full-fledged industry. In years when culture seeds were in low supply, some Shizuoka producers traveled as far as Shanghai, China to purchase seed fish.

During the final years of World War II, eel culture had to be abandoned for lack of feed or other circumstances. But with the return to peacetime in 1945, the industry began its recovery and Shizuoka became the first prefecture in which the industry prospered once again. Eel was at the time a high-priced delicacy food, and Shizuoka's location midway between Japan's two largest consumer markets, Tokyo and Osaka, worked to its advantage.

After the War, eel culture production returned to its highest pre-war level by the year 1963. One of the technical advances during this period was the aeration machine. In the summer, when the water temperature rises, the oxygen supply naturally decreases, causing the eel to "nose up" (surfacing) and eventually to die. Thus, the maintenance of water quality is especially important during the summer months. The idea of replenishing the oxygen supply by aerating the water through the use of water wheels had been tried in the past, but it wasn't until the introduction of a device that didn't injure the eel in the pond, that the practice began to spread rapidly.

The next revolutionary advancement after aeration machines was the development of manmade composite feeds. Silk worm pupa had already been replaced by fresh fish feeds of such mass-catch fishes as sardine, mackerel, saury and sand lance and later by frozen fish. Then, in 1965 a composite feed having fish meal and grain meal as its main ingredients came into practical use. The adoption of composite feeds greatly reduced the amount of labor involved in the feeding process, as well as being much easier to transport and store than fresh fish. The production of composite feed for eel culture grew rapidly from a mere 4,000 tons in 1965 to 13,000 tons in 1966, 29,000 tons in 1967 and 44,000 tons in 1968.

Not only did these improvements in techniques for water quality control and in feeds contribute to increased production in Shizuoka Prefecture, they also enabled other prefectures that, due either to limitations in usable water supply or availability of feeds, had previously only engaged in the raising of shirasu or biri, to create full-fledged industries of their own for the rearing of adult eel.

A major change in the structure of production in the industry was brought about in part by two calamities which struck Shizuoka Prefecture between the late '60s and the early '70s.

1) Between 1969 and 1974 disease struck the culture ponds of Shizuoka on a large scale. At first it was thought to be a rare disease unlike any fish diseases experienced in the past. Later, however, it was believed to be a result of keeping stocks past the proper intensity level and the overuse of composite feeds. In 1970 the disease struck some 22% of the stock under culture, and for the next four years the rate remained between 9 ~ 13% annually.

2) For several years after 1970, poor catches continued in Shizuoka Prefecture's shirasu catching industry. Shirasu ride the warm currents north to the coasts of Japan, but off the coast of Shizuoka a cold water mass

(Continued on next pages)

TABLE 1: Product distinctions by growth stage for eel

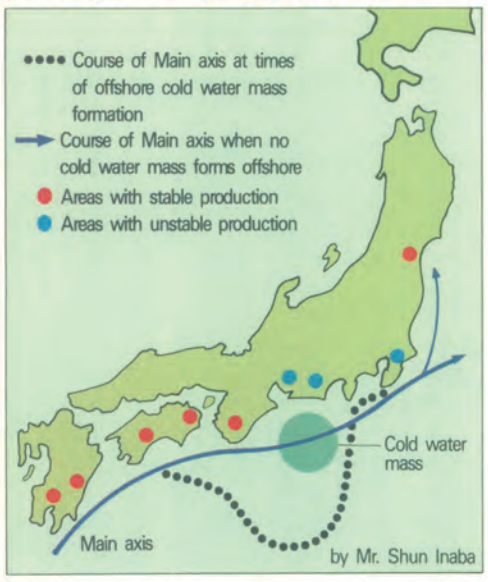
Growth stage	Use	Name	Description
Fry	As culture seeds	1 shirasu or mekko	150 ~ 180 days after hatching, body length of 5cm or less, weigth 0.18 ~ 0.2 g, transparent body
		2 kuroko	The stage after feeding is begun when body color begins to darken. 5 ~ 6 cm, 0.2 ~ 0.5g
		3 biri	6 ~ 12-13cm, 0.5 ~ 2g
Juvenile		4 yochu	12-13cm ~ 20cm, 12 ~ 20g
Adult	As edible products	5 futo or yobuto	120 ~ 250g This is the preferred size for kabe-yaki small → 120 ~ 150g medium → 150 ~ 200g large → 200 ~ 250g
		6 boku	Over 250g. This is the unharvested production of the culture pond and has a low market value in Japan. In the past some operators specialized in the production of boku for export to the European market.

(Continued from previous pages)

forms to varying degrees yearly that can serve to divert the course of the Kuroshio far to the south in some years, resulting in poor catches of shirasu along the Tokai coastal region. Traditionally Shizuoka Prefecture has had an unstable production of shirasu, characterized by fluctuations between years of good and poor catch. **(FIG. 5)**

FIG. 5: Shirasu eel producing areas and the Kuroshio

(from a report of the Hydrographic Department)



Due to these two calamities, operators in Shizuoka were forced to travel outside the prefecture in order to purchase shirasu, resulting in intensified competition to obtain shirasu supply that in turn drove the price up. The price of domestic Japanese-produced shirasu stood at ¥70,000 per 1kg in 1972, but that price rose to ¥120,000 in 1976, ¥150,000 in 1977 and then suddenly to ¥230,000 in 1978.

Meanwhile, in this same period, the price per kg of adult eel on the Tokyo market went from ¥2,350～¥1,500 in 1972 to ¥2,950～¥1,850 in 1978.

After one to one and a half years of culture, shirasu can be reared to the "futo" stage (adult eel), having increased in weight by about 1,000 times. Even when one takes into consideration limited survival rates and feed and other operational costs, eel culture yields sufficiently high profits. Recognizing the high market price of eel, the prefectures of Shikoku and Kyushu which had previously supplied shirasu to the Tokai prefectures proceeded to establish prospering culture industries of their own for adult eel one after another.

The people who undertook this industrialization of eel culture were the owners of middle-sized farms. Farmers troubled by poor crop production or market conditions, like lotus root growers in the low marshland area along the lower stretches of the Yoshino River (Tokushima Pref.) or hothouse gardeners from Kochi Pref., decided to switch over to the highly profitable eel aquaculture business. Another factor influencing farmers to change to eel aquaculture was the government policy adopted in 1970 to control the national overproduction of rice by encouraging farmers to switch to other types of crops.

3. Shifts in regional production amid internationalization and production growth

As eel culture production grew to the point where domestic shirasu production could no longer meet the industry's needs, the importing of foreign shirasu began. In 1964, the Japanese eel aquaculture industry began importation of *Anguilla japonica* shirasu from Taiwan, South Korea and China on an experimental basis. And since 1967 imports have continued on a regular basis. Also, in 1969, imports of *Anguilla anguilla* from France, Britain and Italy were begun. For the year 1990, Japan imported 16,647 kg of eel shirasu from South Korea, China, Taiwan, Hong Kong and France.

Note) In recent years imports of shirasu from Europe have been decreasing. During the '70s imports averaged around 50 tons a year. However, physiological differences and differences in life mode contributing to a higher mortality rate, plus their slower growth rate have brought them into disfavor in the industry. In 1990, imports from Europe consisted of only 1,928 kg of shirasu from France.

As was the case within Japan, the purchase of shirasu from overseas producing areas has stimulated the creation of local eel culture industries. In particular, Taiwan's climate and availability of warm water supply contributed to make it the first to engage in aquaculture of market-size eel. In 1969, Taiwan exported 24 tons of adult eel to Japan.

This precedent led to an expansion in production, and by 1973 some 1,250 ha. of land was being used to produce 11,653 tons of adult eel.

Meanwhile, a production system had been developed that supplied not only live eel but also processed eel products for export to Japan. In 1990, Taiwan exported to Japan a total of 16,038 tons of live eel, 8 tons of frozen eel and 25,186 tons of cooked-processed eel.

Elsewhere, China has engaged in the export of shirasu to both Japan and Taiwan. But, as of 1990, the export of shirasu has been prohibited as a measure to encourage export of adult eel for the benefit of greater influx of foreign currency. Furthermore, in order to prevent overcatching of shirasu, this has become a fishery requiring a special license.

In 1975, there were 876 operators engaged in eel aquaculture in Shizuoka Prefecture, but by 1989 that number had dropped to 279 operators. Over the past ten years or so, the dramatic increase in production made possible by the improvements in culture technology and the growth of imports, have led to long-term stability in the market price of eel. This has meant that the kinds of profits that were once possible in conjunction with the rising market price of eel back in the 1950's and '60s can no longer be expected. Those operators who did not have the ability to respond to the competitive pricing of the new high-production age the industry has entered have been forced to drop out. Besides the pressures to become more competitive in production costs, there is another factor that has caused many operators to drop out of the industry. That is the tremendous growth in economic value of formerly remote areas due to the vast improvements in transportation, road networks and communications that have accompanied the country's economic growth. For example, in the area around Shizuoka Prefecture's Lake Hamana development is now underway to create an international-class resort, while the Haibara and Shita districts along the Ohi River have become the sites for factories of major food, electronics and film manufacturers. As a result, a number of former aquaculture operators have either filled their ponds in and sold the land to developers, or built warehouses on their own initiative and entered the distribution business.

Even though eel aquaculture is one of the most profitable of all the types of fish culture, this fact cannot prevent the movement to constantly seek more profitable ways to make use of available land in light of the limits of its productivity. In areas other than Shizuoka as well, one sees a tendency for the eel culture industry to shift from areas with good transportation access to more peripheral areas like peninsulas.

Presently, Japan, Taiwan, China and South Korea are the only countries exploiting the resources of Japanese eel, *Anguilla japonica*. Until the technology for artificial hatching is realized, there will be a limit to the supply of culture seeds. This fact will surely lead to increased pressure for the nationalization of these resources. With its advantages of large land area, abundant water supply and inexpensive labor, China's aquaculture production is sure to grow in proportion to the other countries.

The shift from

During the 1970s, prospering new producing areas were established in Shikoku and Kyushu as the eel aquaculture industry began to spread nationwide. At this same time there were revolutionary advances in eel aquaculture technology in the areas of cuture facilities, methods of water quality control, stock density and productivity that gave a whole new appearance to the industry. This change began in Shikoku's Kochi Prefecture where indoor (hothouse) culture ponds and the practice of heating the pond water were used for the first time. Here, let us introduce both the traditional open-air pond aquaculture method and the modernized hothouse pond aquaculture.

OPEN-AIR POND AQUACULTURE

In the photo can be seen an area of outdoor eel aquaculture ponds along the Ohi River in Shizuoka Prefecture as it looked in about the year 1970.

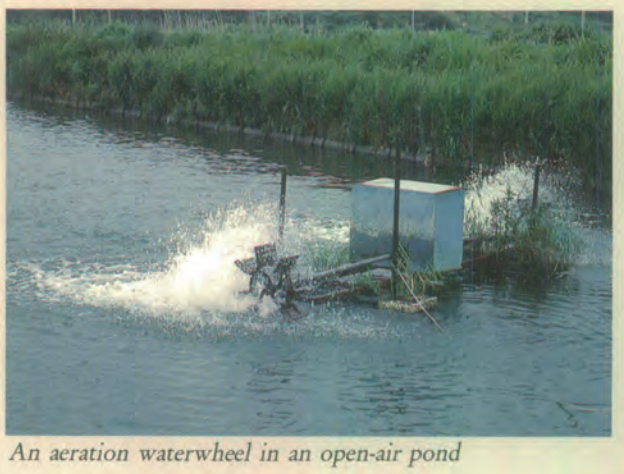
For many years, rearing eel in open-air ponds at the natural water temperature was the basic method of eel aquacuture. During the winter, the eel would burrow into the mud at the bottom of the pond and hibernate. The water used in these stillwater ponds was usually riverbed under-current water that was pumped up to fill the ponds. A suitable amount of blue-green algae, *Microcystis*, was grown to provide a natural oxygen supply in the daytime. And, as mentioned earlier, beginning around 1950 waterwheels were employed to aerate the pond water.

The ponds are divided into two types; **1)** those for rearing shirasu (fry) to yochu (juveniles) and **2)** those for rearing yochu to adult eel.

1) Fry rearing ponds: Because the culture stock must be divided according to growth stage, three different ponds are necessary, a primary pond, a second pond and a third pond. Compared to the primary pond, the second pond should be 4～5 times larger and the third pond 8～10 times larger in surface area. The primary pond is the place where the shirasu are instilled with the feeding habit. When the shirasu learn to gather at the feeding spot immediately after the dispensing of feed begins, it means they have acquired the necessary feeding habit. Those individuals that demonstrate this habit are then scooped out of the primary pond with a net and transferred to the second pond. Once they begin feeding, shirasu grow at a rapid rate, roughly dou-

OPEN-AIR POND AQUACULTURE

Eel culture farms (photo provided by Maruhai Yoshida Eel Fisheries Cooperative Association). The Ohi River can be seen on the righthand side of the picture.



An aeration waterwheel in an open-air pond

Harvesting the stock from an open-air pond. The eel are caught by hauling a seine net around the pond.

Until recently, fresh or frozen and th sand lance, mackerel etc. were used a

open-air ponds to hothouse ponds

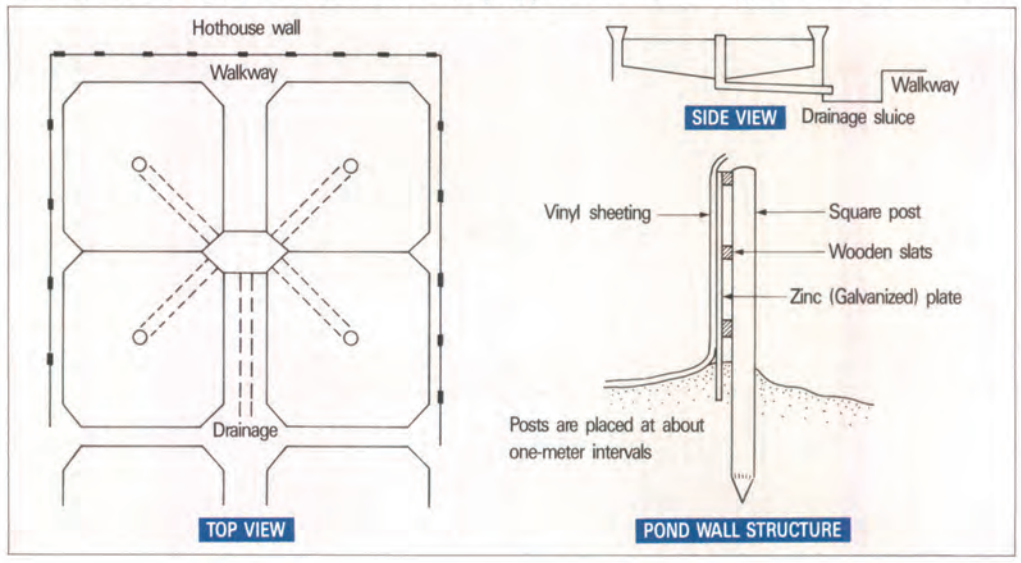
bling in body weight in two weeks.
Shirasu caught between December and March will grow in this way to the yochu stage by summer.
2) Adult eel rearing ponds: Open-air ponds used for rearing the eel to adulthood are usually of an elongated shape with a surface area of 1,000 ~ 6,000 m^2. Yochu are released in the pond for this feeding culture stage at a density of 0.5 ~ 0.3kg per m^2. A year to a year and a half after the start of feeding culture, the eel will grow to a marketable size of about 200g. In Shizuoka Prefecture during the latter half of the 1960s, the productivity of one ha. of land was 10 ~ 12 tons of eel.
Open-air ponds have a sand/mud bottom and a water depth of about one meter. The walls of the ponds are either covered with a layer of concrete or lined with round stones. As for the wall height, it is sufficient if it rises 50cm above the water level.

HOTHOUSE POND AQUACULTURE

In 1971 a new type of eel aquaculture was developed in which all the ponds were enclosed in hothouse (greenhouse) type structures, and soon this method spread throughout the country. This method began to be used on a large scale in Shizuoka Prefecture beginning in 1975, with open-air ponds being converted to hothouse ponds. At present approximately 85% of Japan's eel fish farms use this method.
The hothouse method got its start when farmers who had been engaged in greenhouse production of vegetables or flowers converted their greenhouses into indoor eel culture facilities. The conversion involved digging out the dirt floors of the greenhouses a little and erecting zinc (galvanized) plates along the four sides of the dugout floor as pond walls and then lining the whole thing with vinyl sheeting before filling it with water. **(FIG. 6)**
The surface area of one hothouse pond is 300 ~ 500 m^2. Operators in Shizuoka Prefecture partitioned up their 5,000 ~ 6,000 m^2 outdoor ponds into smaller concrete-walled ponds, built roof frameworks of steel pipe and covered the entire structure with vinyl sheeting to create a hothouse.
In order to maintain water temperature, the vinyl sheeting is applied in two or three layers.
There are two types of bottoms used in these indoor ponds, sand/mud bottoms and concrete bottoms. In the Tokai region the majority of the ponds have sand/mud bottoms, while in Shikoku and Kyushu they are usually the concrete type.
The switch to hothouse type ponds meant that the size of the individual ponds became smaller, a fact which had several merits:
1) In the case of an outbreak of disease, the diseased group can be isolated.
2) The feeding and stock harvesting work become easier.
3) It is possible to select and separate individuals according to size several times before they reach adult size, thus promoting better growth overall and eliminating inconsistencies in the size of individuals within a given stock.
At the same time, the transition was being

(Continued on next pages)

FIG. 6: The structure of a Kochi Pref. vinyl type culture pond (by Mr. Minoru Yoneda)

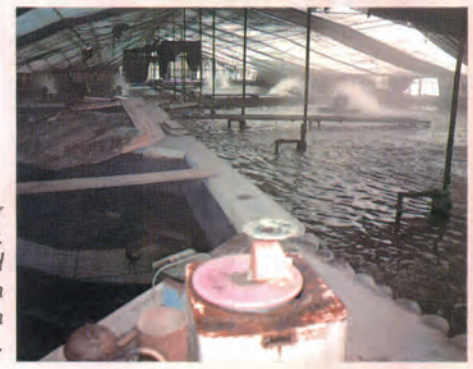


HOTHOUSE POND AQUACULTURE

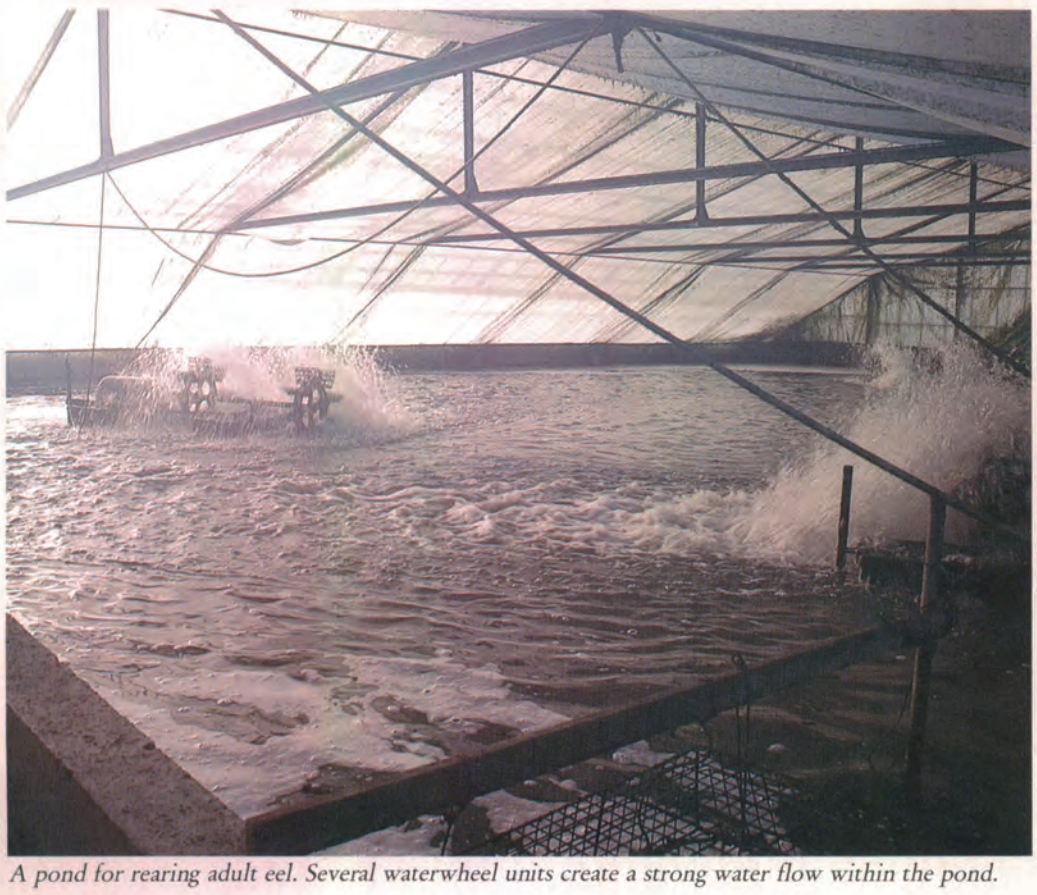
hawed sardine,
d.

Eel aquaculture facilities in the Haibara-Yoshida district of Shizuoka Pref. The surrounding area was in the past covered with outdoor culture ponds, but now residential developments and factories have been built in their place.

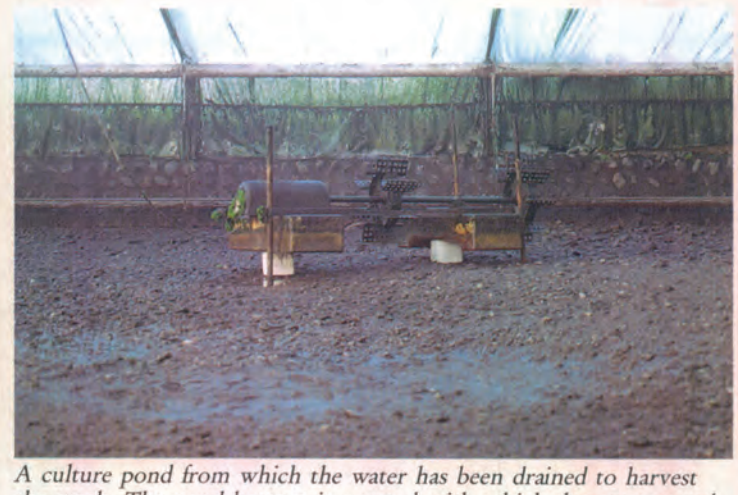
The roof and walls of the hothouse are covered with two layers of vinyl sheeting to maintain the temperature inside.



A hothouse type fry rearing pond facility. The ponds are divided into a primary pond, a second pond and a third pond.



A pond for rearing adult eel. Several waterwheel units create a strong water flow within the pond.



A culture pond from which the water has been drained to harvest the stock. The pond bottom is covered with a high-clay-content red soil over which are spread a layer of crushed rocks. This is because the facet rocks are better suited for the growth of bacteria. At the base of the far wall of the pond can be seen a heating pipe.

(Continued from previous pages)

made from outdoor ponds to indoor ponds, the technique of heating the pond water was also being adopted. At first the technique was used only for the fry rearing ponds. When water temperature drops to 10°C or lower, eel cease feeding activities and enter hibernation. Since the season when shirasu are caught for seeds, winter into spring, falls in the hibernation period, and because their response to the pond environment is unstable just after release in the pond, mortality rates tended to be high in the spring. The purpose of heating the fry pond water is to raise the temperature to the shirasu's preferred range, thus inducing the commencement of feeding activities and reducing the mortality rate. This technique eventually came to be used not only for the fry ponds but for the ponds for rearing adult eel as well, which led to a big reduction in the total culture period. To heat the pond water, operators first used such methods as pouring hot water directly into the pond or installing a heating tank next to the pond and circulating the pond water directly through the heater's hotpipes. At present, however, an indirect system is used in which hot water heated by an oil-burning boiler is circulated through pipes installed along the bottom of the pond.

Once the heated indoor pond method became established, the productivity of eel aquaculture increased remarkably. After the shirasu are released in the initial pond, the water temperature is kept at 25°~30° while they are reared by feeding for 15~20 days until they reach the "biri" stage with a weight of 1~2g. At this point they are ready to be moved to the adult eel rearing pond. In this pond, too, the water is kept at a suitable temperature so that the eel continue to feed actively and grow without ever entering a winter hibernation period. The fastest growing individuals will reach a marketable size of 200g within six months, and even the slowest do not require a culture period of more than a year and a half. The intensity at which the culture stock can be maintained has also increased to the point where skillful operators can raise a stock of 20~30 kg of adult eel per square meter of pond surface. **TABLE 2** shows the status of production by prefecture for 1989. From it we can see that in the case of Shizuoka Prefecture, the production per hectare of pond surface is twice what it was 20 years ago during the era of outdoor ponds. We also see that the warmer prefectures of Shikoku and Kyushu are able to achieve

TABLE 2: Production by prefecture (1989)

	[A] Culture pond surface area (in ha.)	[B] Production (in tons)	[B]/[A] Productivity (tons/ha.)
National total	916	34,301	55.8
Shizuoka	397	8,258	20.8
Aichi	322	12,365	38.4
Mie	41	1,600	39.1
Tokushima	38	1,768	46.5
Miyazaki	58	3,270	56.5
Kagoshima	53	6,501	122.6

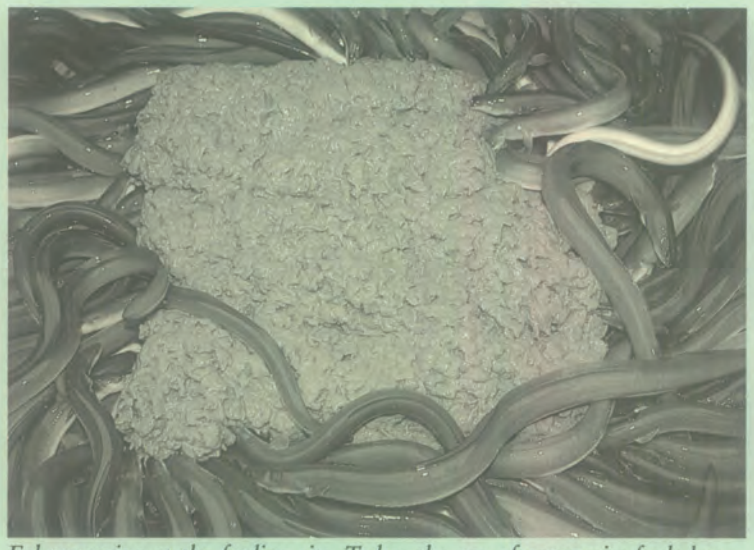
productivity that is nearly double that of the Tokai region.

In the case of hothouse ponds, every pond has several waterwheels to provide aeration for the water. In addition, a waterflow is created in the ponds to wash settled wastes to the drain located in the center. Also, the water in the ponds is changed constantly in small amounts in order to maintain water quality. Since the larger the rate of water exchange the greater the loss in heat from the standpoint of maintaining water temperature, the exchange rate is limited to about 10% of the pond volume per day. The kind of constant flow of fresh water supply that is seen in rainbow trout or sweetfish aquaculture is not used in eel culture. Also, in hothouse ponds blue-green algae are not grown as a means to maintain water quality.

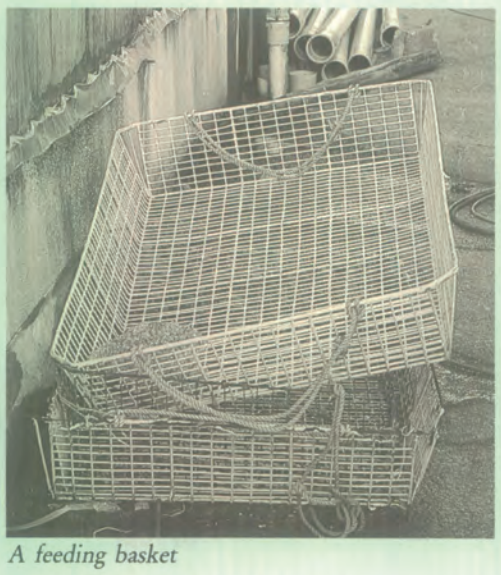
Since entering the age of hothouse pond culture, there is no longer a division of roles within the industry between operators specializing in seed production and those rearing eel to adulthood. Most operators now raise the eel all the way from the shirasu stage to adulthood within their own facilities.

The switch to heated indoor type aquaculture not only improved the survival rate for the shirasu from the 30~40% that was common for outdoor ponds to about 80%, it also had the important advantage of enabling a shorter culture period. On the other hand, however, it created a high-cost type production system from the standpoint of initial investment in facility construction and running costs. Taiwan, with its warmer climate than Japan, is blessed with an environment that is ideally suited to eel aquaculture, as the water temperature stays around 24°C yearround, thus eliminating the need for heating the culture ponds. It also has the advantage of abundant water supply. In Taiwan, all culture ponds are outdoor type, meaning reduced facility investment, running cost and labor cost. From

HOTHOUSE POND AQUACULTURE

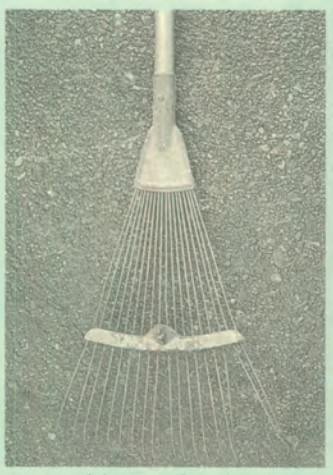


Eel swarming at the feeding site. Today, the use of composite feeds has become common. There are two types of composite feed, pellet form and powder form. The powder form feed is mixed with water and kneaded into a dough before use, or it is kneaded together with minced fish meat.



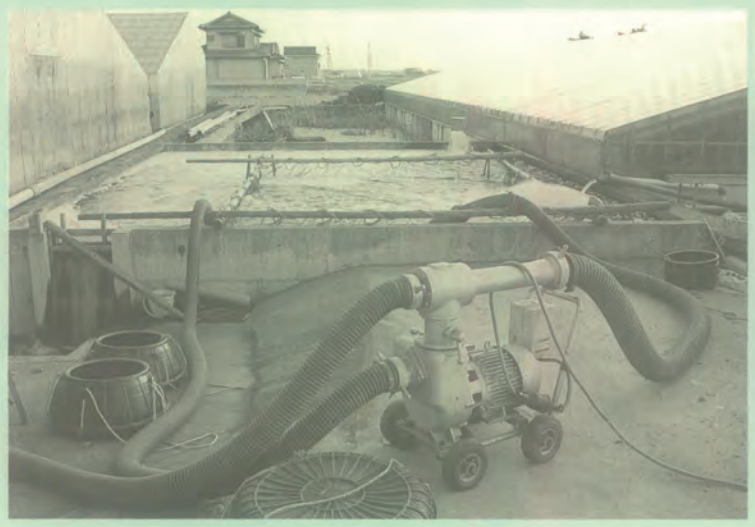
A feeding basket

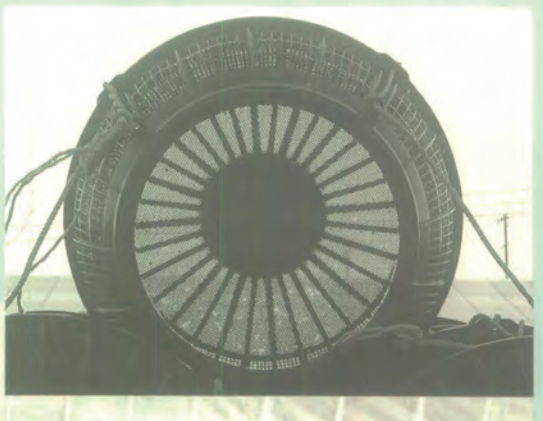
Scissors for holding the eel. The blades are notched to prevent slipping.



A metal broom for cleaning the culture pond. It is also used for gathering the eel together.

In recent years, pools are built at eel aquaculture facilities specifically for the harvesting process as a means to reduce labor. Eel are removed selectively from the various culture ponds by means of a fish pump and deposited in the harvesting pond where they are gathered in one corner by means of a net.





The harvested eel are placed in creels made of plastic (mouth diameter: 44cm, bottom dia.: 67cm, height: 32cm) and the lids closed.

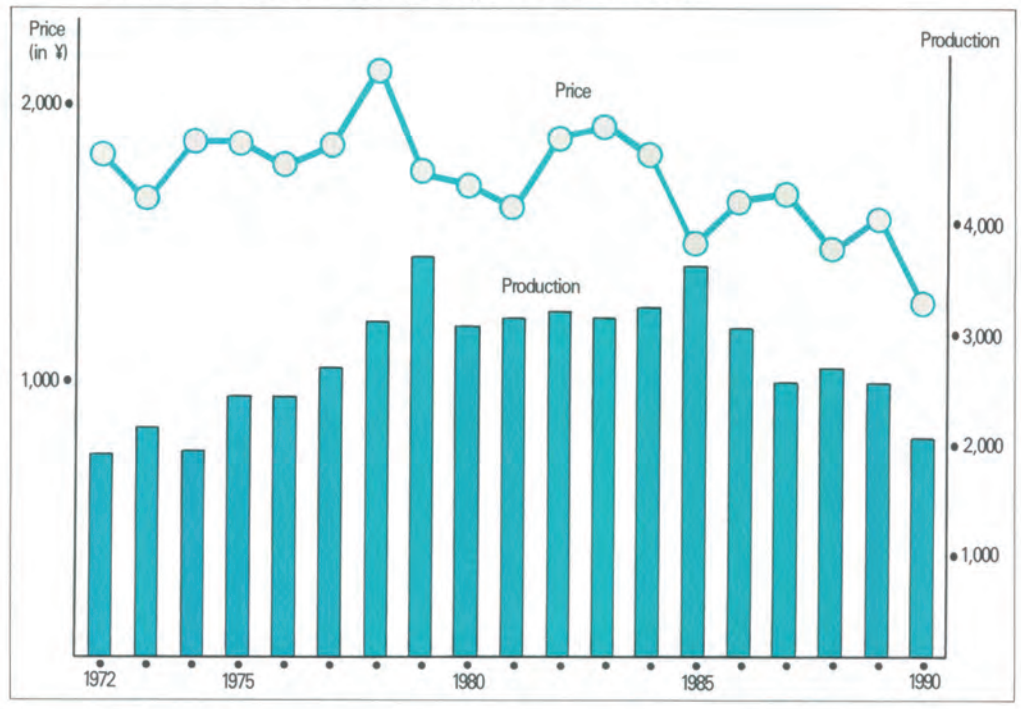
the standpoint of international competition, Japan is at a disadvantage compared to Taiwan and the emerging force in the industry, China.
The price of eel over the past twenty years has remained basically unchanged, and even seems to be dropping slightly in recent years. (FIG. 7)
In Shizuoka Prefecture today, it is said that the cost of raising one kilo of adult eel is about ¥1,300. (TABLE 3)

TABLE 3: Breakdown of the overhead cost for 1 kg of cultured eel
(based on interviews)

Seed fish	¥400
Feed	¥400
Labor	¥150
Fuel	¥90
Electricity	¥110
Drugs, sterilizers	¥70
Others (depreciation, repairs)	¥80
Total	¥1,300

It is a characteristic of eel aquaculture that the burden of seed cost and feed cost is especially high, accounting for 60~70% of the total production cost. Amidst the competition between producing regions and between individual operators that grows more intense every year, the culture operators will have to make efforts to reduce costs by improving the survival rate of seed fish and making more efficient use of feed.
Furthermore, they will have to work to maintain the market price of adult eel by improving the product quality of the eel they produce.
Toward this end, they will have to focus their efforts on such basic aquaculture problems as water quality control, finding out the ideal level of stock density and feed volumes, as well as disease prevention.

FIG. 7: Price of eel shipments vs. production volume
(Maruhai-Yoshida Eel Fisheries Cooperative Association)



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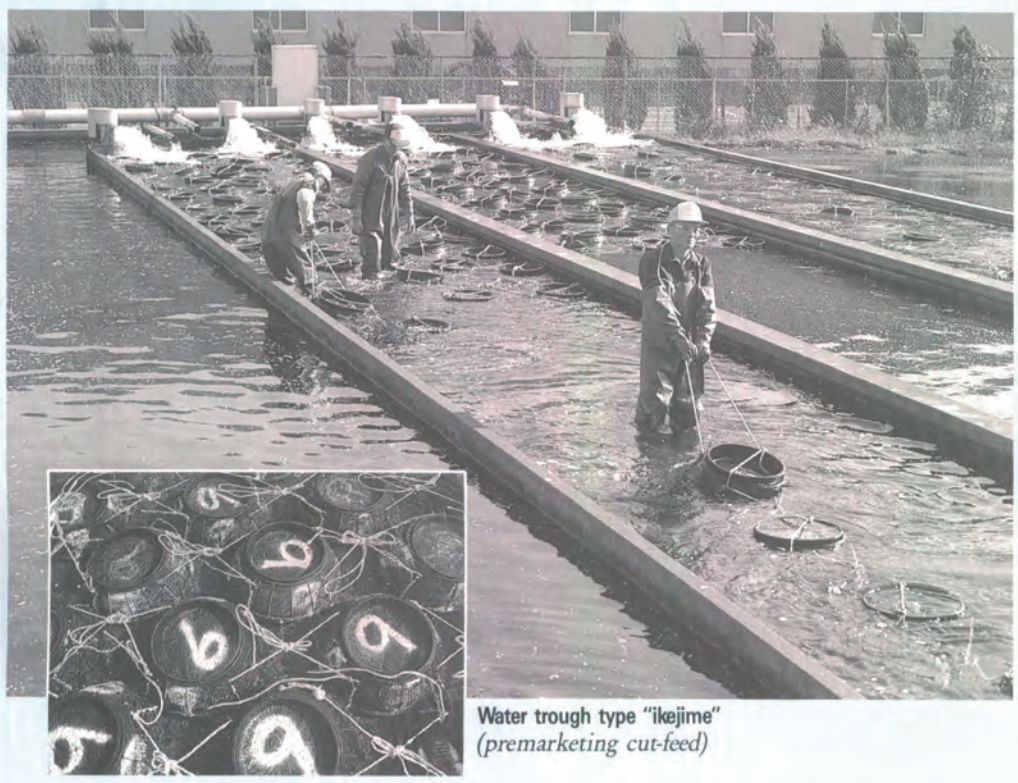
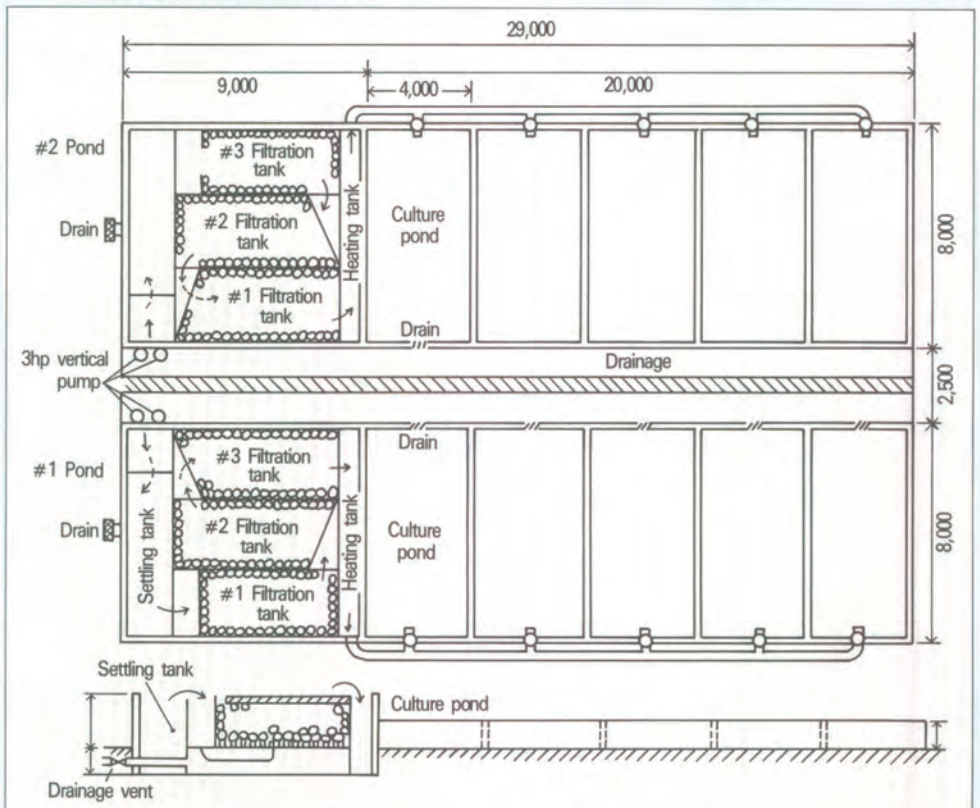


Water trough type "ikejime"
(premarketing cut-feed)

FIG. 8: Circulating filtration type eel culture pond as used in Mie Pref.
(by Mr. Yoichi Yamagata)



In regions that do not have abundant water supply, a system in which the water of the culture ponds is circulated through filtration tanks is used. Organisms which are grown in these tanks will break down and purify organic substances such as the eel wastes and leftover feed so that the water can be reused. In this case, however, the system is not a completely closed loop; freshwater supply and drainage is continued to some degree.

Shower type "ikejime"
There are two methods for ikejime; one in which the eels are placed as they are in the creels in a trough with a water flow of 4~10cm/sec, and a shower method in which 4~5 kg of eel are placed in stackable vats (dia: 40cm, heigh: 20cm), several vats stacked up together and tap water run down on them from above. The usual method is to leave the eel in a trough type ikejime facility for about 24 hours and then exposed them to shower type ikejime for a few hours.

The eel are selected for size (large, medium, small) while sliding down a sloped tank and then placed in the shower vats.

When shipping eel live, about 10 kg of eel are placed in polyethylene bags along with one kg of crushed ice. Oxygen is then injected into the bag via a nozzle and the mouth sealed with a rudder band. They are then shipped by means of a refrigerator truck.

Kaba-yaki Processing

Whereas in Europe there are a number of traditional ways of preparing eel, including smoked eel, marinated eel and eel cooked in olive oil, in Japan kaba-yaki is far and away the most popular eel dish.

Kaba-yaki is prepared in the following way: After spiking the head of a live eel, it is laid on its back (or stomach) and slit open. The head, fins, innards and bones are removed and the opened body put on skewers. Then, it is grilled once as it is to remove excess fat, after which a sauce made of soy sauce, sugar and mirin (sweet sake) is used as a basting that is applied to both sides several times as the grilling is continued.

Note) The cooking process differs slightly between Eastern and Western Japan, as represented by the styles of Tokyo and Osaka.

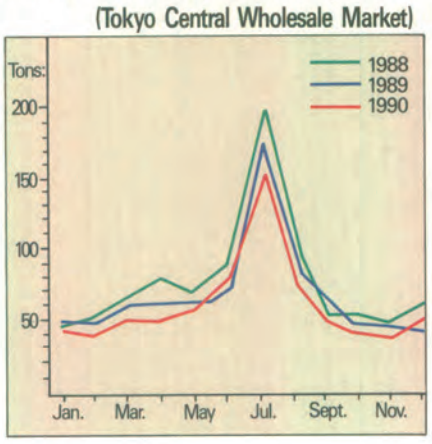
Traditionally, filleting the live eel and charcoal grilling it was the job of cooks at specialized restaurants, but the spread of kaba-yaki processing at the producing areas has led to the development of automatic skewering machines and grilling machines utilizing ultra-red light and gas burners. However, the job of filleting the eel properly is one that cannot be automated, requiring the skilled hand of an experienced worker.

In recent years, kaba-yaki has become a mass consumer product with yearround demand, although 40～50% of the demand is still concentrated in the summer months of June, July and August. For this reason, distributors in the producing areas as well as the consuming areas freeze and store shiro-yaki, or semi-processed kaba-yaki, in order to time shipments in accordance with the season of peak demand. **(FIG. 9)**

Preparing live eel. It is said that 2～3 years of training are required to become proficient in the job of filleting live eel and cooking it. A worker who has mastered the skill can prepare 50～100 kg (250～500 eel) in a day.

An automatic skewering machine

FIG. 9: Eel market volume by month
(Tokyo Central Wholesale Market)



A shiro-yaki production line

The vacuum-pack line

A delicious variety of eel dishes

The point of kaba-yaki preparation is to achieve the special flavor and aroma that comes when it is well saturated with the cooking sauce and the meat and skin are cooked to a softness that makes it seem to melt in the mouth. Although kaba-yaki can be eaten by itself, it is usually served on top of steaming rice so that the flavor of both can be enjoyed in balance. Due to the fact that the one dish of kaba-yaki can only generate a certain amount of demand for eel, lately the eel aquaculture industry is attempting to expand that demand by developing new types of eel dishes. By way of example, photos 1)～10) show an a la carte menu of new ways to serve eel in combination with other foods that is being promoted by the Maruhai-Yoshida Eel Fisheries Cooperative Association.

1) Kaba-yaki

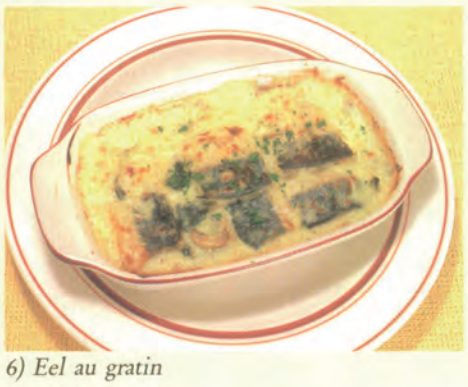
2) Marinated eel

3) Chinese style stir-fried eel

4) Eel with spinach and sesame

Eel (kaba-yaki) on rice

5) Fried in a cheese roll



6) Eel au gratin

7) In fried egg rolls

8) Eel sushi

9) Eel skewer-grilled with leeks

10) Eel sandwich

Photos provided by Maruhai Yoshida Eel Fisheries Cooperative Association