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RAINBOW TROUT CULTURE

Selection after selection creates quality strains

Culture ponds for mature fish.

Rainbow trout are shipped fresh from the pond. Shown in the photo is a standard 4kg case which is packed with fish from one of the six weight categories to make 20, 22, 24, 26, 28 or 30-fish packs.

In rainbow trout, *Salmo gairdneri*, aquaculture in Japan, a process of thinning out the cohort of culture stocks through selection is repeated several times between birth and maturity. Then, as the cohort reaches a marketable size of 100～150g, the fish that are harvested from the culture pond are once again subject to a selection process in which they are divided by weight into several size categories before being neatly packed in styrofoam crates for shipment. All in all, the intensity of this selection process might be likened more to a modern education system than to simple aquaculture.

Rainbow trout is a land-locked type species of steelhead trout, *Salmo gairdneri gairdneri*, native to North America where it is distributed from southern California to southern Alaska. Being both well suited to aquaculture and an excellent game fish, rainbow trout was actively transplanted to Europe and Asia beginning late in the 19th century. Today it is also found in Central and South America and Africa.

The first introduction of rainbow trout to Japan took place in 1877.

Since then, eggs have been imported repeatedly for release as fry in rivers and lakes, or for rearing in aquaculture facilities. Today, rainbow trout aquaculture is conducted in all of Japan's prefectures with the exception of Okinawa. Among these, however, Nagano and Shizuoka Prefectures have productions that far exceed the other prefectures. The primary requirement for rainbow trout culture is an abundant supply of cold, clear water. In the case of Nagano, this is supplied by the rivers and springs originating in Japan's central mountain chain, while in the case of Shizuoka it comes from the runoff of the lower slopes of Mount Fuji. On the other hand, rainbow trout culture has not been successfully established in Okinawa Prefecture because of its geographical situation as a sub-tropical group of small islands with a lack of rivers and no high land to provide a source of cold water.

Japan's annual production of cultured rainbow trout is 15,600 tons (1989), making it the third largest freshwater aquaculture production in Japan behind eel (39,700 tons) and carp (17,500 tons). The fact that a fish not native to Japan like rainbow trout became the object of such a culture industry can be accredited to the continuous process of selection that produced strains well suited to aquaculture. Attempts to transplant rainbow trout to local rivers and lakes, on the other hand, were generally not successful. Although there are reports of cases in which natural propagation did occur, there remains question as to the legitimacy of the verification methods.

Rainbow trout aquaculture has a long history in Japan, stretching back over a century. However, it only began to develop as a true industry after the Second World War. Whereas prior to the war the annual production had remained between 100 and 200 tons, that number had grown to 600 tons in 1954, after which it grew to 5,000 tons in 1965 and surpassed 10,000 tons by 1970. While this growth was supported in part by an expansion of exports to the U.S., it also reflected the development of seasonally early-spawning strains through breeding, as well as revolutionary advances in the culture technology in the fields of man-made composite feeds and seed production.

It should also be noted that the species of the family *Salmonidae* native to Japanese freshwater areas such as Japanese char, *Salvelinus leucomaenis*, Masu trout, *Oncorhynchus masou*, Amago trout, *Oncorhynchus macrostomus,* and Silver trout, *Oncorhynchus nerka* are also the object of aquaculture, though on a limited scale, in different parts of the country. For all of these species, the culture technology has been developed case by case based on the techniques acquired for rainbow trout culture.

FIG. 1: The progress of Japanese trout production and export

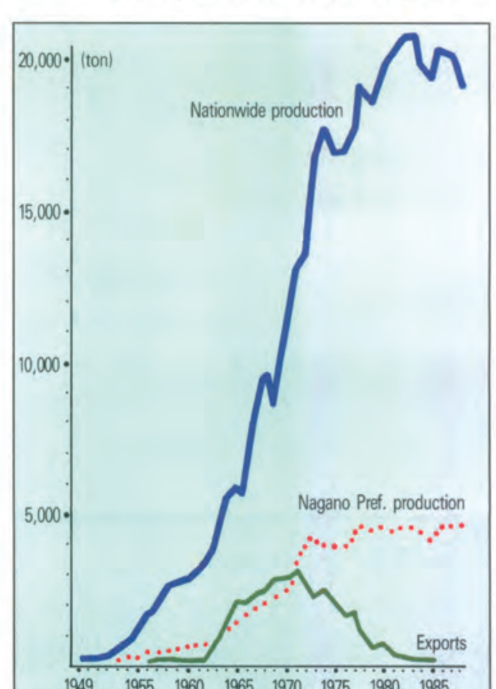
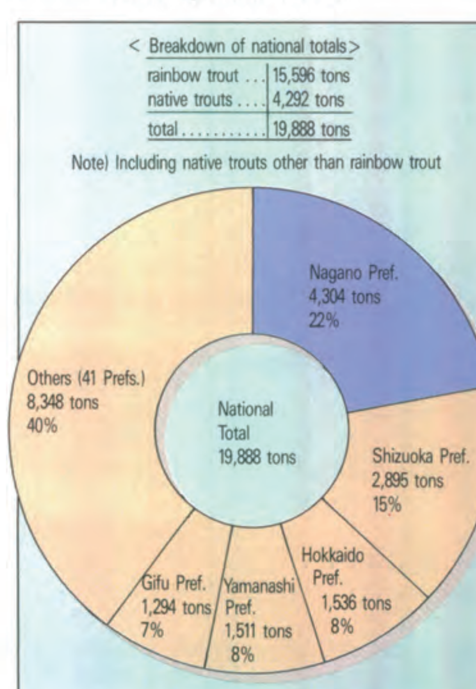


FIG. 2: Aquaculture production of trout species (1989)



Creating new character or adapting to a new environment ——The breeding of rainbow trout——

The process of manipulating a genetic group of biome in order to change its character to one more beneficial to mankind is called breeding. Breeding practices with regard to fish and other aquatic organisms are so far behind those used in agriculture and animal husbandry as to render comparison inappropriate.

This is because, with regard to marine resourses, mankind has thus far continued to concentrate almost completely on the capture of naturally existing resources. Today, however, in Japan as well as most of the rest of the world, aquaculture is accounting for a larger and larger percentage of fishery production. For this reason it must be said that research in the field of breeding will play an extremely important role in aquatic production in the future.

In breeding, the basic technique involved is selection for superior strains. Subsequently, in order to establish the superior characteristics gained through selection from parent to offspring requires the use of heterosis through the practice of crossing (cross breeding). In this way selection and crossing are two inseparable techniques of the breeding process. Of course, preserving characteristics that occur through mutation is another important part of breeding technology.

The first step in the breeding process is defining its aim. Usually, research efforts are directed at achieving superior growth rate, resistance to disease, high prolificacy, etc. In some cases, however, like that of Japanese ornamental carp, the object may be body shape or coloring. There are also cases in which the object is to improve meat quality or taste. Therefore, researchers must first of all verify what traits they are looking for and then clarify the way in which those traits are inherited, or whether or not they are traits that are not genetically transferred but rather the products of environment or certain age groups.

Generally, variations in individuals are believed to be the composite effect of a combination of hereditary and environmental factors. However, because the environment is not a constant quantity, it is difficult to judge to what degree a new characteristic is controlled by genetic factors simply by distinguishing between individuals. Advances in breeding technology have, therefore, always followed closely in the footsteps of advances in the science of modern genetics. In other words, breeding research has expanded its realm from the study of individuals to the study of populations and from the study of populations to the study of genetic polymorphism. This has in turn led to a shift in methodology from attempts to create new individuals with certain desirable characteristics, to attempts to bring the contents of the genetic pool of the species in question closer to what mankind would like it to be.

With regard to breeding of fish, it is a well known fact that the practice was used in medieval Europe to produce improved strains of carp. This was followed by intense efforts to improve rainbow trout through group selection. Professor L. R. Donaldson of the University of Washington in the U.S., began selective breeding for high growth rate trout in 1932, and by 1972 it was reported that a strain had been achieved that reached an average body length of 62.6cm as second year fish and 69.1cm as third year fish. Considering that at the start of the program in 1932 second year fish averaged 36.3cm and third year fish 41.2cm, we can see that after 40 years a strain with a 1.7 times faster growth rate had been achieved. It must be noted, however, that selection such as this that is based on human priorities, unlike natural selection, proceeds without regard for adaptability to thc natural environment of the species. This means that in some cases results can only be achieved under specific conditions. For example, there are cases in which a strain achieved over long years of selection fails to display its acquired characteristics when transplanted to a new environment. Rainbow trout from the Donaldson project were transferred to the Nikko Branch of the Aquaculture Research Institute in 1954 and again in 1966. In this case, the first batch of transplanted fish showed a growth rate almost identical to ordinary rainbow trout, while showing a survival rate that was lower than normal.

This result led to their being selected out of the breeding project three years later. A part of the second batch was kept under culture, however, and after 1971 the faster growing portion of the population began to produce three superior strains: one with high prolificacy, one with two spawnings a year and one with larger eggs. Thus, when transplanting strains that are deemed superior, it should be kept in mind that efforts must be made to ensure that they continue to display their superior characteristics in the new environment.

During the century-long history of rainbow trout aquaculture in Japan, the biggest results in breeding have come in the area of seasonally earlier spawning. As can be seen from **FIG. 3**, some 55 years of repeated selection have achieved a spawning period that is three months earlier than before. Attempts to artificially manipulate sexual maturity began in earnest in the early 1950s as a result of the following two desires on the part of the aquaculture industry:

1) In order to be able to harvest 100g yearlings in time for the autumn tourist season when seasonal demand reaches its peak, culture operators sought early eggs spawned in November or December.

2) Operators wanted to realize a production schedule in which groups of trout with different spawning periods could be introduced to the rearing ponds one after another at 2 ~ 3 month intervals, thus enabling continuous year-round shipments of mature fish to market.

In recent years, however, this has been achieved more commonly by the use of shade culture techniques to accelerate or delay spawning.

By the way, although Donaldson strain rainbow trout have not shown significant results in Japanese freshwater aquaculture in terms of growth rate, they are recently being used for post smolt stage seawater rearing on an experimental basis in some parts of Hokkaido. Donaldson strain rainbow trout are slow in sexual maturation, taking three years to reach their first spawning. However, this fact means that on the other hand a period of high growth rate can be expected between the first and second years when the fish are reared in seawater. For this reason the characteristics of the Donaldson strain are now receiving new attention.

Furthermore, since about 1982, a technique of applying a shock to fertilized eggs has led to a non-reproducing strain with triploid genes and, subsequently, the start of full-scale research into the raising of large-size rainbow trout. **(FIG. 4)** Concerning the growth of rainbow trout, raising large-size fish by means of seawater rearing or biotechnology methods is receiving more attention today than the development of new strains.

However, in these cases, too, the parent fish and the fry used must be of superior strains, and a thorough knowledge of the strains and the techniques involved with them are still essential.

A new issue related to rainbow trout strains in recent years is the increased practice of stocking rivers and streams for game fishing purposes. The rainbow trout strains that are available in Japan today are ones that have been adapted over many years with characteristics suitable for pond aquaculture. In the future, as the social demand in the game fishing sector increases, there will certainly be a need for raising catchable strains suitable for angling purposes. Active stocking activities that have been undertaken in Japan's rivers and streams in recent years for existing trout species such as masu trout and Japanese char, are good examples of responses to this growing demand.

FIG. 3: Historical change in egg gathering period (Nikko) (from Kato. Fukuda,1973)

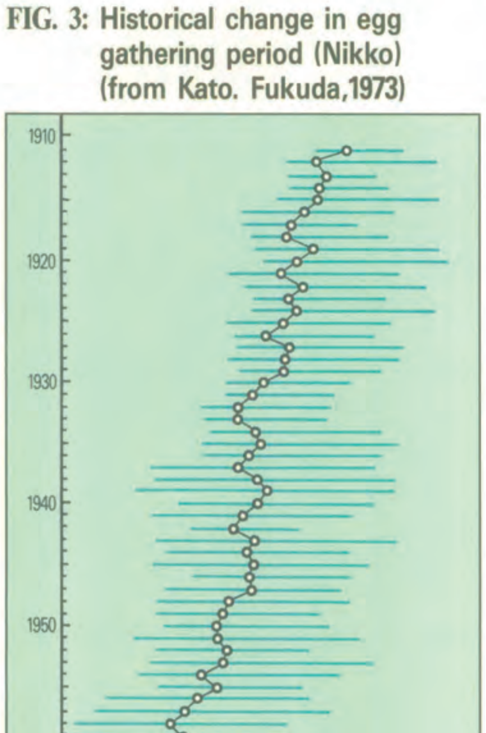
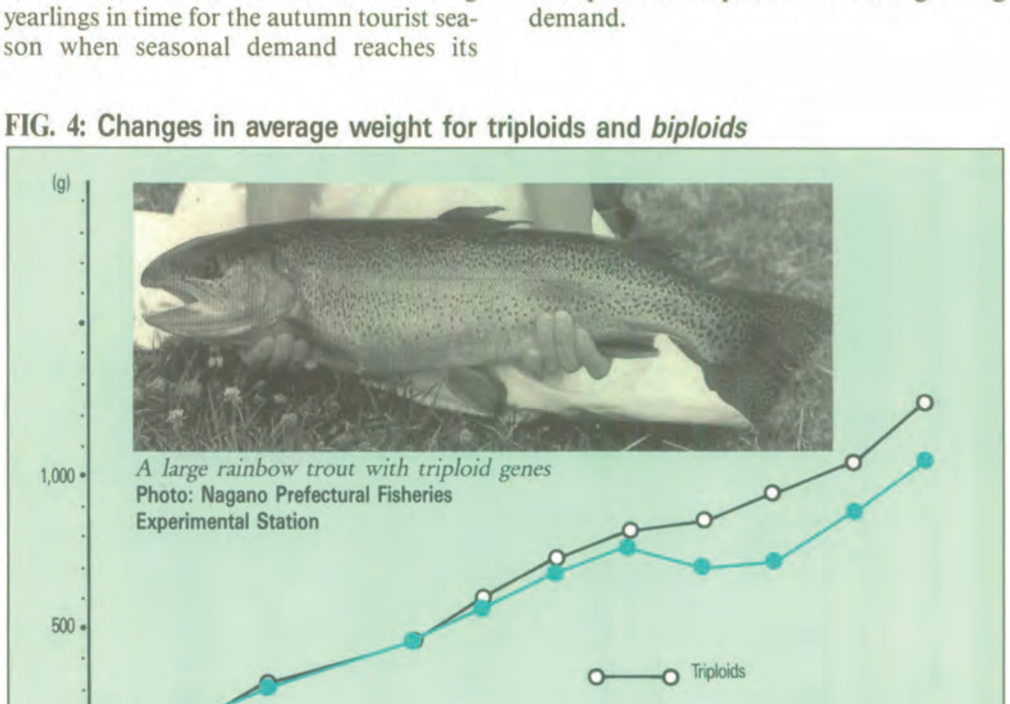


FIG. 4: Changes in average weight for triploids and *biploids*



A large rainbow trout with triploid genes
Photo: Nagano Prefectural Fisheries Experimental Station

(Nagano Prefectural Fisheries Experimental Station statistics)

The development of Japanese trout aquaculture

Making maximum use of cold water

Fish and other marine animals do not have the ability to adjust their body temperature to compensate for changes in the outside temperature as do mammals. Therefore, it is an absolute necessity that they live in waters of a suitable temperature range. Rainbow trout is a cold water species that prefers a cold water range. It is said that they are able to live within a temperature range of 0 ~ 25°C. However, it is believed that the temperature range at which normal feeding habits and growth can be expected is 13 ~ 18°C. And within this range, the higher the temperature, the more active the feeding habits and more rapid the growth will be.

With regard to spawning and hatching of eggs on the other hand, the suitable temperature range is said to be a lower 7 ~ 15°C. Furthermore, throughout their life cycle and particularly during the reproductive period, it is important that the environmental conditions be as constant as possible with regard to water temperature, volume and quality.

It is interesting to note that most of the major producing areas for rainbow trout aquaculture in Japan also happen to be areas that are well suited to the growing of the unique Japanese hot spice plant wasabi, *Wasabia japonica*. Wasabi grows naturally along pebbly mountain streams.

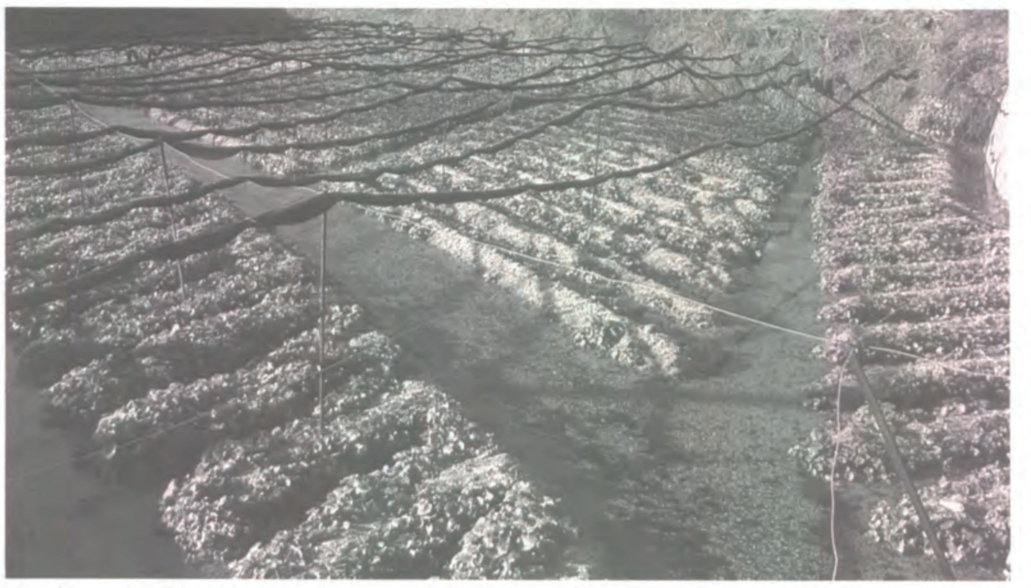
And when cultivating it commercially, it has been found that a water supply with a temperature that stays within the 11 ~ 14°C range and having little variation in either water temperature or water volume throughout the year is necessary. These are the same conditions that are essential for rainbow trout aquaculture, and it therefore stands to reason that the main producing areas for both are found in the same valleys of Japan's central mountain range in Nagano and Shizuoka Prefectures.

In Japanese rainbow trout aquaculture, the fish are reared primarily in ponds having a supply of flowing water coming from rivers, streams or springs. The shape and structure of these ponds fall into several different categories, each of which is used for a different purpose. There is one case of a locality in which the trout are reared in net cages in a lake, but this practice has not become common.

Japan is an island country, and its rivers are extremely short in length. What is more, the country is located in the temperate zone and in the summer the water temperature of the middle and lower stretches of these rivers climbs to around 20°C. Therefore, the areas suitable as a habitat for trout are limited to cold water flows in mountain regions.

And, as such mountain areas with an abundant supply of cold water flow from streams or springs were deemed suitable for rainbow trout culture, it tended to develop in a certain number of aquaculture farms in rather remote areas far from the major cities, creating local consumption and demand for the cultured fish there.

Shipment of eyed-eggs.
After draining away excess water, eggs are introduced to polyethylene bags with breathing vents. Styrofoam cases are lined with sponge as a shock-absorbing material and the bags of eggs placed inside. Polyethylene bags filled with crushed ice are also placed on both sides of the case. Each case is packed with five bags containing 10,000 eggs each.



Wasabi patches like this ensure an uninterrupted flow of water.
In the Azumino region of Nagano Prefecture, wasabi patches and rainbow trout culture facilities are found lying alternately along the regions, rivers and streams. Wasabi is an irreplaceable spice for the sushi and sashimi dishes the Japanese love so much.

Drawing impetus from exports to the U.S.A.

The history of aquaculture for the fish family *Salmonidae* in Japan is long.

Beginning with the first import of rainbow trout eggs from the U.S. in 1877, we find domestic hatching stations and culture operations appearing one after another. In 1926, the Ministry of Agriculture, Forestry and Fisheries established a subsidiary scheme for providing financial aid for the promotion of aquaculture fisheries, and this became the catalyst for the start of full-scale aquaculture for *Salmonidae* fishes in Japan. During World War II we find rainbow trout aquaculture reaching the highest pre-war levels, with records showing some 210 million eggs being hatched at 361 hatcheries around the country in 1943. As socio-economic conditions worsened after that due to the war, feed and materials became harder to obtain, causing operators to quit the business one after another. By the end of the war only about ten operators remained in the entire country.

After the war, it was the man who was referred to at the time as the leading rainbow trout merchant in the world, P. K. Christman, who sparked the recovery of Japan's rainbow trout culture industry. When Christman visited Japan in October 1951 and concluded a deal for 0.5 ton of rainbow trout in Nagano Prefecture, it impressed the domestic trout culture industry with the value of rainbow trout as an international commodity. The following year some 4.5 tons of frozen rainbow trout were exported to Christman's company.

During his visit to Japan, Christman toured the country's rainbow trout culture facilities and was impressed enough by their productive potential to prompt him to send the manager and technical director of his own X'man Trout Farm, W. L. Mulheron, to Japan to teach operators about the international market standards concerning product quality, specifications and packing, as well as giving technical instruction in techniques of rearing fish to harvest, processing, freezing and packaging.

In the latter half of the 1950s, exports to the U.S. reached full-scale proportions, with sales routes developing beyond those with Christman's company. This in turn provided the impetus for a continued growth in Japan's aquaculture production. From the late 1960s into the early '70s Japan's exports reached a stable volume of 2,500 ~ 3,000 tons, headed not only for the U.S. but for the countries of Europe as well.

However, about this same time a price war began with the leading exporter to the U.S. at the time, Denmark, causing Japanese exports to suffer.

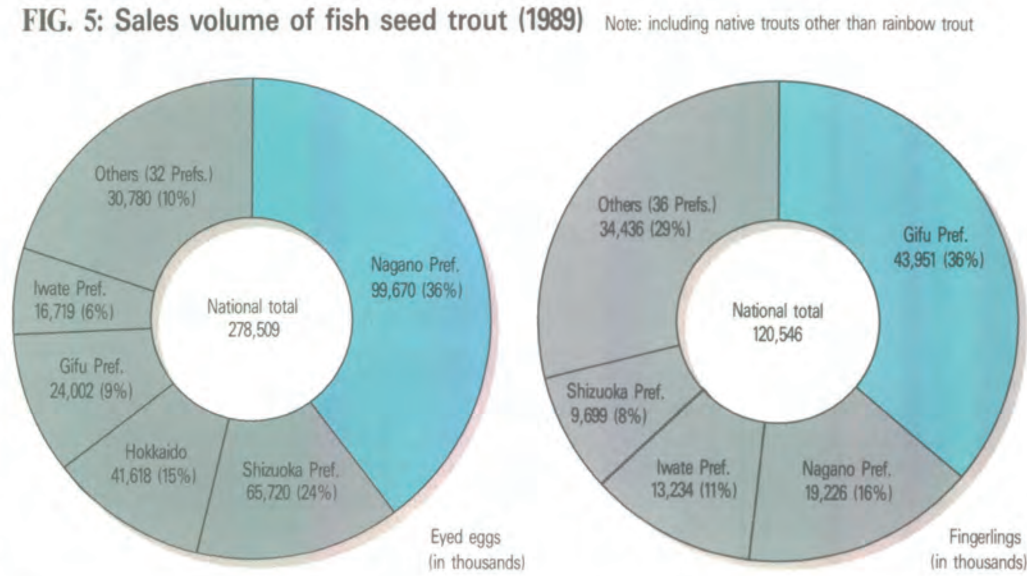
Then a devastating blow to the industry came in August of 1971 with the "dollar shock", after which the inflated value of the Yen caused Japanese rainbow trout to lose their competitiveness on the international market.

Finding themselves suddenly cut off from the export market and worried about the future, the Japanese trout culture industry quickly changed strategy and began to channel all their efforts into the development of domestic demand. As will be seen in the following pages, the Japanese rainbow trout culture production of today is supported entirely by two types of domestic demand, those for use as foodstuff and those for stocking purposes for game fishing.

Concentration of culture operations and regionwide distribution of seeds

There are two major characteristics that distinguish Japanese rainbow trout aquaculture; **1)** the high concentration of operations in certain areas deemed suitable for culture activities, and **2)** seed production over a wide area (meaning eyed-eggs or fingerlings) supported by sales through distribution routes covering many different regions. **(FIG. 5)** Several advances in culture technology can be cited which made these conditions possible.

FIG. 5: Sales volume of fish seed trout (1989) Note: including native trouts other than rainbow trout



(1) Introduction of composite feeds

Rainbow trout is a typical carnivorous fish. In the early days of rainbow trout culture in Japan, raw cow's liver or fresh fish were used as feed.

Later, the unique Japanese aquaculture feed, chrysalis also came to be used, as further development of feeds for rainbow trout culture continued on a trial-and-error basis. After the end of World War II, materials concerning research in the subjects of fish nutrition and aquaculture feeds became available from the United States. From these materials, several faults of conventional feeds used in the Japanese trout culture industry became apparent, like the fact that most diseases seen among fish under culture were due to nutritional deficiencies in the feeds. By that time composite feeds had already been developed and put in use by the culture industry in the U.S., and beginning about 1955, the basic knowledge pertaining to composite feeds was introduced to Japan and domestic development begun. By 1961, Japanese developers had succeeded in formulating and testing a nutritionally sound composite feed, which was soon put into production by private sector feed manufacturers. From this point on, Japanese rainbow trout aquaculture underwent a period of large-scale development.

(2) Improvements in egg gathering methods

In the 1960s there were improvements made in the area of egg gathering that led to a dramatic rise in the percentage of fertilized eggs obtained.

Unlike the fish of genus *Oncorhynchu* that spawn only once in their lifetime and die immediately after, the fish of genus *Salmo* spawn several times during their life span. Thus, whereas salmon egg gathering is performed by cutting open the belly with a knife, egg gathering for trout uses a method in which the eggs are squeezed out of the belly portion by hand in a way that does not kill the parent fish. As a result, however, the batch of eggs squeezed out of a parent fish will inevitably contain a number of eggs that have been burst by the squeezing pressure. And at the time of insemination, the spermatazoa tend to gather on the yolk protein released from these burst eggs, thus reducing the overall fertilization rate. In order to prevent this defect in the method, two techniques were proposed:

Egg washing method: Since yolk protein is soluble in certain salt solutions, washing the eggs with an isotonic solution (i.e. a physiological salt solution having the same salinity as blood plasma) before insemination, results in a high fertility rate.

Air-pressured expulsion method: In this method a large guage syringe is inserted in the rainbow trout's belly and pressurized air is injected to force the eggs out. This method prevents the bursting of eggs due to outside pressure, while also ensuring complete removal of all the eggs carried in the parent fish's belly. It also eliminates the fear of the fish's outer skin membrane being damaged by human hands. However, because it requires careful monitoring of the parent fish's gonad maturity in order to be successful, it is not well suited to facilities involved in mass scale egg gathering.

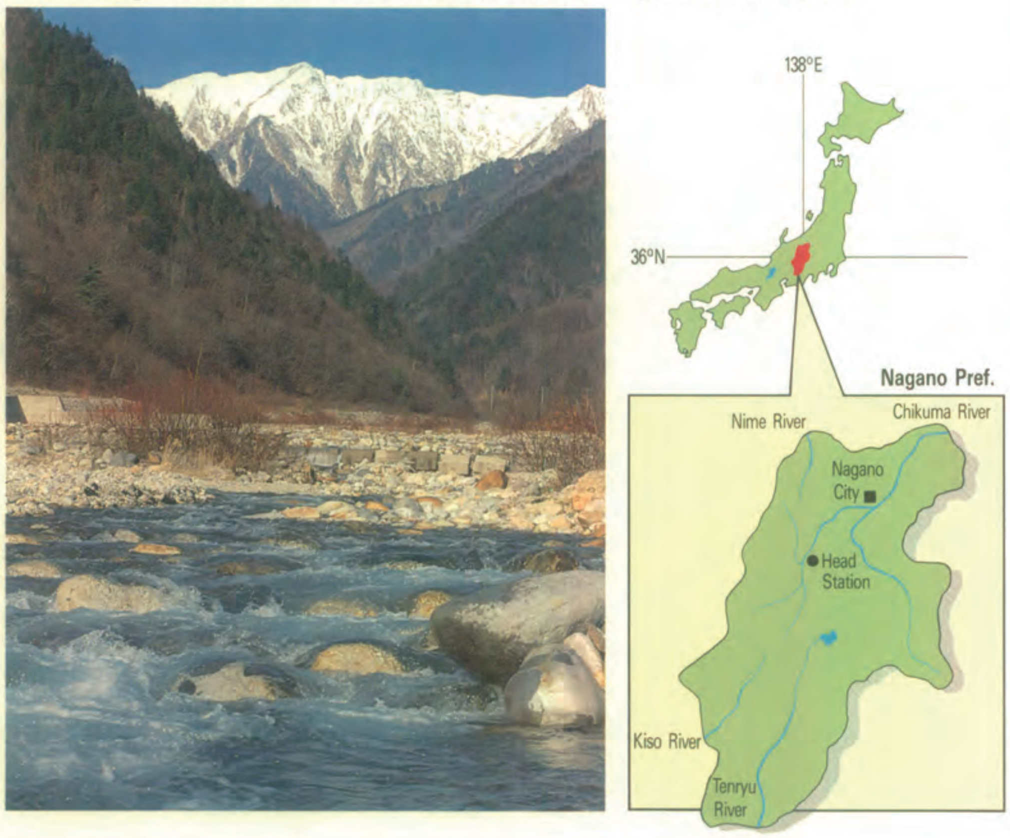
(3) Shipping containers for eyed-eggs

As rainbow trout eggs reach the eyed-egg stage they acquire sufficient resistance to vibration to allow them to be shipped. In the 1960s, the Nagano Prefectural Fisheries Experimental Station developed a low-temperature insulated shipping case (photo) with a capacity to carry 50,000 eyed-eggs. This case makes it possible to ship eggs with an average mortality of 0.1% (or less than 1% even in the worst conditions) within a 5-day period. Today, eyed eggs produced in Nagano are shipped as far as Korea and Taiwan.

Supported by an abundant supply of water

Nagano Prefecture is located in the central region of Japan's main island and is a highland area surrounded by mountain ranges reaching 3,000 meters in elevation. The 699 rivers and streams that comprise the eight river systems flowing out of these mountains stretch for a combined length of some 5,031 kilometers. The region also has scattered natural and man-made lakes. Blessed as it is with an abundant resource of freshwater, the region has long been the site of active aquaculture for carp, rainbow trout and other freshwater fishes, as well as having a tradition in advanced research in aquaculture technology. In 1988, Nagano Prefecture produced a total of 3,705 tons of rainbow trout and 319 tons of other trout species, making it Japan's largest trout producing prefecture. In this issue we will report on our findings from local research of the seed production, rearing, processing and distribution aspects of Nagano Prefecture's rainbow trout aquaculture industry.

FIG. 6: Nagano Prefecture and the Head Fisheries Experimental Station



1 SITES SUITABLE FOR AQUACULTURE

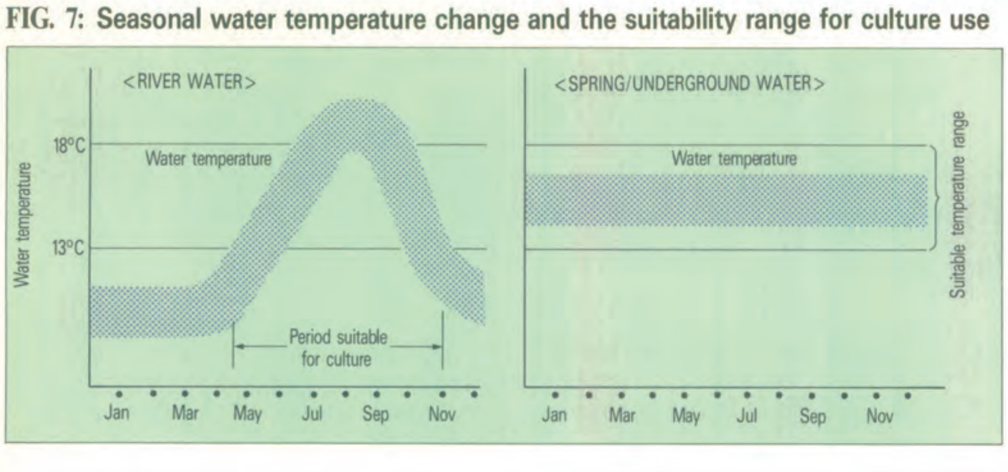
When undertaking rainbow trout aquaculture a site must be chosen which offers a year-round supply of water with suitable temperature, volume and water quality. In cases where spring water or underground water supplies are used, a suitable water temperature is assured year-round. But in cases where river water is to be used, a survey of the fluctuations in water temperature during the course of the year must be made beforehand to determine the length of the period in which water of a suitable temperature can be obtained. If the water temperature stays near the limit of the suitable range for growth for four or five months during the summer, the growth rate of the rainbow trout will be so poor as to not make commercial aquaculture viable. **(FIG. 7)**

Water volume is another important point determining the suitability of a site for aquaculture. This is because the scale of the culture operation and the quantity of fish that can be produced is determined by the lowest water volume that will be available during the course of the year. Although it may vary some with the culture techniques, in general a site with a flow of one square meter of water per minute can support an annual production of 2 ~ 3 tons of rainbow trout. This means that the survival of the trout depends on the amount of dissolved oxygen in the water it inhabits. Attempts to raise more fish than the average capacity will require mechanized aeration or recycling of the water circulation system. Excessive culture intensity makes the environmental conditions too stressful for the fish. And, when one considers the increased risk of disasters such as the outbreak of disease, water famine, etc., it is clearly not a wise practice.

With regard to water quality, the best guideline is that the water be clear. If it is water that is supporting such species as caddis fly, stone fly and shrimp, it is certain to be water of suitable quality. A PH value of 6.5 ~ 8.0 is considered suitable for rainbow trout. In cases where underground water supply is used, there is sometimes a lack of dissolved oxygen or an excessive amount of nitrogen gas. So, it is best to be certain that the water is sufficiently aerated above ground before use.

Topographically, sites with an inclination of more than 1/100 and less than 1/30 are preferable. This is because such terrain **1)** provides an appropriate velocity of water flow to ensure good circulation through the culture pond, **2)** enables the ponds to be terraced in a way that allows for the construction of descending sluices between them for the purpose of aeration and **3)** makes possible the construction of troughs between the ponds for catching floating debris and depositing silt.

FIG. 7: Seasonal water temperature change and the suitability range for culture use



2 THE CULTURE PONDS

The ponds used in the culture of rainbow trout are divided into **1)** feeding ponds, **2)** fry growing ponds and **3)** adult fish rearing ponds. Culture facilities that engage in their own egg gathering and hatching operations also need **4)** a pond for keeping parent fish. Furthermore, for the purpose of shipping operations an additional **5)** preserving pond and **6)** stocking pond are sometimes prepared.

Important requirements for culture ponds are that they have good circulation, that they be resistant to the build-up of wastes and that they be easy to clean. In terms of shape, there are water channel type, elongated rectangle type, circular type, turtle shell type and irregular shaped type, and each of these types has its unique strong points and weak points. **(FIG. 8)**

With regard to fry and adult ponds, there must at least be two ponds for each in a farm, and normally it is desirable that a facility has 3 ~ 5 of each. This is because as the fish grow, the relative density of fish with respect to the pond size increases, creating the need to divide the stock at various stages of growth. Furthermore, as individual variation in body size begins to appear in a brood, it is necessary to regroup the stock according to the size category as a process of selection for standardizing the size structure of the stock at several stages in the culture cycle.

As a general rule, fry ponds are built upstream and the adult ponds downstream from them. With regard to the formation of the ponds there are basically two types; a linear type with the ponds arranged in sequence, and a lateral type with ponds laid out in parallel. **(FIG. 9)** In a linear type the volume of water entering each pond is larger, meaning better circulation of water within the pond. But, because the same water is used repeatedly from pond to pond down the line, contamination occurring in the upstream ponds directly effects the downstream ponds. Conversely, in a lateral type the volume of water entering each pond is smaller but a fresh supply of water is always ensured, making it easier to cope with the outbreak of disease, etc.

If the area of the individual ponds is too small, it inhibits production, whereas if it is too large, it becomes inconvenient from the standpoint of daily operations and maintenance. For fry ponds an area of

FIG. 8: The different pond shapes and their advantages/disadvantages

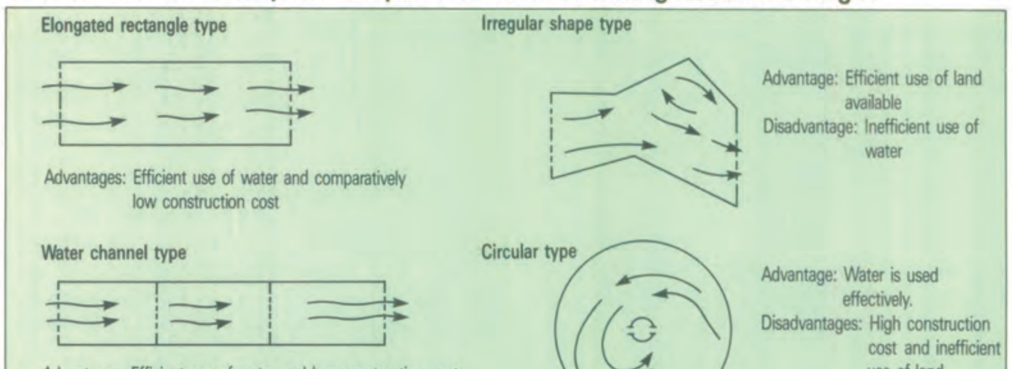
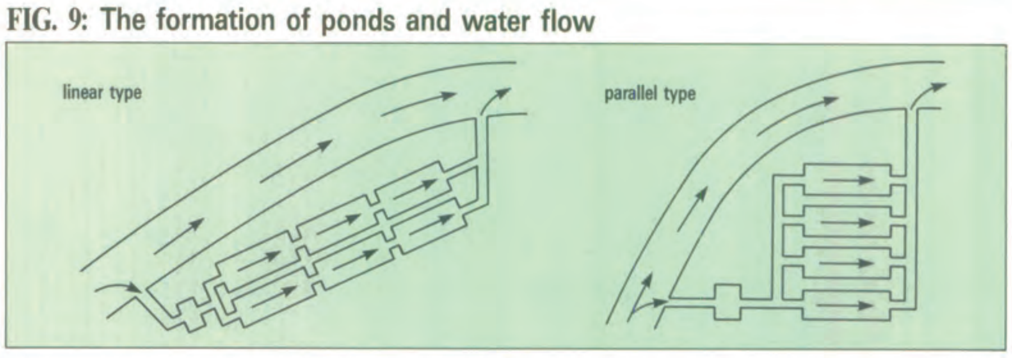
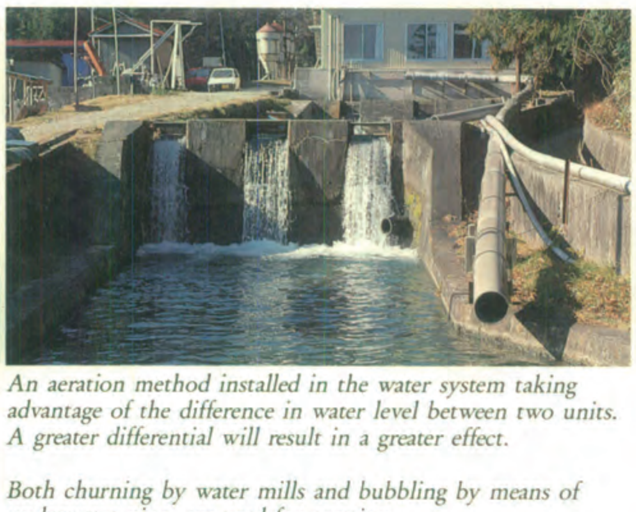


FIG. 9: The formation of ponds and water flow





An aeration method installed in the water system taking advantage of the difference in water level between two units. A greater differential will result in a greater effect.

Both churning by water mills and bubbling by means of underwater pipes are used for aeration.

$10\sim50m^2$ and adult ponds an area of $50\sim150m^2$ are considered suitable. The appropriate depth for the ponds, considering water circulating capabilities and operational aspects, is about 50cm for fry ponds, 60 ~ 90cm for rearing ponds and about 1m for adult ponds. When the ponds are too deep, the water tends to run along the upper layer, making for poor water circulation on the bottom layer.

Regarding the pond walls, in areas with hard soil, bare earth walls are sufficient, while in other cases walling of boards or stones is often used. Considered from the standpoint of durability, however, a ferro-concrete construction is probably best. For the pond bottom, with the exception of areas where the soil has especially poor water retention qualities or there is an especially high built-up of silt, a bare earth bottom is usually sufficient. In the case of the fry ponds, however, for the sake of maintaining a clean environment and simplifying cleaning and sterilizing operations, both the sides and bottom are always covered with ferro-concrete.

3 SEED PRODUCTION

From seed gathering to eyeing stage

FIG. 10 shows the seed production process for rainbow trout. In Nagano Prefecture the natural seed gathering season begins in November when the water temperature falls below 13°C and continues for about five months into March, with the peak season being in Nov. ~ Dec. The operations from seed gathering to the eyed-egg stage are as described below:

1 Separation of the males and females: In October, just before the spawning season, the fish that are being kept as parent fish are separated into different ponds according to sex to prepare for egg gathering.

2 Examining females for degree of gonad maturity: To determine when sufficiently mature eggs can be obtained, each female is examined individually by feeling the belly section. When complete gonad maturity has been reached, the entire belly section will feel soft to the touch.

3 Egg gathering: Egg gathering can be performed by one of two methods; squeezing the eggs out by hand, or injecting air into the belly to force them out. This facility uses the former method. After anesthetizing the fish by placing it in water containing a slight amount of 2-phenoxyethanol, the fish is placed on the egg gathering platform, held securely by the tail section and the eggs squeezed out. Mature eggs will have a yellowish color and a diameter of 5 ~ 6mm. One fish will yeild about 4,000 eggs.

4 Egg washing: Mixed in with the eggs that have been squeezed out of the fish will be burst eggs, feces, urine and blood. These impurities are cleaned away by washing the eggs several times with an isotonic solution.

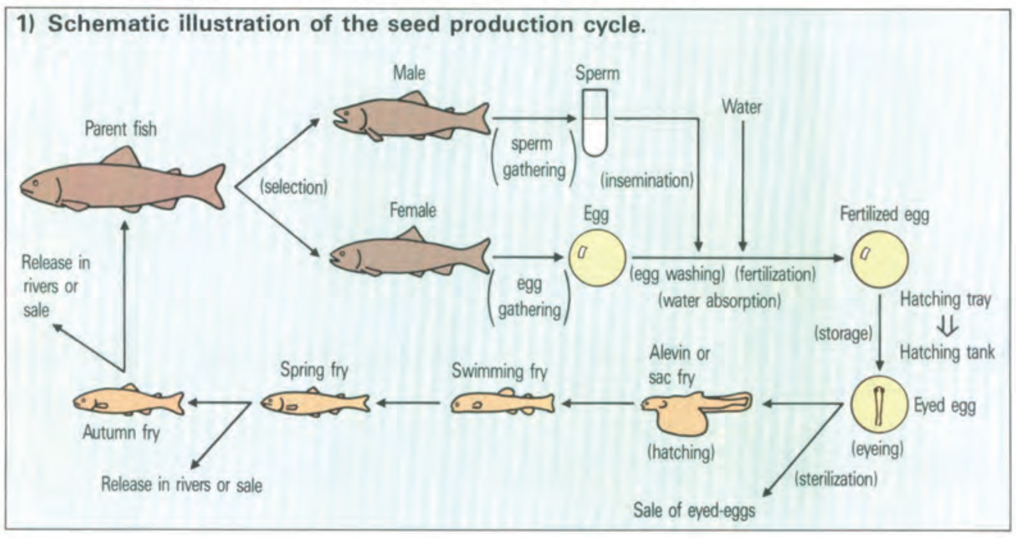
5 Gathering sperm: Sperm is squeezed out of a number of males.

6 Insemination: If the eggs are exposed to pure water before the sperm is spread on them, the water will cause the micropyle, a portal through which the spermatazoa pass into the egg to close, thus preventing insemination. Therefore, care must be taken to prevent water from getting onto the eggs. After covering the eggs with sperm, a feather is used to mix them together gently but quickly.

7 Microscopic verification: One drop of sperm is then removed and viewed under a microscope to verify that the spermatazoa are moving. If they are not, the insemination process is repeated.

FIG. 10: The egg production process for rainbow trout

1) Schematic illustration of the seed production cycle.



8 Insemination: If the microscopic inspection verifies that the spermatazoa are active, clean water is immediately added. With the addition of the water the spermatazoa begin to move actively and the insemination process is complete in less than a minute.

9 Water absorption: Eggs that have been inseminated begin to absorb water and become firm. During the period directly after insemination the eggs are very sensitive to vibration (shock), so they must be handled gently.

10 Storage: The fertilized eggs are next placed temporarily in hatching tanks. Since the eggs at this stage are sensitive to ultraviolet light, direct sunlight must be avoided.

11 Eyeing: After 15 ~ 20 days in the hatching tanks the eggs reach the eyeing stage. These eyed eggs are now able to endure vibration sufficiently to allow transport or shipping.

12 Egg inspection: About 93% of the fertilized egg batch will develop normally to the eyed-egg stage. An inspection is conducted at this stage for the purpose of removing dead (unfertilized) eggs and fertilized eggs which have not developed normally. First, the eggs are sent through a machine that automatically sorts out the whitened dead eggs. Then, the remaining dead eggs and fertilized eggs which show abnormal development are sorted out by hand. The introduction of egg inspection machines using photo-electric sensors to sort out dead eggs has dramatically improved the productivity of egg production operations.

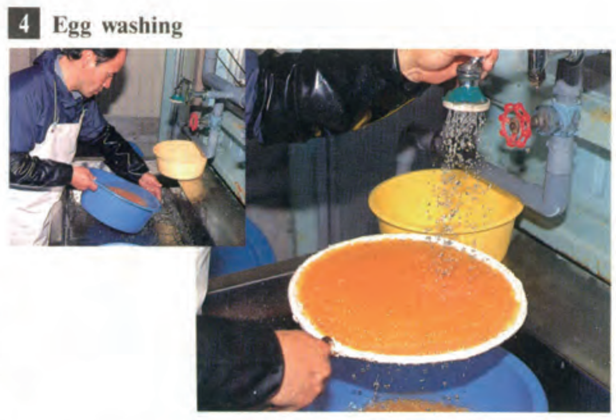
13 Sterilization before shipment: After the egg inspection process has been completed the eyed eggs are sterilized in a vat filled with an iodine solution. The purpose of this bath is to rid the eggs of viruses.

1 Separation of the males and females

2 Inspecting female parent fish for gonad maturity

3 Egg gathering

4 Egg washing



5 Sperm gathering

6 Insemination

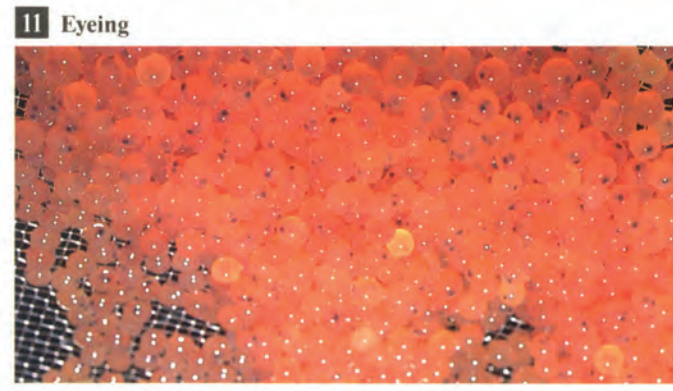
7 Microscopic verification

8 Insemination

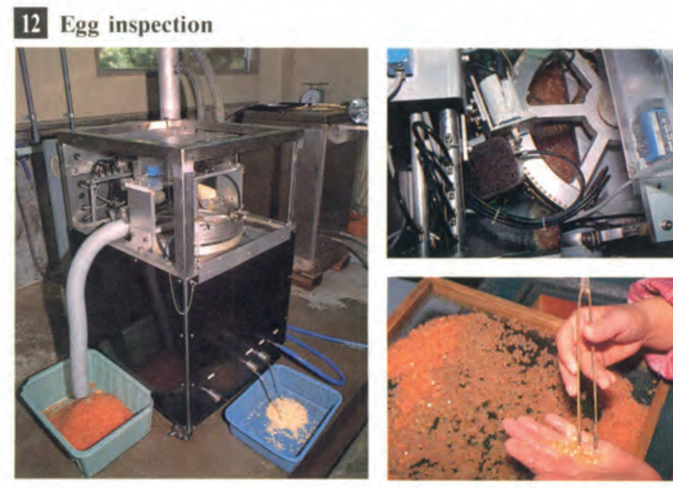
9 Water absorption

10 Storage in hatching tank (incubator)

11 Eyeing



12 Egg inspection



Hatching and feeding

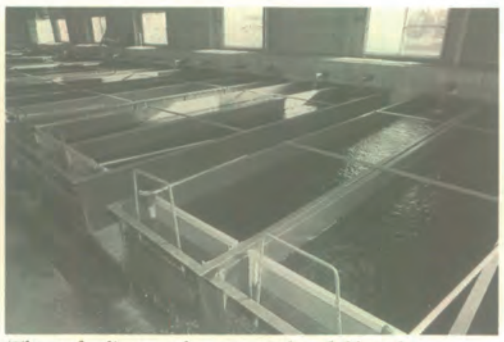
The eyed eggs which have been sterilized are then placed in hatching tanks under a flow of cold, clear water for 15 ~ 20 days to hatch. The suitable temperature range for hatching water is 7 ~ 15°. As long as it stays within this range, the warmer the water, the faster hatching will occur. This relationship can be expressed in terms of a set equation of the number of days to hatching (D) and the water temperature (T). In other words, TD = k. This is called the temperature - day - degree equation and it has a fixed value for each species of fish.

Immediately after hatching, the alevin carries the yolk sack under its belly section, is almost transparent in color and tends to lie quietly on the bottom of the hatching tank. After consuming all of the nutrients in the yolk sack, the young rise from the tank bottom, begin to swim and show a darkened color. When the commencement of active swimming is observed, the fry are moved to a feeding tank and the feeding process is begun. Feeding is done by means of man-made composite feeds in crumble form made of fish meal and flour with vitamin and mineral additives.

These feeds are prepared with all the nutrients necessary for healthy trout growth. Since it is best to keep the fry out of contact with the outside environment during this period when they are most susceptible to viral diseases, feeding tanks are set up indoors. These feeding tanks are made of a number of different materials such as concrete, wood, stainless steel and fiberglass.

Although growth rate will vary with the water temperature and feeding methods, in general the young will reach a size of 5 ~ 10g within 4 ~ 5 months of hatching. At this stage they are moved to an outdoor fry pond to begin the ordinary intensive culture process. Or, the fry may be sold as seeds to culture facilities in other areas.


A hatchery room. Some 3.6 million eggs are being kept here.


These feeding tanks are made of fiberglass. They are 90cm wide, 6 meters long and 50cm deep (water depth 30cm). One tank holds about 1.6 tons of water. In each tank are kept about 70 ~ 80 thousand fry.


A hatching tank. In this 50cm × 45cm × 40cm-deep tank are kept about 50,000 eggs.

A hatching tray. Eggs are spread across the tray in one layer and the trays are then stacked in the tanks.


Unconsumed feed and excretions are cleaned out of the tanks every day. To prevent the spread of viral diseases, each tank has its own cleaning brush that is used only in that tank.

4 REARING OF ADULT FISH

A year-round production system

Rainbow trout culture operators in Nagano Prefecture engage in the production of seeds for their own use in the months of October through March. **FIG. 11** shows a yearly schedule for home-use seed production based on a seed gathering season of Oct. to Dec. In the cases of these operators, the seeds are raised for one year after hatching and sold to market at a weight of about 100 grams. And, in addition to their own seed production, these operators buy eyed eggs or fry at different growth stages from other areas to supplement their own culture populations at three stages during the culture year; April ~ May, June ~ July and Aug. ~ Sept. This means that, at any time, each operator is keeping a number of groups of fish, each staggered in terms of growth stage by two or three months, that reach marketable size one after another in a way that enables him to continue shipments of rainbow trout on a year-round basis.

In order to achieve high productivity in a rainbow trout culture operation, it is necessary to use the available water resources efficiently without waste, while keeping the size of the culture population near the capacity level of one's ponds, and, through proper feeding, to successfully raise the population one has been able to secure to a harvestable size.

In order to do this, it is important to prevent the culture density from exceeding suitable levels by dividing the population and moving the groups to separate ponds at appropriate stages in the culture process, thus maintaining a favorable growth rate. This process is called "pond management" and constitutes one the single most important techniques in rainbow trout culture.

Selection

All the fish do not grow at the same rate. Inevitably, differences will emerge between the individuals in a given group. The fish that become dominant within a group will eat more and grow at a faster rate, while the weaker ones will be intimidated during feeding, eat less and show supressed growth. This phenomenon is especially prominent in the high-growth-rate fry stage, and in its extreme will lead to cannibalism and thus a reduction in the culture population. In light of this, throughout the culture process operators repeat a process of selection aimed at keeping fish of the same size together in any given pond. This process of selection by body size and separation into different ponds usually is performed four times during the culture period; at the 2 ~ 5g stage, the 10 ~ 20g stage, the 50 ~ 60g stage and the over-100g stage.

Selection is done by first gathering all the fish in one corner of the pond by means of a seine net, and then separating them by means of a sifter type sorting device. Such selection is performed with the intention of preventing cannabalism and other growth-deterring factors, as well as improving feeding management by ensuring that the ponds contain fish of similar body weight, and ensuring uniformity in product size when the fish are finally sold.

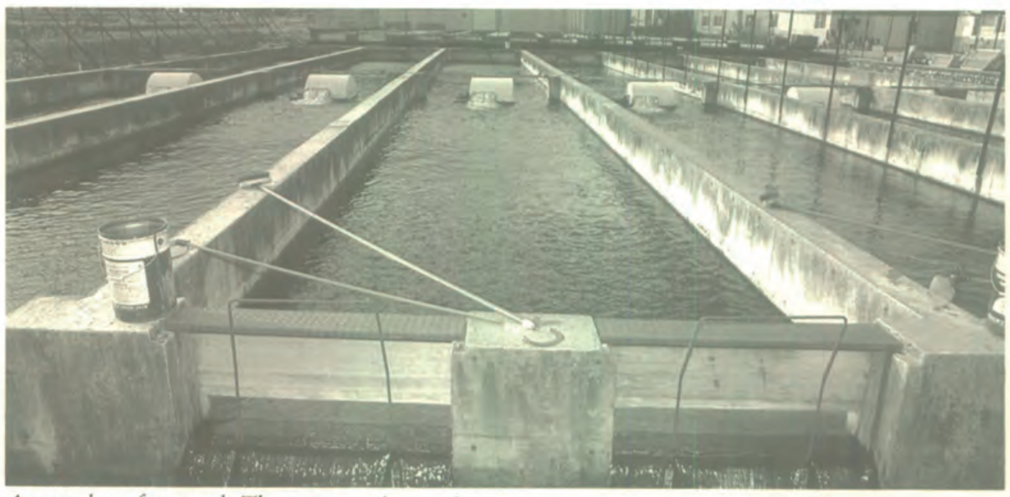
Feeding

Rainbow trout have a well-developed stomach that enables them to take in a considerable amount of food at one time. Therefore, a portion of the day's feed can be spread across the pond by hand all at once. At the start of the feeding stage the daily feed is divided into seven or eight portions. But, as the fish grow accustomed to the feedings, that number can be reduced to three or four times a day. When the fish reach adulthood one or two feedings a day are sufficient. However, it must be noted that not giving enough feed or giving feed in pellets of uneven sizes can hasten the occurrence of differing growth rates among individuals of the same group.

Composite feeds for rainbow trout have a high percentage of protein, ranging from 40 to 50%. In terms of size, the pellets are graded into seven or eight sizes for the different growth stages.

Preventing fish diseases

Aquaculture and fish disease have an inseparable relationship.


An outdoor fry pond. The outer perimeter is surrounded by a wire fence and a synthetic fiber net is hung across the top to prevent intrusion by birds and animals.


Selection (sorting) sieves. The fish are sorted out according to the guage of the wire mesh or the spacing of the rods. Six or seven such sieves with different mesh dimensions are prepared.


An adult-rearing pond

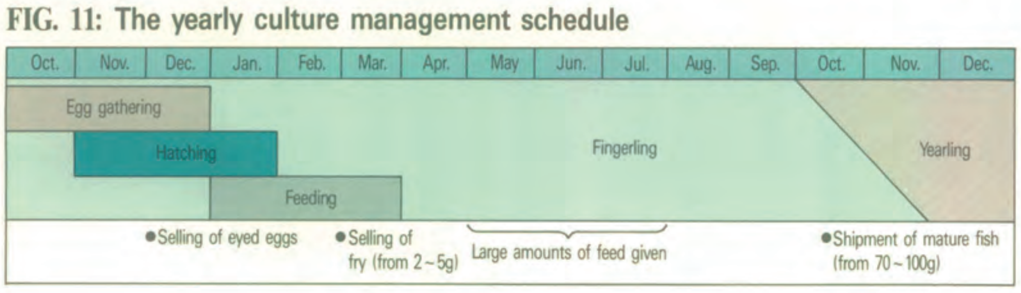

At the entrance to the culture pond area workers sterilize their boots with cresol solution.


The entrance of the sluice leading to the ponds (in background) is covered with a fence for catching debris like floating sticks and leaves. To ensure a smooth flow of water the fence is extended for some distance.


When landing the fish for shipment, they are first gathered in one corner of the pond with a seine net and then scooped out with a landing net.


A turtle-shell shaped culture pond. A descending slope extends toward the center where the drain is located.

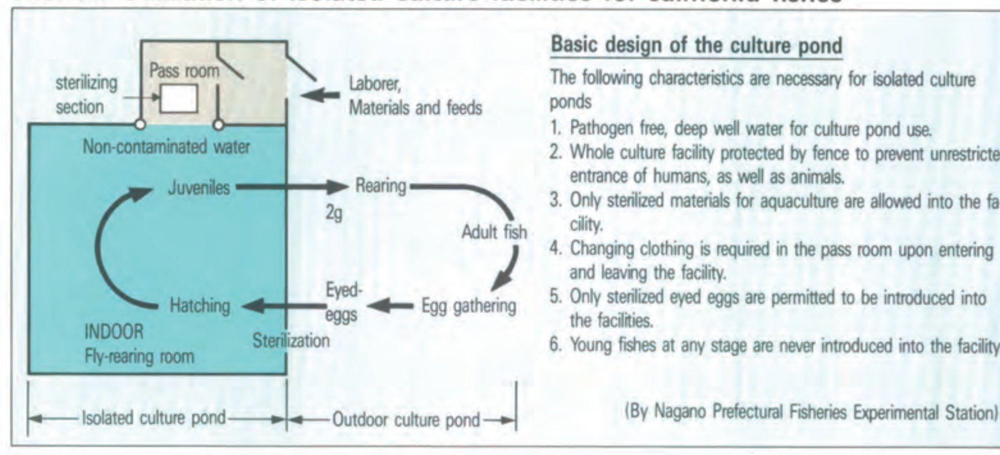
FIG. 11: The yearly culture management schedule



Prevention and treatment of diseases is one of the fundamental elements of aquaculture technology. One of the main causes of outbreak of disease is **1)** deterioration of the culture environment. Fouling of the pond water, excessively high water temperature, excessive culture intensity and excessive feeding are some of the primary causes of disease. Besides these, **2)** nutritional deficiencies in the feed, **3)** excessive nitrogen gas in the water and **4)** parasitic organisms can be cited as causes of fish disease.

With regard to disease spread by parasites, two viral diseases, an epidemic of Infectious Pancreatic Necrosis (IPN) in 1965, and an epidemic of Infectious Hematopoietic Necrosis (IHN) in 1974, have caused major problems in Japanese rainbow trout culture. In both cases, fry about one month after the start of the feeding stage proved the most susceptible, dying quickly and causing large culture losses. As of yet, no chemical treatments have been developed for these viral diseases. For this reason, the operators of Nagano Prefecture have adopted the practices of **1)** using virus-free subterranean water supplies in the seed production process, **2)** sterilizing the eyed eggs with an iodine solution and **3)** raising the young in quarrantined conditions during the fry stage, as the three basic principals in their disease-prevention efforts.

FIG. 12: Utilization of isolated culture facilities for salmonid fishes



Culture development with the prospects of game fish stocking

Roughly 40 years have passed since rainbow trout culture became a full-fledged industry in Japan in the years after World War II, and now the industry seems to be at a turning point in its history. When one looks today at the future of rainbow trout culture in this country there seem to be an exceptionally large number of variables influencing its course. Let us look at some of the factors that are influencing rainbow trout demand today.

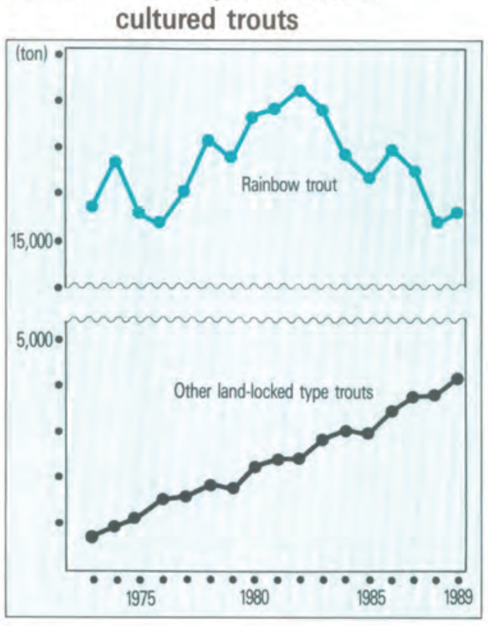
● For the past 12 years or so, rainbow trout culture production has remained fairly steady at 15,000 ~ 18,000 tons. At the same time, however, the culture of native land-locked type trout family fishes like "Yamame" (masu trout) and "Iwana" (Japanese char) is becoming more active every year. **(FIG. 13)** Complete aquaculture techniques for masu trout and Japanese char have been established in Japan since the 1960s. To the Japanese consumer, both of these fish carry a strong image of game fish caught in streams deep in the mountains and are loved as a special delicacy. Thus they fetch a high price at market as top class products. Whereas the producer's price for rainbow trout is ¥550 ~ 650 per kilogram, masu trout and Japanese char are traded at the high price of ¥1,000 per kg. This fact encourages culture operators to increase production.

● The culture of coho salmon, which began in Northeast Japan in about 1975, has been showing steady growth, with annual production exceeding 20,000 tons for the first time in 1989. The freshwater stage of coho salmon culture, from hatching to the smolt stage, has traditionally been conducted as a supplementary culture by rainbow trout culture operators in Nagano and Shizuoka Prefectures. Because of the high profitability of coho salmon fry culture, however, more and more former rainbow trout culture operators are turning over to this fry culture full time.

● Up until now, rainbow trout from about 100g up to as large as 200g have been the "regular size" sold on the market. Fish between 100 ~ 150g have been considered grilling size, while fish of 150 ~ 200g have been used as game fish. And, the one-year culture rotation that culture operators have used until now has been based on these market sizes. However, in recent years a culture system in which sterile triploid strains of rainbow trout are reared for 2 ~ 3 years to a size of 2 ~ 3 kilograms has been established. Because a high market price can be expected for these large-size fish as material for sashimi and other dishes, it is foreseeable that strategic changes in production patterns on the part of the operators aimed at this market will alter the future structure of rainbow trout supply.

● At present there are two main sales routes for grill-size rainbow trout; to hotels and inns in resort areas or to supermarkets in the urban centers where they are sold for household use. Demand in the latter market has begun to show growth in the last few years. With this popularization of rainbow trout as a household commodity, the traditional consuming areas, the mountain resort areas, are showing a tendency to change over to Japanese char or masu trout.

FIG. 13: Annual production of cultured trouts



Shipping fresh rainbow trout. Fish are packed in the round into syrofoam cases, covered with chopped ice and the lids sealed tightly.

Processing for frozen rainbow trout. The fish are cut open from the anus and the viscera and gills completely removed. After washing away the blood and thoroughly taking off waters, the fish are placed in individual plastic bags. The individually bagged fish are sorted according to size, packed in boxes and quick-frozen at −40°C.

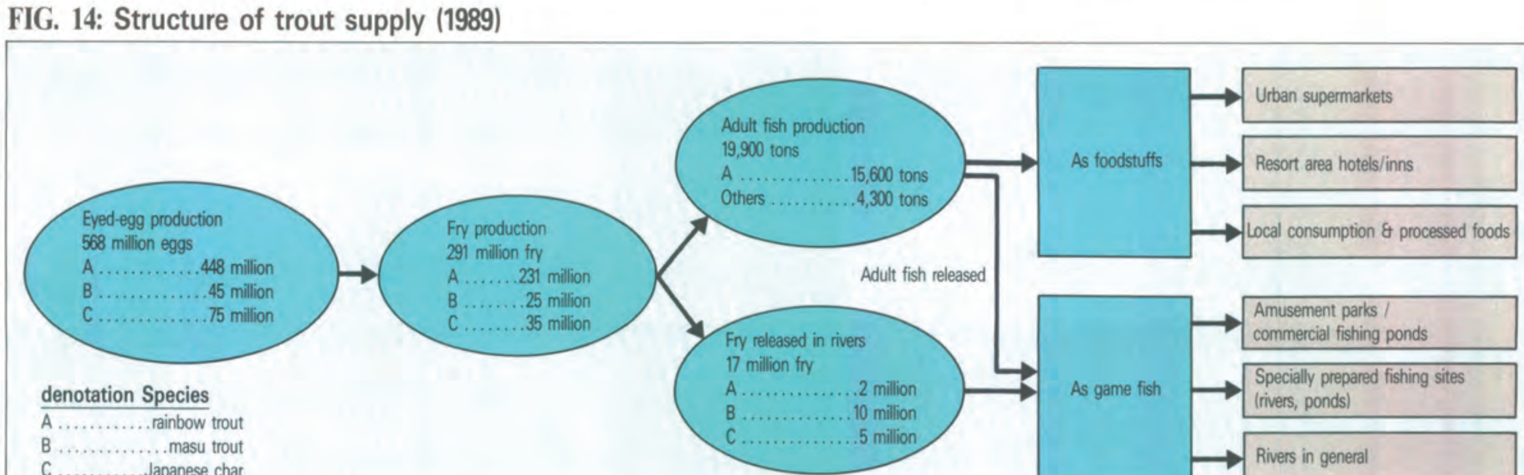
● The number of people enjoying game fishing in Japan's rivers and lakes is growing every year, and the population of freshwater game fishermen is now believed to exceed ten million. In response to this, the practice of stocking rivers and lakes with such freshwater fish as sweet fish, trouts, carp and crucian carp is on the increase. Concerning trouts, both fry and adult rainbow trout, masu trout and Japanese char are presently released every year in all parts of the country. In Japan the rivers and lakes are considered important recreational sites for the citizenry, and this fact bears a vital relationship with the freshwater culture of game fish. In the future this demand for game fish will certainly come to be considered a major sales route.

● The objects of game fish stocking can be divided into the stocking of cold water streams for the benefit of fly-fishing enthusiasts and stocking of specially prepared fishing stream or pond facilities frequented by families on holiday. With the former, Japanese char and masu trout are the primary fish, while the latter stock mainly rainbow trout.

There are two types of stocking practices; that in which partially mature fish of 40 ~ 50g are released in streams and rivers before the start of the fishing season in March, and that in which 150 ~ 200g adult fish are released in special fishing facilities repeatedly throughout the summer season. In either case, almost all the fish that have been released are caught during the course of the season in what is referred to as "put and take" type river management. However, with regard to Japanese char and masu trout, some fishery experimental stations are now engaged in research on river stocking techniques aimed at achieving natural propagation. In the case of rainbow trout, on the other hand, there are no expectations whatsoever of achieving natural propagation.

When all of these factors are considered, it becomes evident that the existing supply/demand system must be restructured, with the supply side being expanded to include native trouts like Japanese char and masu trout as well as rainbow trout, and the demand side being reconsidered in terms of foodstuff and non-foodstuff sales routes. **FIG. 14** shows the total nationwide supply of trouts for 1989. Although the supply of adult fish for release as game fish is not shown in this table, from speaking to producers it is possible to make a conservative estimate that about 5% of the total supply (approx. 1,000 tons) go for release purposes. When we add to this the portion released as fry recalculated in terms of 100g adult fish, we can estimate that at present 2,500 ~ 3,000 tons of trouts are being supplied to the citizenry as recreational resources.

FIG. 14: Structure of trout supply (1989)



Multi-faceted culture management in tune with local resources

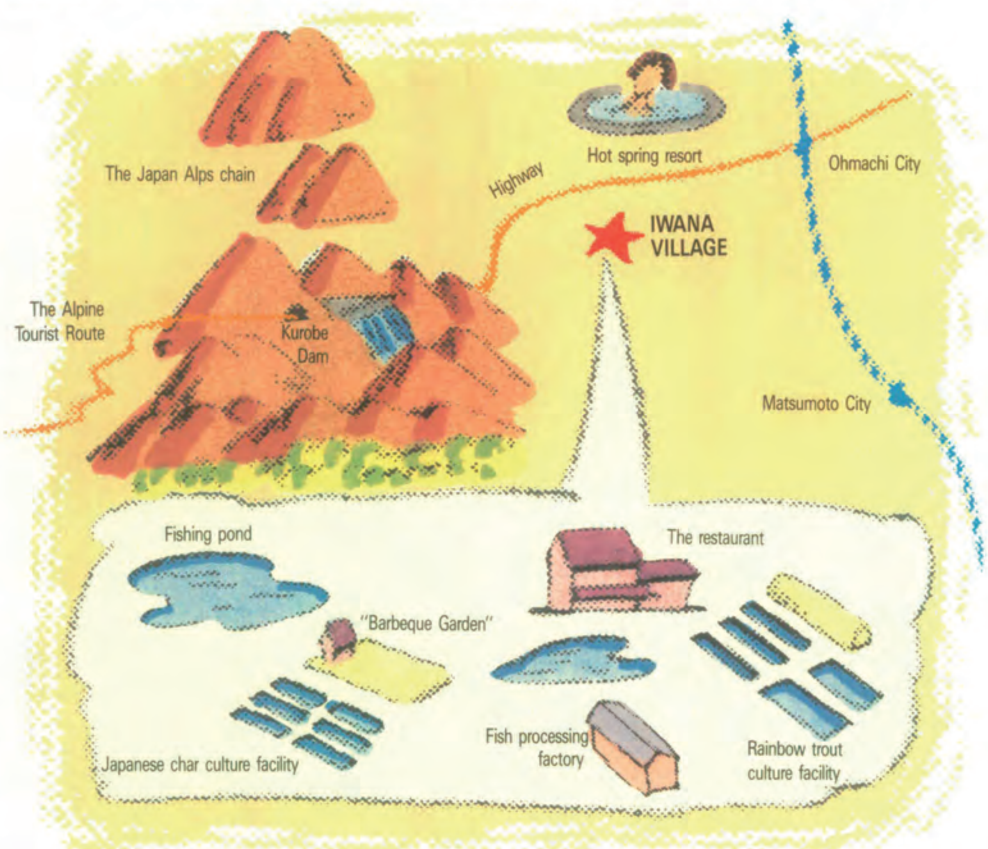
Developing adequate sales routes (markets) is said to be a prerequisite of successful aquaculture management. In the case of Japanese rainbow trout culture, it was the promotion initially of sales routes to the U.S. and later the development of wide-ranging domestic markets that have been responsible for its present prosperity. At the same time, however, development of demand in the local producing area must not be overlooked as an important potential base for commercial culture operations. In Japan, tie-ups with local tourist industries have been an especially effective method of establishing stable demand.

Here we will introduce an example of trout culture management that makes full use of the resources of a local tourist industry, through a successfully integrated system of production, processing and marketing.

Ohmachi City is a township located in northern Nagano Prefecture at an elevation of 1,000 meters. It is situated at the entrance to a popular tourist course that stretches from the Kurobe Dam to the Tateyama Alpine Route. During the spring, summer and autumn tourist seasons some 1.6 million tourists visit Ohmachi. Mr. Chinami Yanoguchi, who until twenty years ago had made his living at rainbow trout culture and wasabi growing, took up the culture of Iwana (Japanese char) after moving to Ohmachi. His decision was based on the abundant supply of water not exceeding 14～15°C in the summer season, and the area's advantage as the access point to a large tourist area. With the profits from his first year's culture production Mr. Yanoguchi opened a fishing pond and "Barbeque Garden", which soon became a popular haunt of families in the prefecture. Ten years of business provided Mr. Yanoguchi then with the means to plan the next stage of development. In his 15th year of business he constructed both a culture facility and a restaurant. Built in a garden-type layout on a large plot of land, Mr. Yanoguchi's new facility included a restaurant, culture ponds and a processing factory. Advertising his new complex as "Iwana Village", he soon succeeded in contracting with tour bus companies operating on the Kurobe-Tateyama route to schedule courses with a lunch stop at his establishment.

The culture facility has an annual production of about 50 tons of two year-old Japanese char (80～100g), 30 tons of yearling rainbow trout (130～150g) and 50 tons of 3 year-old rainbow trout (approx. 1 kg), for a total production of 130 tons. The sales routes for this production are varied, including the following:

FIG. 15: The location of the all-around trout culture farm "Iwana Village"



1) At the restaurant various kinds of trout dishes are prepared and served to the customers.
2) Supplying fish to customers through the fishing pond and Barbeque Garden where they can cook what they catch.
3) Fish are sold to hotels and inns in the Ohmachi and Matsumoto areas.
4) Various types of fish delicacies are prepared at the facility's processing factory and sold mainly to hotels and inns.
5) Fish are sold to the urban centers through the network of fisheries cooperative associations.

In this way, a management system has been established in which one-third of the culture production is sold directly to the facility's customers, one-third to establishments in the local tourist industry and one-third sold as processed foods produced at the facility's factory. No special effort is made to sell large quantities of products to the urban markets. Among the processed foods produced at the factory are smoked fish, fish preserved in olive oil, fish boiled in sweet sauce, salted fillets, minced fish wrapped in "kombu" seaweed, "ikura" (salted trout roe) and "shiokara" (salt-preserved trout innards).

In his management policy, Mr. Yanoguchi strongly emphasizes two points; **1)** maintaining the high-class image of "Iwana" dishes in the promotion of his restaurant, and **2)** achieving good profitability by constantly pursuing added value in his processed foods and the dishes sold at his restaurant. In addition to 20 full-time employees, his establishment employs about 20 part-timers during the summer season. Each year the establishment serves some 30,000 customers at the Barbeque Garden and another 30,000 at the restaurant, and annual sales total ¥260 million.

A full course dinner of Iwana and rainbow trout dishes (upper left)
The restaurant (bottom left)

At the Barbeque Garden people can grill the fish they have just caught themselves.

Processed foods made at the Village on sale (center).
Smoked Iwana (photo right) and sweet-boiled (caramelized) Iwana (photo left).
Processed foods factory (right)