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The Wealth in Seaweeds
from nutritious foods to industrial materials

According to FAO statistics, over 30 countries around the world produce a total yearly harvest in recent years of between 3.1 ~ 3.8 million tons (wet weight) of seaweeds, which are used profitably either for human consumption or as raw materials for processed goods in a number of industries. Among these countries Japan, along with Korea and China, ranks as one of the major producers as well as a principal consumer of these seaweeds, **(TABLE 1)**.

Throughout their history, the Japanese people have made abundant use of seaweeds. For example, in ancient times they burned seaweeds to produce salt from their ashes. With the development of agriculture, people learned to plow seaweeds into their fields as a form of fertilizer, and to use them as feed in animal husbandry. In modern times, with the appearance of chemical industries, seaweeds were used abundantly for some time as a source of potassium and iodine. However, compared to these non-edible uses, the Japanese use of seaweeds as foodstuffs for human consumption have always been more active and enduring.

In inland areas as well as coastal areas, seaweeds have long been eaten as substitute types of vegetable "greens", and, in times of need, as a nourishing emergency food. Since the 17th century, with the development of nationwide trade infrastructures for foodstuffs, and with the development of processing industries producing regional specialties, seaweeds assumed a larger and lasting place in the Japanese diet.

Traditionally, the staple of the Japanese diet has been made up of grains, tubers and beans, with seafood and vegetables to supplement them. To this basic diet the Japanese have added seaweeds as a unique supplementary food or an ingredient in a variety of dishes. Through this long history of culinary adaptation, the Japanese have developed an appreciation for the special taste and texture of a variety of seaweeds.

At two periods in its modern history, the opening of Japan to foreign trade in the Meiji Period (1868 ~ 1912) and the rapid economic growth period following World War II, Japan has undergone intense stages of "Westernization" in which the country's eating habits have also changed dramatically. But the Japanese love of seaweeds has not changed, and even today seaweeds enjoy a stable place in the national diet. **(FIG. 1)**

There are roughly 50 species of seaweeds that the Japanese eat, but the largest volume of consumption falls among the three groups of laver [*Porphyra*], kelp [*Laminaria*] and *Undaria*.

With regard to these three groups, the Japanese have engaged since olden times in not only the gathering of naturally occurring seaweeds but also a variety of methods of artificial proliferation and marine culture. In the 1960s, the techniques for the artificially induced germination of laver were perfected, and this turned out to be a revolutionary advancement. As a direct result, culture activities for laver quickly spread throughout the country. Subsequently, artificial germination techniques for Undaria and kelp were also undertaken and perfected, resulting in a dramatic increase in their production, as well. Entering the '70s, germination techniques for a number of other species of seaweeds were developed and their culture came to constitute significant local industries in the various regions. Some examples include "hitoegusa" [*Monostroma latissimum*], "matsumo" [*Analipus japonicus*] and "okinawamozuku" [*Cladosiphon okamuranus*].


Harvesting cultured kelp in the Japanese producing area, Hokkaido. Although kelp can be raised in areas other than Hokkaido, factors like water temperature and nutrient salts in the regional waters make it difficult to raise quality kelp.

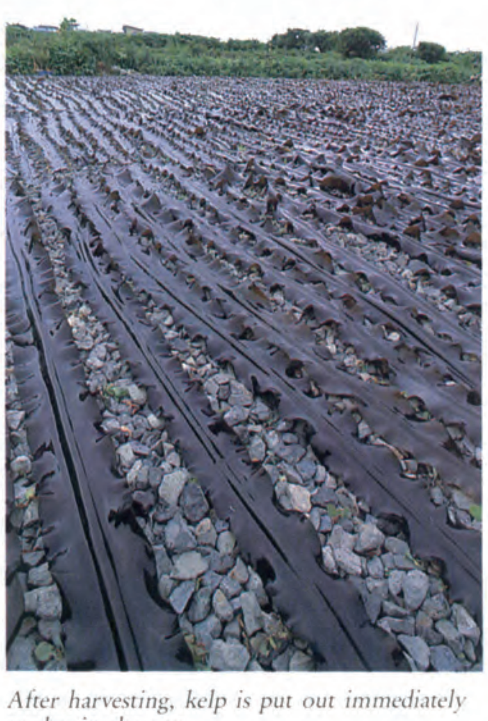

After harvesting, kelp is put out immediately to dry in the sun.

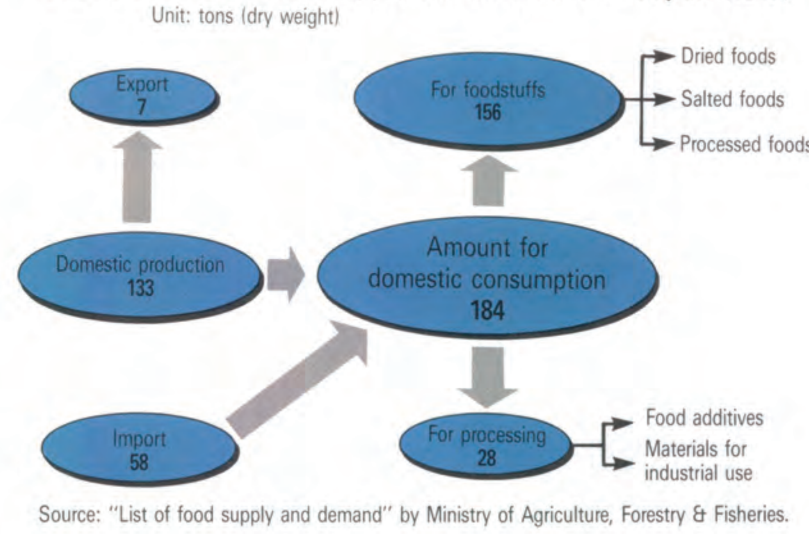
TABLE 1 : World Seaweeds Production (1987)

	Brown algae Paeophyta	Red algae Rhodophyta	Green algae Chlorophyta	Other seaweeds	Total
World total	2,160,667	972,957	12,596	97,231	3,243,424
China	1,073,400	122,850	–	–	1,196,250
Japan	294,516	330,549	1,284	37,772	664,123
Korea	339,289	93,140	11,248	12,979	456,715
The Philippines	–	222,003	–	–	222,003
Norway	174,109	–	–	–	174,109
Chile	33,532	83,643	–	–	117,115

Unit: tons (wet weight) (Source: FAO statistics)

FIG. 1 : Demand and supply for seaweeds in Japan (1987)

Unit: tons (dry weight)



Source: "List of food supply and demand" by Ministry of Agriculture, Forestry & Fisheries.

Tripolar structure provides immeasurably great utility

Preserved foods	Health foods	Colloid materials

Biological characteristics of seaweeds

The term "seaweeds" as we shall use it here means leaf-forming species of algae that grow in sea water. Algae contain a wide variety of species from single-cell organisms to multi-celled plants with an equally wide variety of body forms and life cycles. Among these, the ones called "seaweeds" are limited to those with large body forms that are visible to the naked eye, and include three botanical groups - green algae [*Chlorophyta*], "red algae" [*Rhodophyta*] and "brown algae" [*Phaeophyta*].

Since seaweeds live in seawater with high salinity, their cell walls are thicker than land plants, having developed a special structure for controlling the passage of ions. Their cell walls consist of a cellulose framework embedded with gelatinous polysaccharides. In the case of brown and red algae, intercellular polysaccharides usually account for about 30% of the dry weight of the algae cell. These cellular carbohydrates give the seaweeds a strong and flexible body composition that helps make them suited for life in the seawater environment.

Preserved foods, health foods and colloid materials for industrial use

The uses that the Japanese have found for seaweeds over the years go beyond their culinary and nutritional values as a food for human consumption. In the mid-17th century, the Japanese learned to cook "tengusa" [*Gelidium amansii*] into a gelatin consistency and cool it to make a jelly-type food called "tokoroten". This "tokoroten" was later found to be useful when freeze-dried and powdered into an agar called "seaweed gum" suitable as a base for raising bacteria, etc. in medical research and other industrial uses.

Furthermore, in recent years it is being proven that a variety of organic substances found in seaweeds have medicinal effects on the human body.

The useful qualities of seaweeds can be divided basically into three areas. It is **1)** a food with good preservation characteristics, **2)** a health food with medicinal qualities, and **3)** a seaweed gum that is a good source of colloid material for industrial use. With regard to all three of these qualities, the high percentage of polysaccharide in the seaweeds seems to be an important factor.

Processed foods from seaweeds

In Japan seaweeds are eaten in a number of ways. Some are eaten raw in salads, some are flavored before eating and some are made into processed foods. However, the fact that so many species are eaten in so many ways can be seen as the result of an early recognition of the fact that, when processed in the right way, they became long-lasting and easily stored preserved foods. Here are some of the observations that surely led to the use of seaweeds as processed foods.

1) When dried seaweed is soaked in water again it regains its original shape and can be eaten with very little loss in nutritional substance or texture.

2) The common seaweed dish "tsukudani", which is made by cooking seaweed in soy sauce, can be left out for several days without losing its density or without its liquid component separating out.

3) "Dried laver" is made by chopping up the seaweed and setting it out to dry in thin sheets. In this process, the resinous substance that exudes from the seaweed serves to paste the leaf fragments together and give the sheet a shiny external gloss.

These food qualities are all due to the functions of the intercelluar polysaccharides.

The processing methods for seaweeds include simple drying (kelp, Undaria, laver), drying with flavoring (laver) salt preserving (Undaria, mozuku), "tsukudani" (kelp, Undaria, laver and hitoegusa), and other flavored processing (for all types of seaweeds).

Seaweeds as health foods

The cell wall materials and internally stored substances which seaweeds produce through photosynthesis are extremely diverse in terms of their chemical composition. This fact gives seaweeds their exceptional value as health foods.

1) Modern nutritional studies have shown that seaweeds contain a great amount of vitamins and trace minerals essential to the human body.

2) We have learned that some of the unique organic substances found in seaweeds help in the prevention of the degenerative diseases. For example, the fucosterol found in kelp and Undaria is believed to reduce blood cholesterol and prevent thrombosis in the blood vessels. Also, experiments with mice have shown that alginic acids are an antitumor agent.

3) Recent studies have also focused attention on edible seaweeds as a valuable source of dietary fiber. The polysaccharides of seaweeds are not dissolved by the digestive juices of the stomach, but they are broken down by the bacterial action in the large intestine. In short, their difficult-to-digest complex carbohydrates act to stimulate the digestive function of the intestines, thereby envigorating them.

Both "Nori rolls" and "Onigiri" (top left) are rice delicacies wrapped in sheet form laver (below left). Salted for long-term preservation this Undaria (below center) is rinsed in water before using in "wakame salad" (top center). Agar-agar (below right) is used to add cohesion to foods like ice cream or sauces.

Seaweed gum as a source of colloid

Polysaccharides are high molecular compounds composed of carbohydrates. Among such high molecular compounds, the water-soluble ones which form colloids create those material characteristics of viscosity or gelation when coupled with water.

Utilizing the chemical behavior of these colloids, people have long employed hydrophilic polymerised compounds as a wide range of stabilizing agents that induce thickening, suspending, gelling, emulsifying, film-forming and so on.

The existing applications for water-soluble polysaccharides are so numerous and diverse that they can be used for a wide range of products, from ingredients for foods, cosmetics and pharmaceuticals, textiles, paper making, paints, printing inks, adhesives and detergents to building materials and many other industrial products.

In the commercial market, the seaweed gums derived from the intercellulor tissues of seaweeds compete with seed gums such as guar guam and locust bean gum, with plant extracts (arabic gum and pectin for example), and with bio-synthetic gums like xanthan gum and others. However, because seaweed colloids offer distinct chemical and economic advantages, the gums can be trusted as a healthy food source and as practical source of various industrial materials. **(TABLE 2).** Today, the main industrial seaweed products employing polysaccharides include **(1)** Alginic acid derived from brown algae, **(2)** agar-agar found in the red-algae Gelidium and Gracilaria, and **(3)** carrageenan derived from the red algae Chondrus and Eucheuma.

Seaweed gum production in recent years can be summarized as in the following table. In Japan, with the exception of the raw material for "tokoroten", seaweed materials for industrial use come entirely from imported produce.
(TABLE 3)

TABLE 3 : Production of seaweed-derived polysaccharides

	World production	Japanese production	Japanese import
Alginic acids	15,000	1,500	500
Agar	8,500	1,700	700
Carrageenan	15,000	700	800

TABLE 2 : Uses of seaweed gum

Uses	Products	Main Functions
Food Additives	Dairy products	Gelation, foaming & suspension
	Baked goods	Improving quality & controlling moisture content
	Sweets	Gelation, increasing viscosity & suspension
	Sauces & juices	Increasing viscosity & emulsification
	Alcohol brewing	Percipitation of suspended matter
	Processed meats	Adhesion & prevention of juice separation
	Frozen fish products	Adhesion & moisture retention
Cosmetics & Pharmaceuticals	Shampoo	Interface vitalization
	Tooth paste	Form retention & increasing viscosity
	Milky lotion	Emulsification
	Tablets	Coking
	Laxatives	Indigestibility & lubrication
	Bacterial agar	Gelation
	Dental moulding material	Form retention
Other industrial uses	Paints	Increased viscosity & suspension
	Thread making	Prevention of thread breaking
	Textiles	Increased printing viscosity
	Paper making	Sizing
	Starches & adhesives	Increasing viscosity
	Pottery making	Suspension
	Casting	Molding sand coking
	Welding rods	Coking

FIG. 2: Life cycle of aosa (Isomorphic alternation of generations)

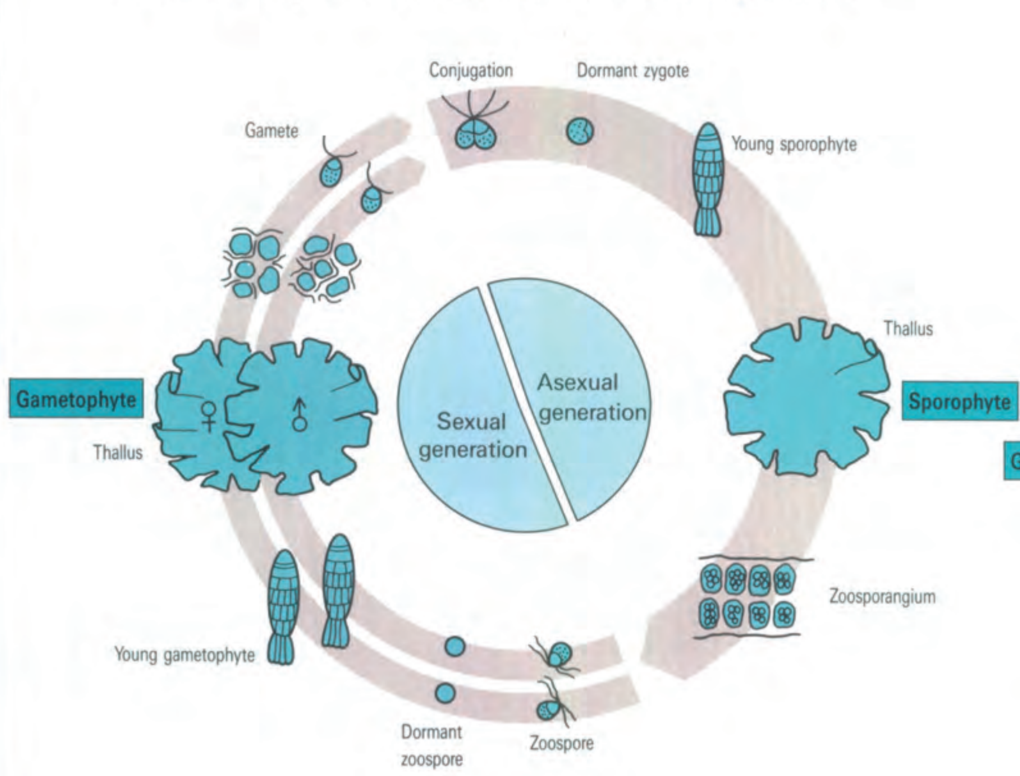


FIG. 3: Life cycle of kelp (Heteromorphic alternation of generation)

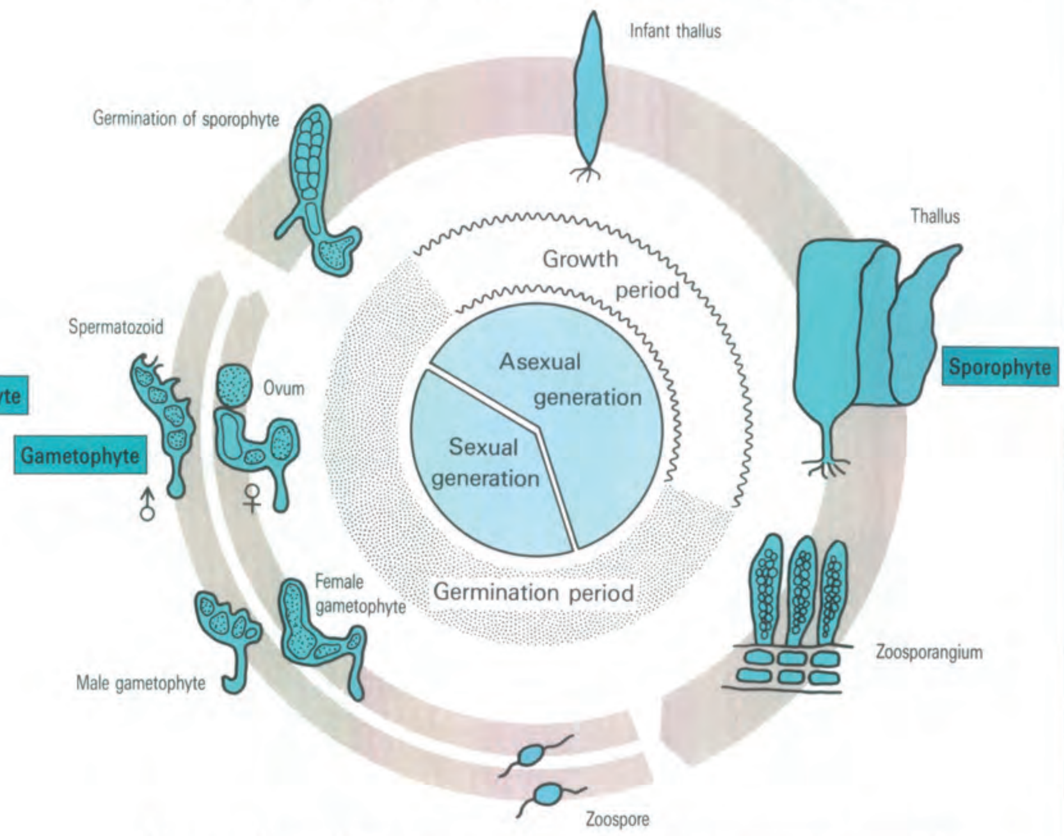


FIG. 4: Life cycle of laver (Heteromorphic alternation of generations)

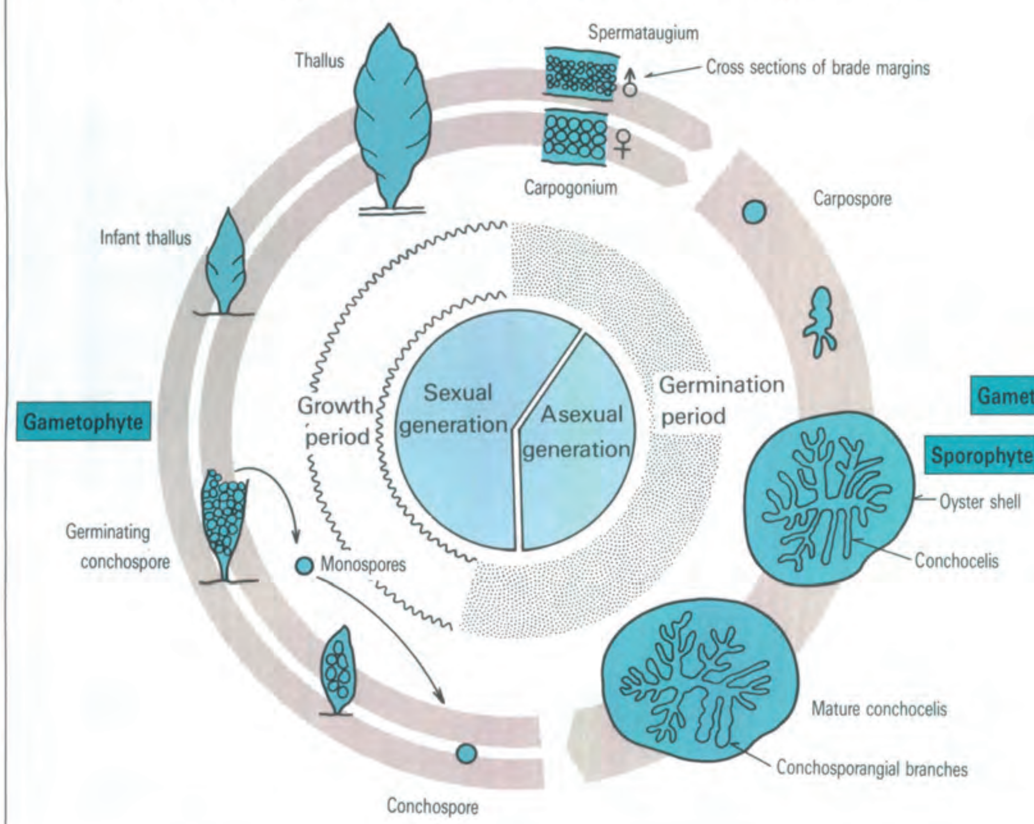
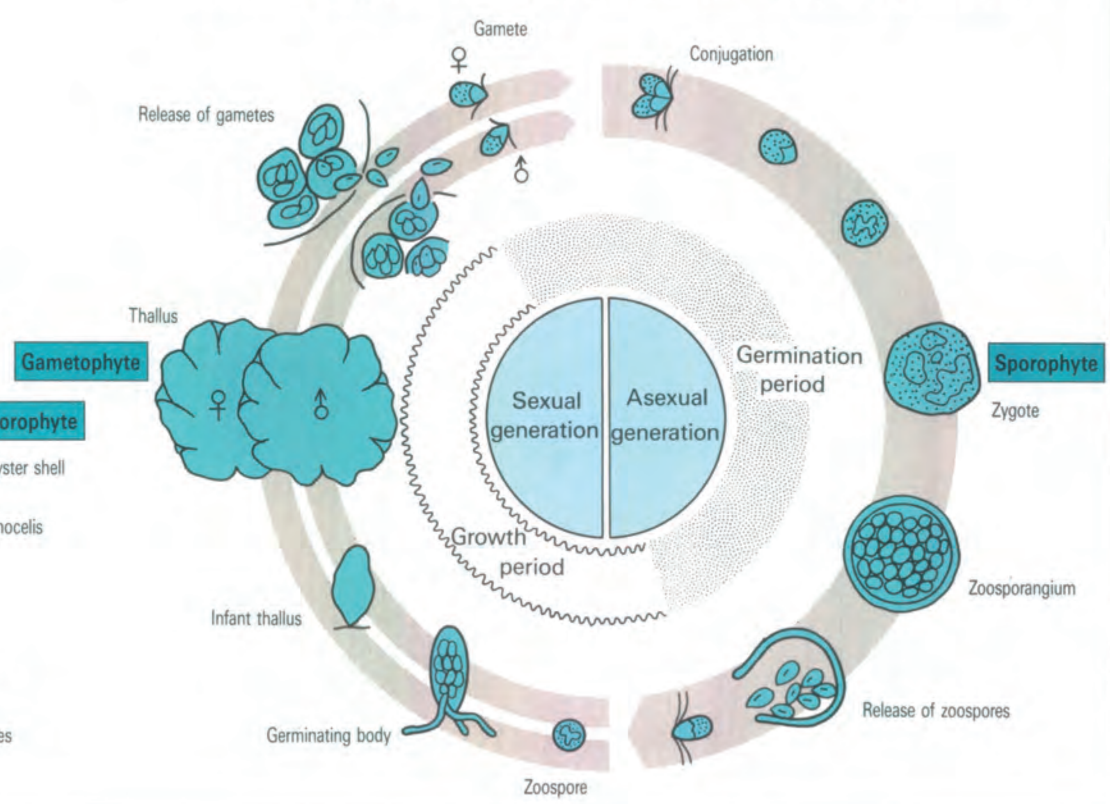


FIG. 5: Life cycle of hitoegusa (Heteromorphic alternation of generations)



The Life Cycle of Seaweeds

When the British algologist Kathleen M. Drew published a report about her experiments concerning the germination of laver [*Porphyra*] carpospores in 1949, it created a sensation among seaweed specialists around the world. What she proved was that the microscopic threadlike seaweed found growing in the calcareous surface of shells, previously known as conchocelis, was in fact nothing less than the germinating form of the carpospore released in the spring from the phyllomic female laver. This discovery filled in the "missing link" in the life cycle of laver. After that, many Japanese researchers began to investigate the remaining blank spots in the life cycle of laver until its entire life history became clear.

By the middle of the 17th century Japanese fishermen had learned methods for getting laver conchospores to attach themselves to bamboo poles driven into shallow water areas and germinate there, and this led to widespread culture of the natural seeding type. After the appearance of Drew's report, however, Japanese seaweed researchers experimented with the seeding of shells with laver carpospores and raising conchocelis over the course of a summer. The success of these experiments then led to the perfection of artificial seed production techniques for laver.

As this episode demonstrates, the birth of modern culture techniques for seaweeds has depended on clarifying the life cycle of the particular species involved and then finding a way to employ the mechanism of its reproduction process.

In land plants, sex differentiation is simple, but with regards to seaweeds different reproductive patterns have been recognized. And, among these, many species produce both sexually differentiated and non-differentiated reproductive cells in the course of their overall life cycle in a pattern of "alternation of generations". By a "generation" we mean a period in which the individual seaweed begins to produce reproductive cells at one point while supporting its life through the metabolism of stored nutrients. In this way, when we have a phenomenon in which the individual seaweed produces alternating "generations" with differing reproductive processes during its life cycle, it is called "alternation of generations".

In the alternation of generations in seaweeds, an investigation of changes in the nuclear phase in cell chromosomes reveals extremely complex patterns. It is best to think in terms of the two principal patterns known as isomorphic alternation and heteromorphic alternation of generations.

Isomorphic alternation of generations: This is the type in which the gametophyte (sexual) and sporophyte (asexual) are exactly the same in terms of configuration and body shape. Only the nuclear phase and the reproductive organs differ. Examples of this type are Ulva and Enteromorpha.

Heteromorphic alternation of generations: This is the type in which the configuration and body shape differ between the sexual and asexual generations. Either the gameophyte or the sporophyte will develop into a thallus of macroscopic proportions while the other remains a threadlike or spherical body of microscopic proportions. An example of a seaweed in which the sporophyte develop especially large is kelp. Seaweeds in which the gameoplyte develop are divided between monoecisms like laver and dioecious like hitoegusa.

The life cycles of "aosa", kelp, laver and "hitoegusa" are shown in **FIG. 2~5.**

Culture technology for seaweeds consists of two techniques; the cultivation of reproductive cells at the microscopic stage and the raising of thallus in the macroscopic stage. The process of cultivating reproductive cells is referred to by the term "seed production". It involves **(1)** gathering of gameophytes or sporophytes released by the mother seaweed, and **(2)** keeping them in indoor tanks under the proper water temperature, water quality and lighting conditions.

Raising of the thallus consists of; **(1)** first getting the reproduced reproductive cells to attach to a net or other artificial attaching material like ropes, **(2)** hanging out these nets or ropes in sea areas with favorable water conditions once they have germinated, and **(3)** raising the thallus to a harvestable size under a controlled schedule that involves such steps as prevention of foreign plant growth, weeding out and sun-drying.

At present, most of the seaweeds being produced by "full-process" culture involving the artificial production of seeds are heteromorphic alternation of generation types. An example of an isomorphic alternation seaweed that is cultured with artificial seed production is "sujiaonori" [*Enteromorpha prolifera*]. However, since the demand for sujiaonori is not large and it requires clearwater raising grounds at the mouths of rivers, the number of regions involved in its culture are limited.

Regarding other isomorphic types like "tosaka-nori" [*Meristotheca papulosa*] and "tengusa" [*Gelidium amansii*], research has begun on artificial seed production technology but, as yet, there is no prospect of practical application in the near future.

Seaweed Culture in Japan

Regarding marine products like seaweeds, shellfish and crustaceans, that inhabit shallow sea areas in a sedentary manner, Japanese fishermen and farmers have employed systems of communal harvest rights on the local level since olden times. This is in fact a habitual carryover from the contribution systems established by regional lords in the feudal period.

In the coastal areas with rich marine resources, their production went beyond supply for the economic self-sufficiency of local farmers and fishermen. They became important products to help stimulate a commodities market economy in certain areas. The important examples are the kelp of Hokkaido and the Asakusa-laver of Tokyo Bay. These seaweeds became special products in these areas in the Edo Period (17th ~ 19th centuries).

As Japan entered its period of modernization in the Meiji Era, capital investment in offshore and open sea fishing ventures became prominent, while traditional coastal fisheries were left behind in a state of poverty and stagnation. In the coastal fishing villages, the pre-modern social class and labor system of "net owners and boat owners vs. fishermen" remained. Under this system the fishermen worked communally operating large-scale net fisheries such as set net, boat seine, dragnet and square net. Because these fisheries are directed at a specific type of fish, they tend to be highly seasonal labor. During the off-season for these fisheries, the fishermen filled out their yearly income by conducting a variety of businesses depending on the geographical characteristics of their areas. For example:

- **Conducting farming as a side-business to their fishing**
- **Conducting a combination of "small-scale fishery" such as pole-and-line, longline and gillnet.**
- **Gathering shellfish and seaweeds**
- **Hiring out their services for offshore fishing or other occupations on land**

Along with shellfish and other sedentary marine animals, seaweeds were a valuable and easily attainable source of income for coastal fishermen. But from the point of view of making a living, they remained nothing more than a supplementary source of income.

After World War II, and particularly after the 60s, seawater culture fisheries have played an important role in increasing the number and the income of fishermen concentrating solely on coastal fishery. The fishing families depend mainly on family labor to conduct their culture operations, and income per family member surpassed that of fishing families operating boat-oriented fisheries. By the late 1970s we see that they had also achieved an income comparable to that of city workers. (**FIG. 6**) Between the years 1960 and 1987 the total production from marine culture quadrupled from 284,000 tons to 1,137,000 tons. In terms of product value it accounts for 40% of the entire production from Japanese coastal fisheries. The total produce of marine culture in 1987 was valued at ¥492.1 billion, and of this seaweed culture accounted for ¥135.1 billion.

The establishment of independently run fishing businesses based on marine culture among Japan's coastal fishermen was made possible by a number of social and historical movements. The main factors involved can be cited as below:

1) Revision of the Fisheries Act in 1962 called for the democratic operation of all shallow sea fishing grounds under the basic principle of control by fishery cooperatives.

2) A government program for the advancement of coastal fisheries made investment funds available to fishermen in the form of long-term, low-interest loans.

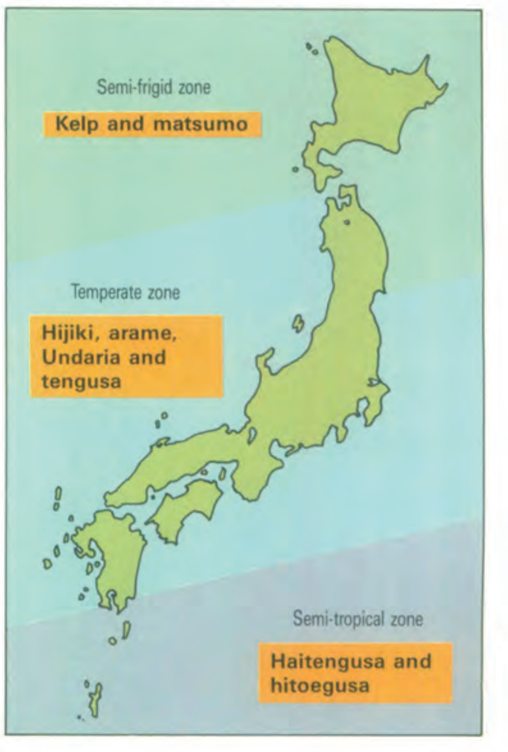
3) New products from the petro-chemical industry like synthetic fiber nets made the building of culture facilities much easier.

4) Fishing boats motorized by means of small engines vastly improved operating efficiency.

5) Rapid economic growth and the resulting rise in per capita income increased the demand for the products of culture fisheries.

The seaweed species inhabiting Japanese coastal waters can be divided into three groups; those living in the semi-frigid zone, the temperate zone and the semi-tropical zone. (**FIG. 7**) In the semi-frigid zone, large Paeophyta like kelp [*Laminaria spp.*] and "matsumo" [*Chordaria spp.*] dominate, forming homogeneous groves.

FIG. 7: Life zones for Japanese seaweeds



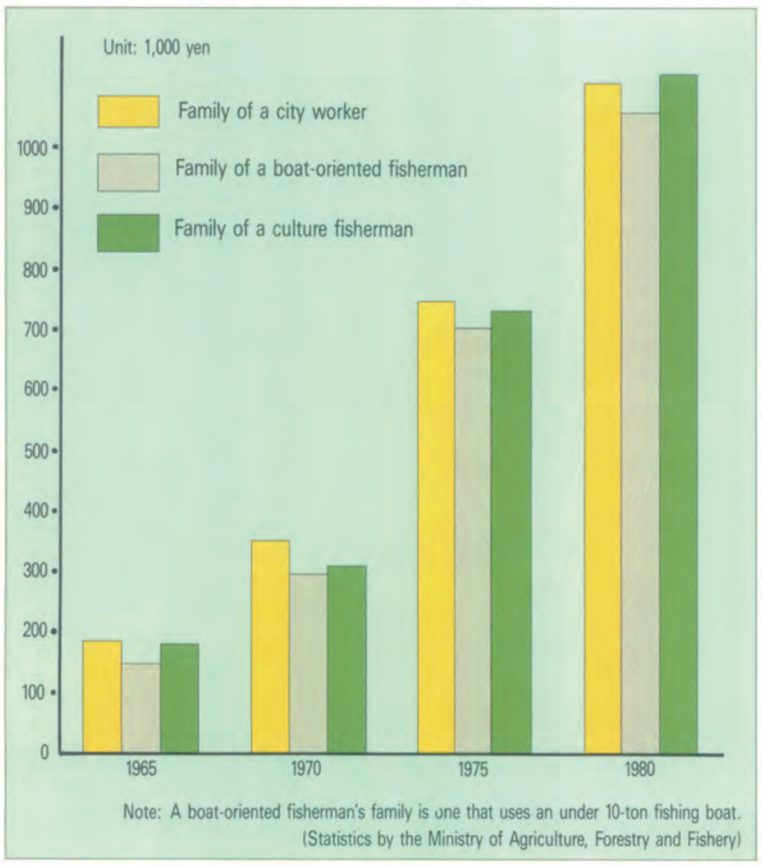
In the temperate zone, numerous varieties of warm current species like "hijiki" [*Hizikia spp.*], "arame" [*Eisenia spp.*], Undaria [*Undaria spp.*] and "tengusa" [*Gelidium spp.*] are inter-dispersed in complicated patterns. In the semi-tropic zone, large seaweeds are not found, and smaller species of Rhodophyta (red algae) and Chlorophyta (green algae) like "haitengusa" [*Gelidium pyramidale*] and "hitoegusa" [*Monostroma nitidum*] proliferate.

The types of seaweeds eaten by the Japanese that are presently the object of culture fisheries include species of laver [*Porphyra spp.*], kelp [*Laminaria spp.*], Undaria, "hitoegusa" [*Monostroma nitidum*], "suji-aonori" [*Enteromorpha prolifera*], "okinawa mozuku" [*Cladosiphon okamuranus*] and "matsumo" [*Analipus japonicus*].

And, with regard to kelp, tengusa and hijiki seaweeds, methods of increasing resourses, such as spreading stones on the sea bottom, or blowing up rock formations to increase growing areas, introducing mother plants to the production ground and weeding out undesired seaweeds, have been employed since olden times.

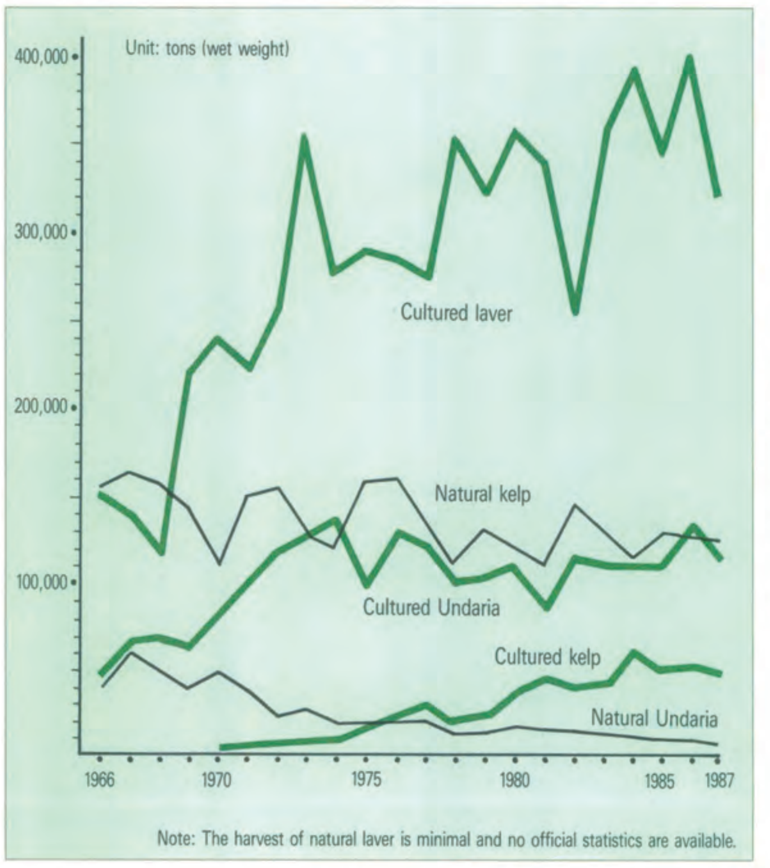
Among these edible species, by far the largest consumption and the largest culture industry efforts have been for laver, kelp and Undaria. The changes in natural gathering and culture production in recent years are shown in **FIG. 8**.

FIG. 6: Income per family member



Note: A boat-oriented fisherman's family is one that uses an under 10-ton fishing boat.
(Statistics by the Ministry of Agriculture, Forestry and Fishery)

FIG. 8: Production of Japanese seaweeds by type



Note: The harvest of natural laver is minimal and no official statistics are available.

(Postscript) In recent years experiments are being conducted in which "arame" [*Elsenia bicyclis*] grows on a grid of stakes driven into the sea bottom to encourage a proliferation of such plant-eating marine animals as abalone.

Kelp *(Laminaria)*

Area of research: Hakodate region of Hokkaido

FIG. 9 : Producing areas for cultured kelp

The name "Kombu" (kelp) refers to Laminaria and other related large edible Paeophyta like *Kjellmaniella*, *Cymathaere* and *Arthrothamnus*, but here we will limit ourselves to the discussion of Laminaria only. The Japanese have long valued kelp as a delicacy eaten alone or as a flavoring called "dashi-kombu". Up until recently the production of kelp has been limited to its areas of natural distribution in Hokkaido. Now, however, since the development of culture techniques, we are seeing its production begin to spread beyond Hokkaido to Iwate and Miyagi Prefectures and other parts of northern Japan. **(FIG. 9)**

Life mode

Laminaria is a cold water seaweed living in waters that range from 0°C in winter to 20°~23°C in summer, and grows most rapidly in seasons when the temperature ranges from 10°~20°C.

It grows below the low tide line in rocky bottom areas of outer sea shores, with highest concentration being found at depths of 8~12 meters.

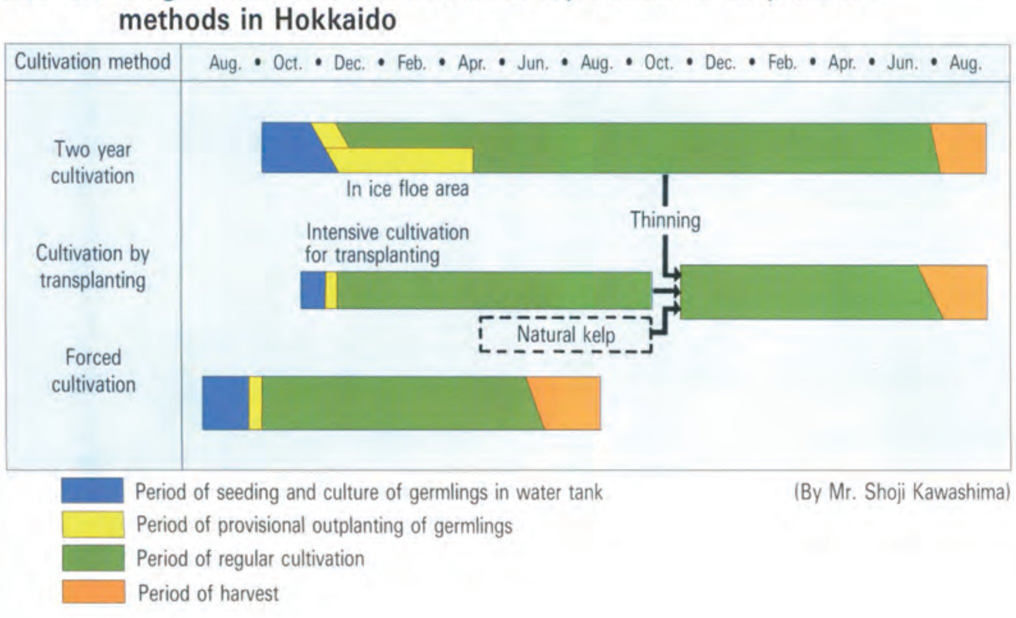
Life cycle and culture schedule

When the water temperature begins to drop in autumn the kelp thallus produces a mature zoosporangium, and in late autumn it releases large numbers of zoospores into the water. After a period of free-floating migration, the zoospores attach themselves to some substrata in the sea and begin the germination process. After passing through the gametophyte stage they become sporophytes once again and by mid-winter have grown into infant thallus large enough to be seen by the naked eye. From winter into spring the activity of the meristem increases and the thallus grows in length. In summer the kelp becomes ripest for harvest. From summer into autumn the growth becomes slower, and because the amount of plants being washed away surpasses the rate of growth, the thallus begins to fade. In late autumn the growth section of the thallus ceases activity, ending the first year of growth.

In the kelp genus there are one-year, two-year and even some three-year species. At present the kelp that are the object of culture fisheries are all 2-year kelp. The culture schedule for kelp culture in Hokkaido is shown in **FIG. 10.** The most common method is one of 2-year culture, and because in winter the meristem of the kelp becomes particularly active and new holdfasts are easily formed, some areas take advantage of this fact in a transplantation method of culture. Furthermore, a "forced cultivation" method that produces the equivalent of second-year kelp in just one year was developed in about 1970, and this method has spread in the comparatively warmer water regions of southern Hokkaido.

Seed production facility for forced cultivation. Seed fixation is achieved under strictly controlled conditions of water quality and temperature, and amount of light.

FIG. 10 : Diagramatic flow chart of three representative kelp culture methods in Hokkaido



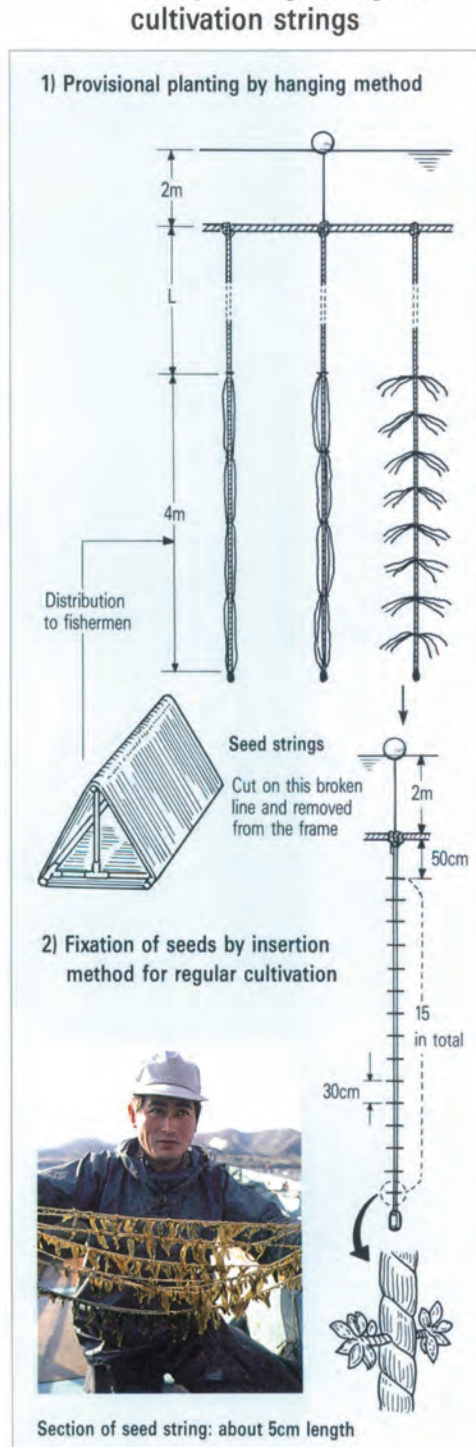
Seed production

Seed production consists of the two steps of "seeding" and "provisional planting"

Mature mother seaweeds are washed and soaked in sterilized water at a temperature of 10°~15°C to bring about zoospore release.

Seawater containing a high concentration of zoospores is filtered with gauze. This sporophyte water is then added to a tank of sterilized water at a ratio of 3~5%. Then a triangular spore collector wound with about 300 meters of synthetic thread is placed in the tank and left undisturbed for about half a day for the spores to fix themselves to it. After verifying that enough spores have attached themselves to the collector it is transferred to a cultivation tank. Within 30~50 days young seaweeds of 3~5mm will have appeared, after which they can be moved to seawater cultivation grounds.

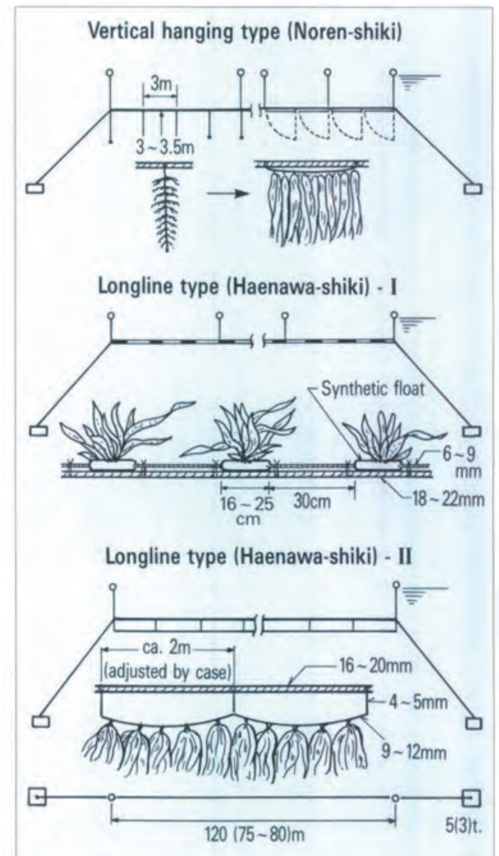
FIG. 11 : Provisional planting and transplanting to regular cultivation strings



Regular cultivation facilities

The type and configuration of the regular cultivation apparatus varies with the sea conditions of the different regions, with the basic types being shown in **FIG. 12.**

FIG. 12 : Kelp cultivation apparatus used in the Hakodate area

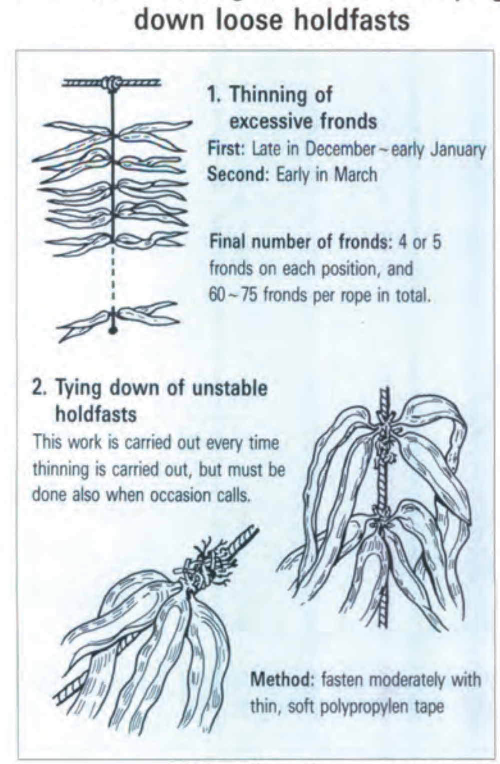


Controlling the cultivation process

1) By hanging the main line near the surface one gains the added nutritional value of the upper water layer, but on the other hand the increased wave activity increases the danger of part of the seaweed population being washed away. Therefore, in winter the main line is lowered to a depth of about 5 meters. In winter the concentration of nutritional salts in the seawater increases so there is little problem of nutritional deficiencies. In spring, as the seaweeds grow in size and the seas become calmer, the number of floats is increased to raise the apparatus closer to the surface. This increases the amount of solar energy and improves the supply of nutrients through the increased water flow near the surface.

2) As the kelp grows in size the density of the culture population increases, thus obstructing the supply of solar energy and nutrients. In order to raise good quality kelp it is necessary to thin out the crop two or three times during the regular cultivation period. At the same time this "thinning" is performed, those seaweeds which are not firmly attached to the ropes are given additional support with vinyl tyings. **(FIG. 13)**

FIG. 13 : Thinning of fronds and tying down loose holdfasts



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Processing

The uses of domestically produced kelp in Japan are reported to be 30% sold in leaf form (for "dashi-kombu"), 30% for "tsukudani", 10% for "tororo-kombu" (thin-sliced kelp), 20% for various processed foods and 10% for export. The producers do a primary processing of their entire crop into dried kelp before shipping it to middlemen or food processing companies.

Harvesting operation on a Japanese utility boat powered by an outboard motor.

Outdoor drying

Managing a culture operation

The fishing households engaged in kelp culture operate either with a 24 ~ 26 ft. utility boat fitted with an outboard motor or a diesel-powered 5-ton class fishing boat. The former is used by families operating 4 or 5 culture set-ups with a main line length of 120 meters, while the latter is used by families operating about 10 set-ups. The former produces from 1 ~ 1.5 tons per year with a market value of about ¥2 million. The latter produces about 3 tons with a value of ¥4 million yearly. In either case the work on the water is performed by two people, but during the harvest season the family operating 10 set-ups from a diesel fishing boat has to hire several additional part-time laborers to help with the on-land part of the operation.

In addition to kelp culture, these families engage in gathering of natural kelp, gathering sea urchin and other types of inshore fisheries (performed from a utility boat), or engage in angling or long line fishery (performed from a diesel fishing boat) to fill out their yearly income. In the past, the Hakodate area and the southern Hokkaido coast areas were labor supplying areas, with their workers going out to work as fishermen in north sea fisheries or other on-land industries. Since kelp culture became widespread about 10 years ago the number of laborers seeking outside work in this way has decreased sharply.

The leaf ends and roots are cut from the dried kelp and it is sorted into four grades depending on the degree of dryness, leaf width, thickness, color and gloss. Then 20kg stacks of the different grades are tied into bundles and boxed.

As soon as the kelp has been harvested it is taken to a specially prepared drying area paved with cracked stones, where each leaf is spread out to its full length and dried for 3 ~ 4 hours in the sun. After that it is hung in a drying room where it is dried for another 3 ~ 4 hours with hot air from an oil heater until its water content is reduced to about 15%.

Indoor drying

(Materials and photos provided by Mr. Shoji Kawashima)

Laver *(Porphyra)*

Area researched: Kisarazu area of Chiba Pref.

The "hoshi-nori" (dried laver) made from laver has been one of the representative seaweed foods eaten by the Japanese since olden times. Of the red seaweeds that make up the laver group there are about 30 varieties found in the coastal waters of Japan. Of these, eleven varieties were produced by culture fisheries by the year 1955, with "asakusa-nori" [*Porphyra tenera*] being the main species. With the development of artificial seed production methods in the '60s, however, the culture of varieties with better productivity and larger harvest potential became more predominent. At present "susabi-nori" [*Porphyra yezoensis*] is the representative variety in laver culture.

Life mode

Laver grows primarily between the tide lines in the shallow waters of inner bay areas. As they display strong resistability to exposure to the air, temperature changes and changes in salinity, all of which makes them suitable for inhabiting a wide range of environments. Thus, they are found growing in waters throughout the span of the Japanese islands.

A vacuum type laver harvesting machine driven by a small electric generator.

A late-model fishing boat equipped with the most recent type of laver harvesting machine.

Laver are thought to grow best in a water temperature range from 15°C to 16°C. But when considering harvest quality, it is believed that a temperature range from 8°C to 10°C gives the best balance of biotic metabolism and supply of nutrient salts. In the past it was thought that low salinity waters were the best growing environment for laver, but now it has been established that low salinity is not an essential. Laver have the highest protein content of any seaweed group, and accordingly it needs large quantities of nutrient salts such as nitrogen and phosphorus for proper growth. Laver is suitable to a culture ground that receives a constant supply of nutrient salts from land, like a river mouth area. But, at the same time, this type of ground is also susceptible to contamination by entrophication. Therefore, it can be said that laver culture is a type of fishery that requires special attention to the reproductive capacity of the environment.

Life cycle and culture schedule

The life cycles of members of Porphyra seaweeds can be divided into several types, but the ones that are the object of culture fisheries all fall into the type that show thallus growth in the winter and conchocelis propagation in the summer. In the case of "susabi-nori" and "asakusa-nori", when the infant thallus appears from the conchospore in October, by late November or early December the thallus will have grown to a pluckable size of 10cm. Growth is most active in the months from December to May. By June the thallus will begin to weaken, and by July it will have almost disappeared.

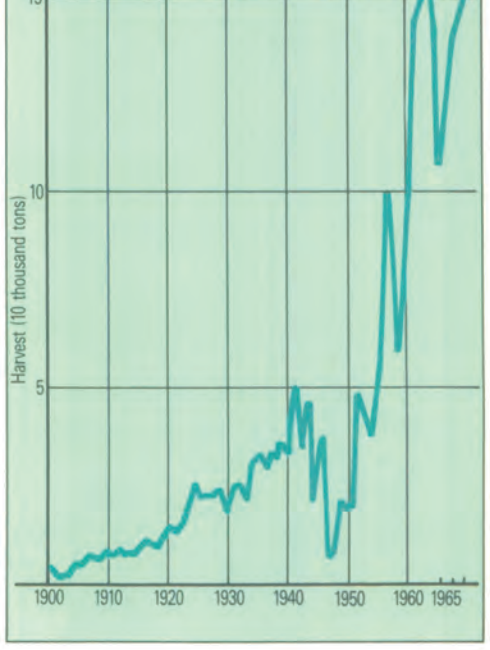
The culture process begins in the spring when carpospores are made to attach themselves to holders such as oyster shells and then produce conchocelis. The shells on which conchocelis have grown are kept in water tanks throughout the summer for cultivation. Then, in October when the water temperature begins to drop below 20°C, nets in which the culture shells have been embedded at appropriate intervals are hung out in the seawater. The regular cultivation stage begins when conchospores are formed on the nets. About two months after this happens the first harvesting can begin. After that subsequent harvests are repeated in accordance with the growth rate until the end of the culture season in March or April.

Innovations in amanori culture technology

Laver culture underwent several technological developments after World War II that led to a dramatic growth in production. Beginning about 300 years ago, fishermen in Tokyo Bay began a form of laver culture in which naturally occurring spores that attached themselves to bamboo sticks driven into shallow water areas were cultivated. Using this method, the Japanese production of laver remained at about 50,000 tons up until World War II. By 1955, however, production began to grow, taking a dramatic leap in the 1960s. **(FIG. 14)**

The factors that caused this rapid take-off in laver culture were adoption of nets made of synthetic fibers like cremona beginning about 1955, and the practical application of artificial seed production methods in the early 1960s. Since then, there has been a

FIG. 14 : Transition of laver production



succession of further advancements in the culture technology. As shown in **FIG. 15**, a complete spectrum of modern technologies regarding biological production, on-sea operations and on-land working methods appeared in the latter half of the '60s. This sequence of technical developments constituted a sort of overall "innovation" in seaweed culture that resulted in a second phase of expansion for the industry in the '70s. (See **FIG. 8** on P. 4) In the 10 years from 1960 to 1970 the total sea area being used for laver culture in Japan was more than doubled.

The regular cultivation apparatus

The apparatuses used for laver culture today include "hibi net" with support poles and a floated-type hibi net. The floated type was developed as a means to expand culture grounds to offshore waters, and they now account for 30% of the 116 million square meters of surface area now used for laver culture throughout Japan. The features of these two types of apparatuses are shown in **FIG. 16** and **FIG. 17**.

Controlling the cultivation process

1) Because unwanted seaweeds or floating sludge will sometimes cling to the culture nets, the culture grounds must be patrolled regularly and the nets cleaned with a water pump when necessary.

2) For three or four hours after dawn the plants are artificially exposed to the air to prevent too sudden a growth of thallus.

3) Sudden environmental changes like high air temperature or water temperature, and low salinity can cause undesirable effects like abnormal shape development, rotting, abnormal cell development and wrinkling due to shrinkage. At these times damaged leaves should be quickly cut away to allow new shoots to grow. Or, the entire net should be unstrung and replaced with a refrigerated seed net that has been kept in a refrigeration facility.

4) With repeated harvesting the plants start to produce tougher leaves and the quality of the product begins to drop. So the nets are replaced several times with refrigerated ones during the course of the culture season.

Processing

The most notable characteristic of laver culture is the high added-value its operators achieve by completing the full process from growing the raw materials to producing the finished product, dried laver, all by themselves. The harvested laver is immediately washed clean of foreign materials and put through a chopping device to produce slurry. The slurry is then spread out on draining mats to remove excess water before placing in a dryer to complete the processing of the dried laver products. Today, all steps of the process have been mechanized and automated. Even though total production of dried laver in Japan has doubled many times over in the past 20 years, the entire manufacturing process can still be done by family labor. On the other hand, the capital investment necessary for the on-sea and on-land facilities has also grown to very large figures.

FIG. 16 : Pole supported net (hibi)

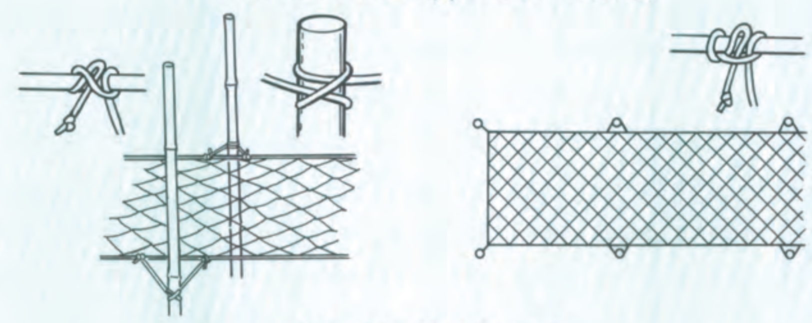


FIG. 17 : Floating net

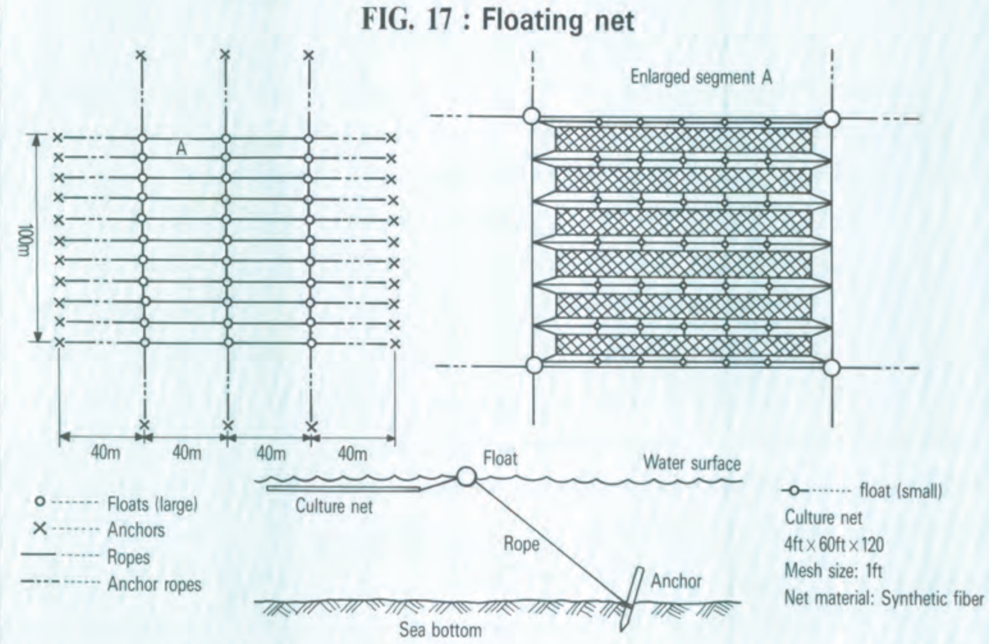
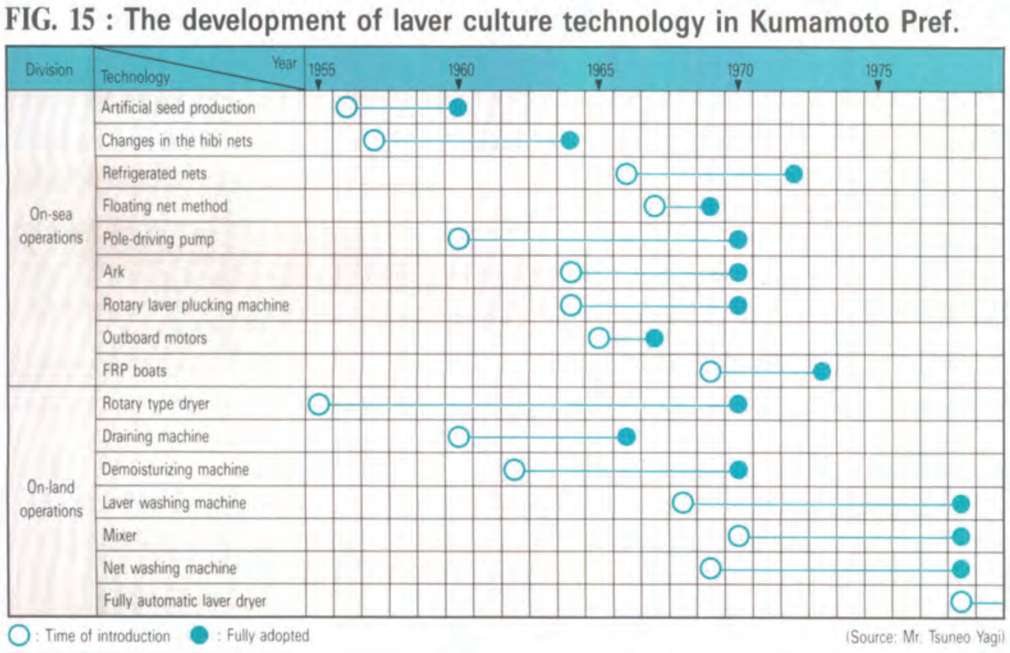


FIG. 15 : The development of laver culture technology in Kumamoto Pref.

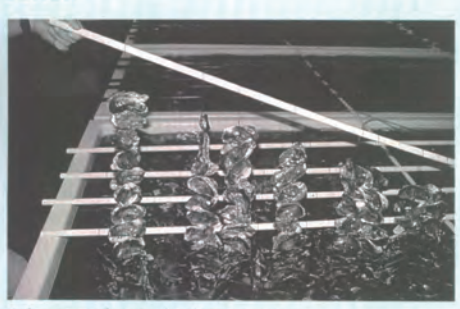


Washing laver after landing.

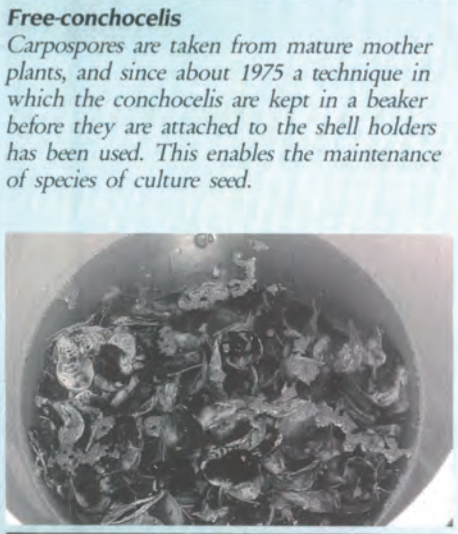
Making dried-nori.

SEED PRODUCTION

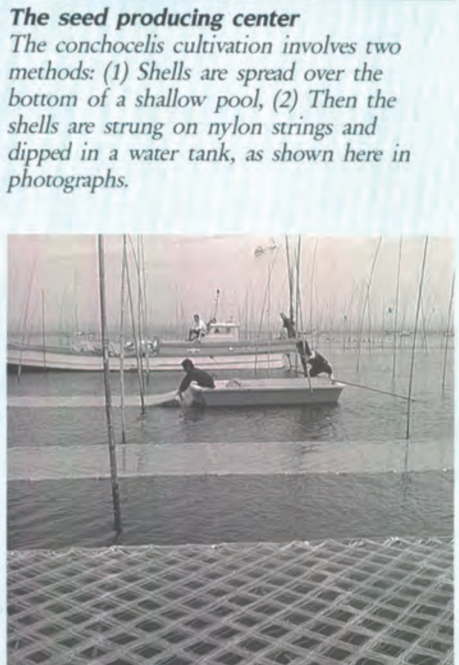
Free-conchocelis
Carpospores are taken from mature mother plants, and since about 1975 a technique in which the conchocelis are kept in a beaker before they are attached to the shell holders has been used. This enables the maintenance of species of culture seed.



The seed producing center
The conchocelis cultivation involves two methods: (1) Shells are spread over the bottom of a shallow pool, (2) Then the shells are strung on nylon strings and dipped in a water tank, as shown here in photographs.



The ten layers of net are set out on the sea surface still as one unit.



After a few days, when sporophytes have attached themselves to all ten layers of net, the layers are taken off one at a time for moveing to the regular cultivation grounds. At this time half of the nets are taken ashore to be preserved in a refrigerator.

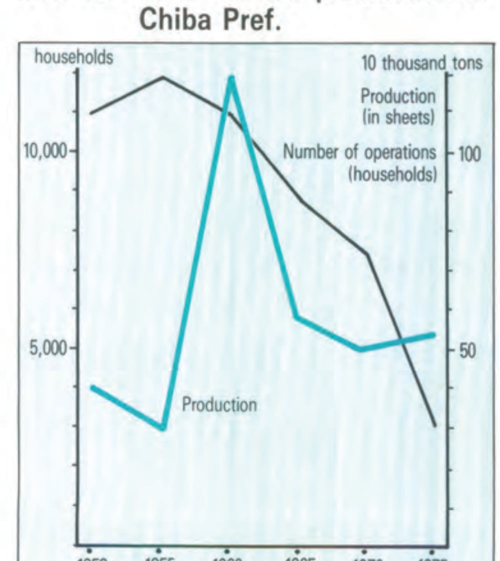
Managing a culture operation

Reaching a peak of 66,000 in 1968, the number of households engaged in laver culture has been steadily decreasing to the point where, in 1987, the number had dropped to 17,000. There are two main reasons that can be cited for this decline. One is the result of culture grounds being destroyed by land-fill projects for industrial purposes in coastal areas. The second is that the industry reached its limit of expansion with a production of about 8 billion sheets of dried laver a year in 1978. After this profits began to fall, competition between producers and between regions intensified and, of necessity, an increasing number began to drop out of the industry. In spite of this decrease in the number of producers, productivity per unit of sea area has continued to increase. This has kept production in the various regions relatively constant. **(FIG. 18** and **FIG. 19)**

According to statistics from the Ministry of Agriculture, Forestry and Fishery, the average earnings per household from laver culture operations in 1986 was ¥5.3 million. Of this the fishery income was an average of ¥2.1 million (fishery earnings minus fishery costs). The average number of man-hours spent on the fishery was 4,300 per year, 88% of which was provided by family labor.

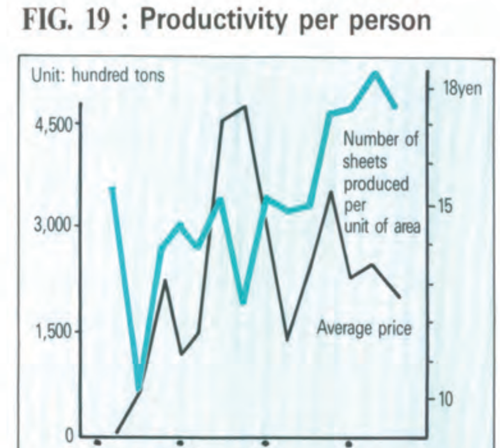
(Information provided by Professor Akio Miura of Tokyo University of Fisheries)

FIG. 18 : Laver culture production in Chiba Pref.



(Source: Annual Report of Agriculture, Forestry and Fishery for Chiba Pref.)

FIG. 19 : Productivity per person



(Source: Chiba Prefectural Laver Seed Production Center)

Hitoegusa *(Monostroma)*

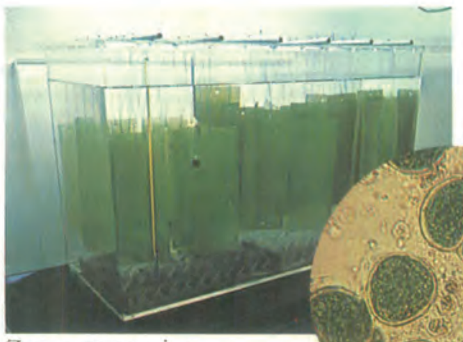
Area researched: Shima Peninsula, Mie Prefecture

The Japanese distinguish between the Porphyra and the Ulvaceae by the terms "kuro-nori" (black laver) and "ao-nori" (green laver) respectively. Concerning their product value as foods, black laver makes superior sheet form dried laver, with green laver several classes below. On the other hand, when making tsukudani, green laver is considered far superior. Among the green lavers are Monostroma, Ulva and Enteromorpha, of which the species considered most important for the production of tsukudani is known as "hitoegusa" [*Monostroma lalissimum*]. The word "hitoe" means "single layer", and "gusa" means "grass". As this name suggests, the thallus of "hitoegusa" is thin and soft, consisting of a single layer of cells. This makes it ideal for processing into "tsukudani". The fact that it does not lose its flavor when boiled - in fact an added fragrance comes out - is another desirable quality of this species.

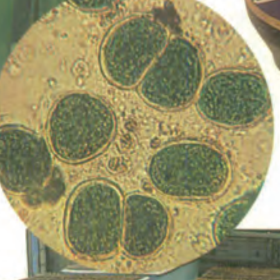
The national production of hitoegusa is 1200 ~ 1500 tons (dry weight) annually, and 70 ~ 80% of this is produced in Mie Prefecture.

Life mode

"Hitoegusa" grows between the tide lines from the inner reaches of bays to outer sea coasts, but they thrive best in the relatively quiet shoaling beach areas of inner bays. Because it often grows on culture nets intended for laver, these culture operators dislike it as a kind of "foreign weed". Compared to laver, it prefers waters of somewhat higher salinity. It also has strong resistance to environmental changes in air temperature, salinity and tidal exposure. But its poor resistance to chilling makes it unsuitable for the seed-net refrigeration technique used in laver culture.



Zygote preparation process



Tsukudani: *Laver boiled down in soy sauce*

Zoospore preparation process

FIG. 20: Zygote preparation process

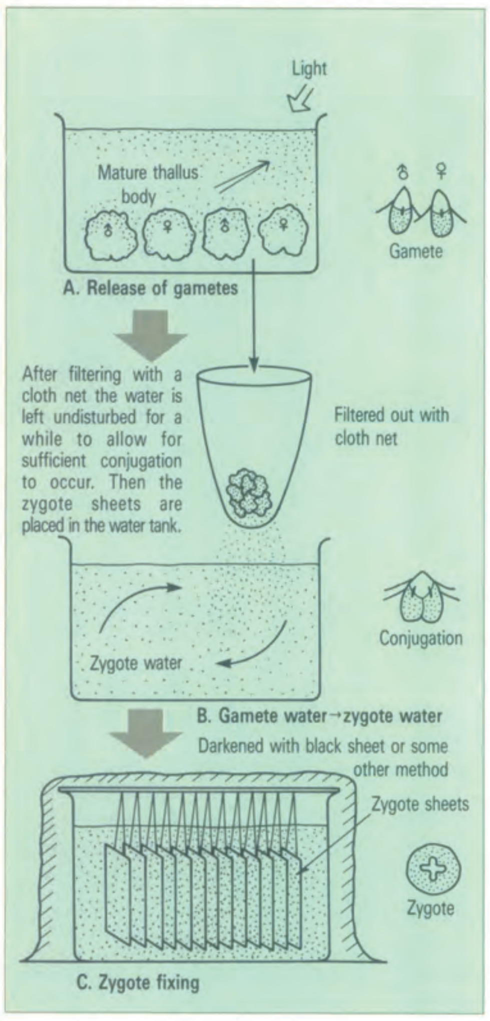
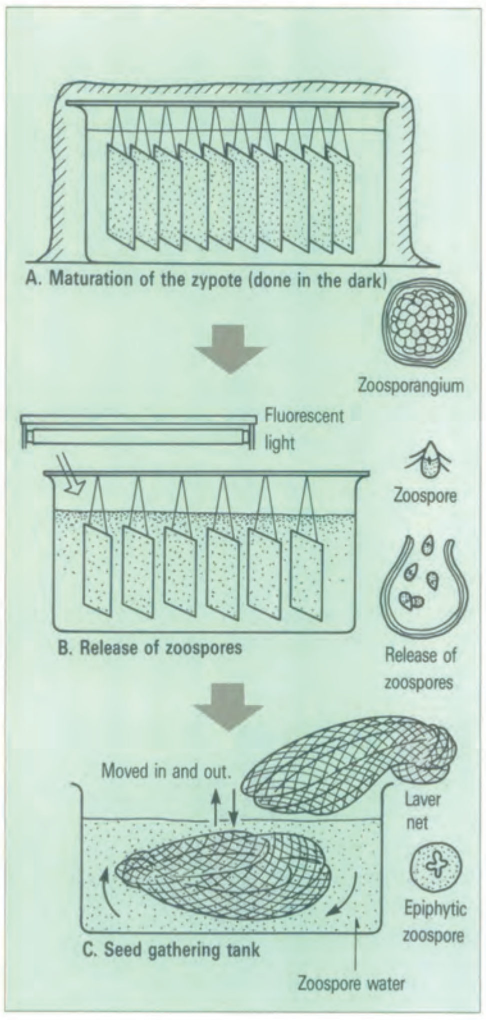


FIG. 21: Zoospore preparation process



Life cycle and culture schedule

From winter to early summer the thallus releases its gametophyte, which produce zygote. The zygote mature in the summer to produce zoosporangium which release zoospores in the autumn. Seed production involves; **(1)** collecting zygote in April and May, **(2)** cultivating the sporophyte over the summer and, **(3)** collecting zoospores in September and making the seed nets. The raising of the thallus and harvesting are roughly the same as in laver culture, occurring from the end of December to the end of April.

Seed production

1) Zygote gathering: The male and female gametophyte demonstrate positive phototaxis which means they conjugate most actively in light places. However, after conjugation begins they exhibit negative phototaxis that causes them to gather in dark places. Therefore, the cultivation tank is placed in a light area for 20 ~ 30 minutes undisturbed. Then after conjugation has begun, it is moved to a dark place or covered with a black sheet. **(FIG. 20)**

2) Gathering zoospores: Mature zygote (in other words zoosporangium) are stimulated by the change in early morning light to release their zoospores. Therefore the introduction of light is a necessary part of the process. Experience has shown that the use of 5,000 lux white fluorescent lights gives more reliable results than relying on natural sunlight. **(FIG. 21)**

The regular cultivation apparatus

The same kind of pole supported net (hibi) as in laver culture is prepared.

Control of the cultivation process

Although "hitoegusa" does not require such intensive quality control as laver, the main job of cultivation control is the same as with laver. That is, to raise and lower the nets to the most suitable depth for growth, depending on such factors as the tidal conditions and amount of light. Care must be taken to prevent disease and quality deterioration from overly dense cultivation.

Processing

The traditional processing methods for "hitoegusa" include drying in sheets and drying in its original leaf form. Since in recent years most of the "hitoegusa" crop is used for making tsukudani, the producers dry their harvests in leaf form under the sun and ship them in that form to the "tsukudani" processing factories. At the factory the dried leaves are soaked in water tanks. Such impurities as small stones and pieces of metal are separated by means of successive percipitation-tanks. Furthermore, brushes are used to separate out shellfish and small shrimps, etc. on the sorting table. The cleaned and sorted seaweed is then stored in a refrigerator until it is time for it to be used in the next step of the processing work.

Managing a culture operation

Matoya Bay on the Shima Peninsula is a very deep inlet well suited for "hitoegusa" culture. The 270 fishing family members who live along the coast of this bay are engaged in "hitoegusa" culture. Their annual production is roughly one ton (dry weight) per household at a value of ¥1.8 ~ 2.0 million. Since the only other type of fishery possible in this bay is small-scale gill net, the fishing households engaged in "hitoegusa" culture fill out their yearly income by creating supplementary businesses or finding other outside employment. Fishery earnings make up about 40% of their total income. Being an area known for its fine scenery, Matoya Bay was recently designated as one of the areas suitable for resort development under a government program. Plans for such development are now underway and local culture fishermen are now forced to consider measures for preserving the culture environment.

(Information provided by Professor Washiro Kida of Mie University)