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THE CULTIVATION OF SEAWEEDS IN JAPAN AND ITS POSSIBLE APPLICATION IN THE ATLANTIC PROVINCES OF CANADA

(A report on a visit to Japan in October, 1966)

by

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for

Industrial Development Service
Department of Fisheries of Canada, Ottawa
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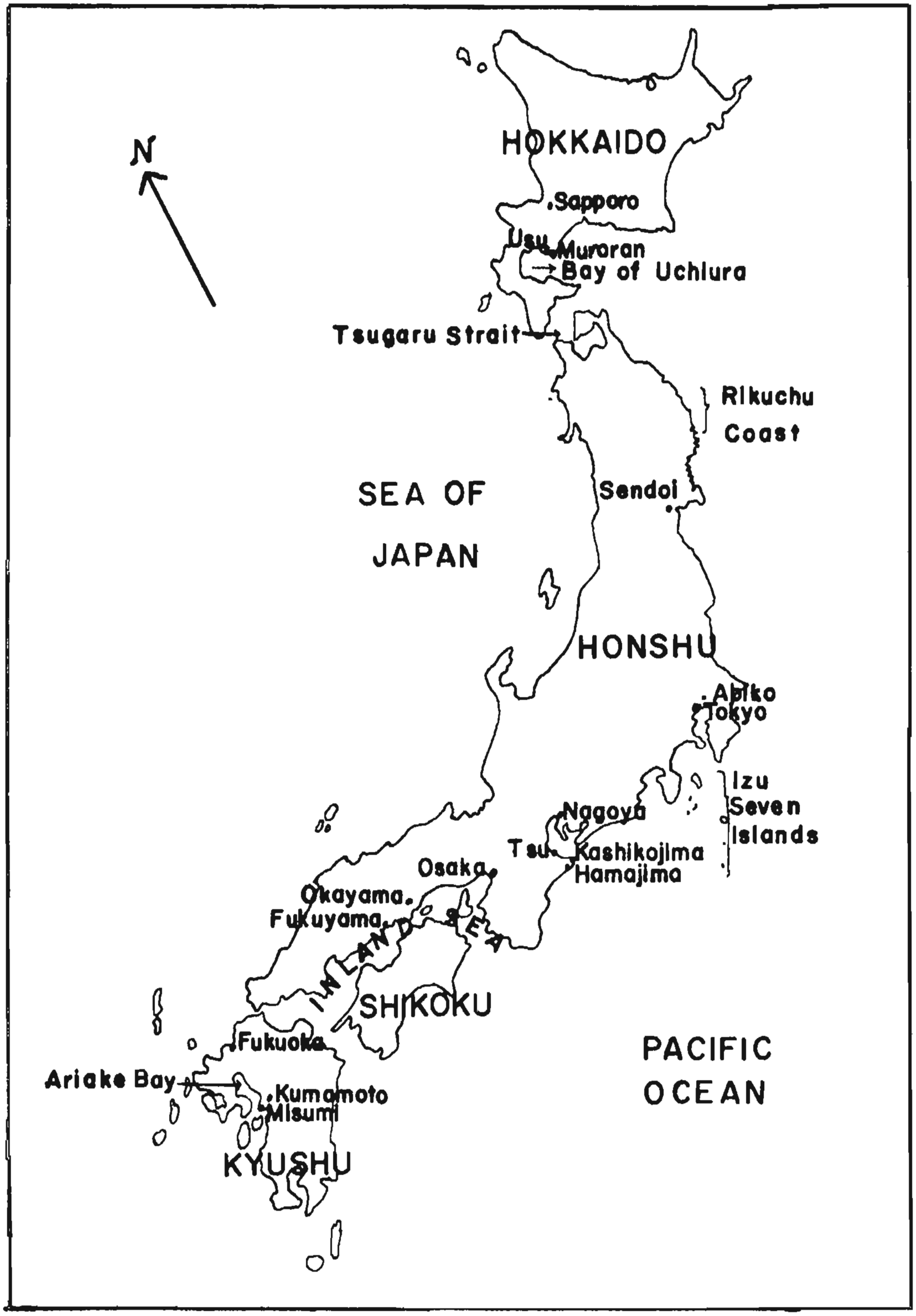
Opinions expressed and conclusions reached by the author of this report are not necessarily endorsed by the sponsor of the project.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Osaka
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INLAND SEA
SHIKOKU
PACIFIC
OCEAN
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Ariake Bay
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Misumi
KYUSHU

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Over the past twenty years there has been a steady increase in the demand for seaweeds for extraction of phycocolloids for various uses in the food, pharmaceutical, textile, paper and other industries. Because of the increased demands on already established commercial seaweed areas, particularly in the last five years, new areas are being surveyed and inquiries made in many parts of the Eastern and Western worlds.

In order to keep pace with the increasing industrial requirements, two additional measures are becoming more and more necessary. First, all possible steps should be taken to ensure the continued conservation of the present populations of naturally occurring commercial seaweeds and of those with commercial potential. Second, the cultivation of such seaweeds must soon be undertaken. Cultivation is especially important for the red algae of commerce as the most sought after species of Rhodophyta are already in short supply.

Japan has long been famous for its utilization of seaweeds. Japan's exploitation of seaweeds has reached a degree of development undreamed of in the Western world. Not only are both native and imported seaweeds exploited effectively but cultivation of several important species has been carried on successfully for several hundred years. It was in order to learn at first hand some of the work of the Japanese phycologists, and particularly to observe something of the seaweed cultivation that the writer made a trip to Japan on behalf of the Department of Fisheries of Canada in October 1966.

IMPORTANCE OF SEAWEEDS IN JAPAN

In Japan seaweeds have been used for centuries both as staple articles of food and as raw material for colloidal extracts. Extracts include agar, alginate, carrageenan and non-jelling colloids (from "funori"), mannitol and iodine.

Agar

The Japanese agar industry is at least 300 years old. Before 1939 Japan manufactured almost the total world supply. In 1939 that country manufactured about 6,000,000 pounds of agar, almost half of which was exported. With the outbreak of war the supply was cut off and importing countries found it necessary to assess and develop resources nearer at

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In Japan the industry began as a "cottage craft". Agar weeds collected during the warmer months, May to October, are dried (sometimes bleached) and stored until winter. When the temperature goes below freezing, the dried partly bleached raw material is processed and the agar extracted by freeze-drying. Because advantage can be taken of the naturally occurring cold temperatures this method is inexpensive, and although some agar is now manufactured in industrial plants, a great proportion of Japanese agar continues to be made in the traditional way in mountain villages in winter. Much agar is exported to North America, Europe and the East Indies. In Japan itself the chief use is as food, agar jellies often being served with sweet sauces and used as dessert. In many countries large quantities are used for bacteriological and other biological cultures as well as for other purposes.

Algae Used For Agar Extraction

About thirty species of red algae used for the extraction of agar are collected from almost the entire coast of Honshu, Shikoku and Kyushu. A few are also found in parts of Hokkaido.

The best quality agar contains a high proportion of extract from *Gelidium amansii* which is blended with extracts of other species. The species commonly used are:-

SCIENTIFIC NAME	JAPANESE NAME	NOTE
Gelidium amansii Lamour.	Tengusa	Found in many places in Japan. 45% may be used in a good mixture.
Gelidium pacificum Okam.	Obusa	Pacific coast from Sendai in Honshu to Cape Sata in Kyushu.
Gelidium subcostatum Okam.	Hira-Kusa	Hachijo I. & islands off Kyushu.
Gelidium japonicum (Harv.) Okam.	Onikusa	Pacific coast from Sendai in Honshu to Cape Sata, Hachijo I., south west islands off Kyushu, and west coast of Kyushu.
Gelidium divaricatum Martens		Pacific coast of Honshu, Shikoku and Kyushu, and islands s.w. of Kyushu, and the Inland Sea.
Gelidium pusillum (Stackh.) Le Jol.		Widely distributed in Japan.
Campylaephora hypnaeoides J. Ag. (Ceramium hypnaeoides (J.Ag.) Okam.) (C.rubrum (Huds.) Ag. var.firmum Ag.) (C. hamatum Cotton), (?C. pumilum Okam.)	Ego-nori	Hokkaido, Honshu, Shikoku and Kyushu. 10% may be used in a good mixture.
Ceramium boydenii Gepp (C. rubrum Okam.(non Ag.)) (C. sugiyamai Yendo)	Amikusa	Around Honshu, Shikoku and Kyushu, and western coast of Hokkaido. 5% may be used in a good mixture.
Gracilaria verrucosa (Huds.) Papenf. (G. confervoides (L.) Grev.)	Ogo-nori	Of general occurrence in Japan. 15% may be used in a good mixture.
Acanthopeltis japonica Okam.	Yuikiri Toriashi	Pacific coast from Sendai in Honshu to Cape Sata in Kyushu,the Inland Sea and northern coast of Kyushu.
Ahnfeltia plicata (Huds.) Fries		E. and N. coasts of Hokkaido. This is the main raw material for agar in Sakhalin Island.

Gelidium amansii, the most important agar weed, is in very short supply and attempts are being made to cultivate it. Harvesting is from April to September, either by hand or by special implements. The best quality is said to be that collected by women divers, especially in the Shima district of Mie Prefecture and in the Izu district, i.e. the Peninsula and the Izu Seven Islands of Shizuoka.

Gelidium species are also fairly common in the warm waters of south-eastern Kyushu and on the islands south of Kyushu. The shores of the Mie Shima district and those of Izu and Wakayama Prefecture are also in the influence of the warm Kuroshio current from the south.

Gelidium is cultivated in Izu, near Tokyo, and in the vicinity of Hamajima in Mie Prefecture. Near Hamajima propagation by "stone-planting" appeared to be successful. Gelidium populations there are increasing in density and the size of the harvest showed improvement at least in 1966. At that time it was reported that in other areas the supply was continuing to diminish.

The Izu district and Wakayama Prefecture have also Gracilaria of excellent quality, much of which is used directly as food.

Two species of Gracilaria, G. verrucosa (Huds.) Papenf. and Gracilaria foliifera (Forsskal) Børgesen, are found in the bays of the southern Gulf of St. Lawrence and Northumberland Strait. Although there would likely be difficulties with epiphytes, Gracilaria could be cultivated in this region of warm summer temperatures and low salinity. Ceramium rubrum (Huds.) Ag. has a wide distribution in our area and could undoubtedly be cultivated. Ahnfeltia, a slower growing perennial, occurs in limited quantities in the Atlantic Provinces.

"Funori"

"Funori" is the Japanese name applied to the dried, partly fermented, bleached raw material made chiefly from Gloiopeltis furcata Post. et Rupr. The extract from Gloiopeltis is a non-jelling colloid said to be completely soluble in warm fresh water and used as a sizing in the textile industry. It is also used as food — but is not an important food item. In some areas harvesting of this seaweed has been decreasing because of competition with new chemical sizings.

Besides Gloiopeltis furcata, G. tenax (Turn.) J. Ag. is also used. The percentage yield of extract from G. tenax is less than that from G. furcata, but nevertheless the former is an excellent raw material.

In addition to Gloiopeltis, Iridaea cornucopiae Post. et Rupr. and several species of Chondrus (not Chondrus crispus which does not occur in Japan) are also used. These are inferior to Gloiopeltis and command a lower price.

Uses of "Funori"

1. "Wall paste", a coloured paste used in the manufacture of mud walls. This usage has declined as in house-building mud has largely been replaced by wall board.
2. Sizing for paint on concrete walls.
3. "Starching" in laundry.
4. Sizing for paper and fabrics.
5. Preparation of water-base paints.
6. Adhesive for plastering.
7. Hairdressing lotions.

In recent years carrageenan has been used in the dairy industry for ice cream and other products.

Alginate

In Japan alginate is made chiefly from species of Eklonia and Eisenia which are harvested in July and August in the Mie Prefecture. Sargassum is also used.

Laminaria would be more useful in alginate manufacture but as it is a very important food material in Japan, it is too costly to be used for extraction purposes.

In 1947 about thirty or so alginate factories were operating in Japan.

In 1960 there were only a few factories, a reduction which had resulted from low production capacity of each small factory and high cost of electricity and fuel. Production of alginate increased from 352 metric tons in 1955 to over 1000 metric tons in the early 1960's. Commercial demand for alginic acid has accelerated, and efforts are being made to increase production. Recent arrangements are reported to have been made to process in Japan the crop of *Macrocystis* and *Nereocystis* harvested on the Canadian Pacific coast by a British Columbia company.

Mannitol

The Japanese Government has supported research on the recovery of mannitol from the brown seaweeds, either before or after the extraction of alginic acid (extraction with liquid ammonia or methanol before alginic acid is extracted, or afterward with acid-clay-$CuSO_4$ treatment followed by electrolysis to separate the mannitol from the waste solution).

Iodine

A few factories for iodine extraction have been in operation in Japan since ancient times. The production costs are high and only a very limited quantity of iodine is produced.

Food

The most important use of seaweeds in Japan is as food. Use is made of red, brown, green and bluegreen marine algae and of certain freshwater algae as well. More than 100 species of marine and freshwater algae may be purchased plain dried, dried after special processing with seasonings, or canned. They are eaten daily in soups or with rice and often with fish and are used also in confectionery (e.g. *Laminaria* caramels) and in other edibles such as *Laminaria* "tea".

Brown Algae

Among the many brown algae used as food are:

Laminaria or "kombu". This is one of the most important dried foods in Japan. It may be purchased dried or canned in seasoned sauce. *Laminaria japonica* and nine other species are used.

Undaria or "wakame". This has been eaten in soy bean paste soups from ancient times. The annual production in the early 1960's was between 60,000 and 65,000 tons.

Eudesme crassa (Suringar) Okamura is dipped in vinegar and sugar and eaten raw in the same manner as a number of other seaweeds, both brown and red, as an accompaniment to raw fish. (*Eudesme virescens*(Carm.)J.Ag. and *E. zosterae* (J.Ag.) Kylin occur in our area, but are not gathered commercially.)

Hizikia fusiforme (Harvey) Okamura, a member of the Sargassaceae, is another brown alga used as food.

Green Algae

The most important green algae for food are:

Monostroma species or "hitoe-gusa"

Enteromorpha spp. or "ao-nori"

Ulva spp. or "ao-nori"

Monostroma and, to a lesser extent, *Enteromorpha* are cultivated. Species of all three genera occur in the Atlantic area.

Bluegreen Algae

Phylloderma sacrum is cultivated to a small extent on rice fields in Kyushu.

Red Algae

In addition to *Porphyra* ("nori"), the most important red alga used as food, *Gloiopeltis* and *Gracilaria* are often used. *Batrachospermum moniliforme*, a freshwater red alga, is dipped in vinegar and sugar and eaten raw with fish.

SPECIES OF SEAWEEDS CULTIVATED IN JAPAN

Porphyra tenera Kjellm., P. kuniedai, P. angusta Okam. et Ueda, and P. pseudolinearis Ueda.

P. suborbiculata Kjellm. is being investigated at Misumi.

Laminaria spp.

Undaria spp. (chiefly U. undariodes(Yendo)Okam., Undaria pinnatifida (Harv.) Sur. and the hybrid of these.)

Monostroma spp.

Enteromorpha spp.

Ulva (occasionally)

Gelidium amansii Lamour.

Gracilaria verrucosa (Huds.) Papenfuss

Atlantic species of all these genera except Undaria and Gelidium occur in our area.

The times for cultivation and harvesting vary with the species. Observation of all phases of the Japanese seaweed industry, or even of all phases dealing with cultivation and harvesting, would require a very lengthy visit.

Spring is the best time for botanical collection as well as for observation of harvesting of Monostroma, Undaria, Hizikia, Gloiopeltis and Chondrus.

In Summer one may see the harvesting of Eklonia, Eisenia, Gracilaria (May to October), and Gelidium (May to September).

Laminaria harvesting is carried on from August to October. This cold water genus occurs in Hokkaido and along the Pacific coast of Honshu as far south as the Rikuchu coast. Cultivation operations in Hokkaido may be observed from September to October.

In Winter one may observe harvesting of Porphyra in many parts of Japan as well as the collection of Heterochordaria, another food plant, in Hokkaido and near Sendai in northern Honshu. Winter is also the season for the manufacture of agar in mountain towns and villages especially in those with an abundance of pure fresh water and much sunshine.

Gracilaria has the most extended "season" for harvesting — from May to October. Gracilaria has a wide distribution in Japan and is said to be harvested extensively. The price is not high and its cultivation has received much less attention than other cultivated algae. It has been grown successfully on nets and ropes in the Mie Prefecture in Honshu and near Misumi in Kyushu.

In addition to the seaweeds harvested in their own country, Japanese processors and brokers also purchase additional supplies from other countries. The writer has had requests from Japan for such seaweeds as Eucheuma, a warm water seaweed found in the Indian Ocean, Taiwan, and in some of the Japanese Islands. Requests for Gracilaria have also been received. Unfortunately our present supply of Gracilaria is insufficient for commerce. It is confined to sheltered bays of the Gulf of St. Lawrence and Northumberland Strait.

Because of the many facets of the Japanese seaweed industry and the prohibitive length of time which would be required to see the whole cycle of cultivation and harvesting of even one cultivated species, it was necessary to make a choice. It seemed to the writer that the most rewarding observations would be those related to the intricate techniques of Porphyra cultivation, and in particular the operations involved in spore-setting and the setting out of the hibi.

A visit was therefore arranged to begin in early October and to continue until the end of the month. An itinerary was arranged through the generous cooperation of Professor T. Segi and Dr. F. Uyeno of the Faculty of Fisheries,Prefectural University of Mie, Prof. Y. Nakamura,Director of the Algological Institute of the University of Hokkaido, Dr. I. Iwasaki of the Faculty of Fisheries and Animal Husbandry,Prefectural University of Hiroshima, Dr. M. Masuda and Mr. F. Ohta of the Nori Research Station of Kumamoto Prefecture, Dr. Inoh, University of Okayama and Dr. S. Arasaki, Faculty of Agriculture, University of Tokyo.

By travelling on Sundays and Wednesdays — by air and railways — it was possible during October to visit a number of centres involved in seaweed research and methods of cultivation. Visits were made to universities and research stations in the islands of Hokkaido, Kyushu and Honshu. Centres visited included Nagoya, Sapporo, Usu, Mororan, Okayama, Fukuyama, Kumamoto, Misumi, Tsu, Yonezu, Oguchi, Toba, Hamajima, Kashikojima, Tokyo and Abiko-Machi. The manager of the Hotel New Nagoya was most helpful in arranging for interpreters who were especially needed in the southern island of Kyushu.

Observations were made chiefly on the cultivation of Porphyra, Laminaria and Undaria and a visit was made to the National Pearl Research Institute.

The extent of the greatly dissected Japanese coastline, its geographical location (30°N to 45°N latitude) and the presence of both warm (Kuroshio and Tsushima) and cold (Oyashio) currents in the current-systems along the coast result in marked regional differences in populations in the marine algal vegetation (Fig. 1).

The tidal amplitude varies from 20 to 30 cm. on the coast of the Japan Sea to more than 5 m. at the head of Ariake Bay. At low tide the shore near Misumi in the southern part of the Bay was observed to bear a strong resemblance to parts of the Nova Scotian Fundy coast.

The velocity of the Kuroshio Current along the Pacific coast from southern Kyushu to Izu is 1 to 5 knots. The surface temperature is 15°C. to 30°C. (15° to 20° in February, 25° to 30° in August)(Figs. 2, 3).

The Japan Sea is usually calm in summer. In winter there are strong stormy winds and snow the result of cold dry northwesterly winds blowing from Siberia.

The Tsushima Current, a branch of the Kuroshio, flows north through the Japan Sea at a velocity of 2 knots bringing water of high temperature to the west coast of Japan. The temperature is above 10° C. in winter and reaches 25° C. in August. A branch of the current carrying a large proportion of its volume (about 70%) leaves the Japan Sea to flow into the Pacific by way of the Tsugaru Strait between Hokkaido and north-western Honshu moderating the water temperatures of the nearby coasts. (5° C. in the Strait in February compared with -2° C. in Northern Honshu, 0° C. in Eastern Hokkaido and 10° C. near Sendai. August temperature is 20° C. in the Strait compared with 15° C. in northern Hokkaido and about 23° C. near Sendai.)

The cold Oyashio Current from the north flows along the south eastern coasts of Hokkaido and northeastern Honshu. Winter water temperatures here are lower than 10° C. and Laminaria populations are luxuriant.

The climate of Hokkaido is very like that of Nova Scotia. The cool coastal waters provide suitable conditions for luxuriant populations of several species of Laminaria as well as for four species of Chondrus. (The Japanese species of both genera are different from those in our waters.) Laminaria japonica of the "best quality" occurs in southern Hokkaido and along the coast of Aomori and Iwate prefectures in north-western Honshu opposite Hokkaido. These are the coasts swept by the moderating branches of the Japan Sea Current on entering the Pacific.

A small research station has recently been built at Usu on Uchiura Bay in southwestern Hokkaido for demonstration and study of local commercial seaweeds and for the improvement of their cultivation techniques. The location is well suited to this purpose. Water rich in nutrients drains into the area which is sufficiently removed from the open sea to afford protection to the Porphyra hibi and yet close enough to the sea to have a good exchange of water from tidal currents (Plates 12 - 14). The station is favourably situated also in its proximity to Muroran, the site of the Institute of Algological Research of Hokkaido University.

Visits were made to Usu and to Muroran under the guidance of Dr. Yositeru Nakamura, Director of the Algological Institute.

Unfortunately the 1966 Laminaria crop had been light and the harvesting was almost completed by early October. The only Laminaria harvesting to be seen was the collection by hand of the few accessible plants remaining attached at Muroran. A fisherman and his wife both on foot collected these during low tide in the early morning. They placed the plants carefully to dry on a rack at the foot of the cliff below the Algological Institute (Plates 1, 2).

LAMINARIA

So important is Laminaria to the food industry of Japan that the harvesting and drying and other preparations are done with the greatest care. Good weather and suitable drying areas are essential. A good drying location is a sunny gentle slope which should be covered with small pebbles or sand. The Laminaria blades must dry without twisting and are therefore turned over once during the day so that they will not curl but may dry equally and evenly on both sides. At night they are stacked carefully in a hut and covered with straw mats to allow the remaining moisture to become evenly distributed throughout the stack. The next morning they are returned to the drying yard and placed flat on the pebbles or sand to finish drying. The drying process should be completed in one or at the most two days. The best dried Laminaria blades are thick and do not show any wrinkles or scratches. For the best quality therefore, good weather and careful handling are necessary.

The loss of Sakhalin and the Kurile Islands to Russia has curtailed the supply of Laminaria in Japan. The demand is greater than the supply and ways have been sought to increase the available crop.

Two methods are in use in an effort to increase the annual production: (1) "stone planting" and (2) "rope cultivation".

1. "Stone Planting" (i.e. "planting" of stones and concrete blocks)

The Laminaria beds are extended by setting out stones and/or concrete structures in suitable places. Various shapes and sizes of structure have been tried. The one now in use at Usu is cylindrical in shape for easy transportation and placement. Openings near the base permit a flow of water through the block, lessening the tendency for the waves to shift it. The openings also lighten the weight making for easier handling. A well-shaped depression in the upper part of the cylinder provides increased surface for attachment of spores and offers a degree of shelter for developing gametophytes and young sporophytes prior to the development of strong holdfasts (Fig. 4, Plates 3, 4).

A factory has been built nearby with financial assistance from the government for the fabrication of these concrete "planting blocks".

2. "Rope Cultivation"

Within the research station is a series of large concrete tanks used for certain stages of seaweed cultivation. Twine is wound about frames which are then placed in the tanks with sea water. Portions of *Laminaria* blades with ripening sporangia are added. Zoospores are released from the sporangia and after a period of motility they settle, many of them on the twine. The *Laminaria* blades are then removed. The frames are allowed to remain hanging in the tanks, with occasional changes of sea water, throughout the period of the microscopic gametophyte phase and until small sporophytes develop. The twine with attached young sporophytes is wound about lengths of rope and set out into the sea. A number of these rope lengths of diameter sufficient to provide attachment for holdfasts have previously been hung from much heavier ropes which are held in place by a system of anchors and buoys (Plates 5, 6).

Since 1950 Nakamura has been cultivating Laminaria in the sea near Muroran. Plants two or, when they are available, three years old are considered suitable for harvesting. Plants less than one year old are usually not collected.

Studies made of attachment and growth of Laminaria on concrete cylinders in Hokkaido closely parallel somewhat similar studies in Nova Scotia. In Hokkaido concrete cylinders had been placed near the borders of natural beds of Laminaria japonica (a ruffled, undivided species). In Nova Scotia in 1949 concrete slabs had been placed in Yarmouth County beds with a Laminaria population of two species, L. longicruris De la Pyl. (blade ruffled and undivided) and L. digitata (L.) Lamour. (blade split lengthwise into several divisions). The purpose in Japan was to test the usefulness of the cylinders for commercial crops. In Nova Scotia it was an attempt to determine the life span of plants of L. longicruris, the longevity of which had been unknown.

At the end of the first year the concrete structures in both places bore dense populations of ruffled Laminaria, L. japonica in Hokkaido, L. longicruris in Nova Scotia. On blocks in both countries the second year showed a slight decrease in the number of Laminaria plants. By the third year the populations were greatly reduced. In the fourth year in Hokkaido the cylinders had only a few Laminaria plants left. In Nova Scotia at the end of the third year the concrete block had a single Laminaria longicruris remaining attached. The holdfast was becoming loose because of the disintegration of the concrete surface at the points of attachment of the holdfast, and the plant having previously been tagged, and therefore of known age, was removed for preservation. Meanwhile, many individuals of *L. digitata* which had begun development earlier as a constituent of the successional "undergrowth" (including *Corallina*, *Lithothamnion* and *Chondrus*) had become the dominant species. Some individuals had become detached but others had grown to become sturdy plants with strong spreading holdfasts typical of this perennial species.

Succession of flora, storms, and other factors reduce the *Laminaria* populations on concrete blocks (Plates 7-11). In Japan new cylinders are set out each year.

Nakamura finds the most suitable locations for cylinders in Hokkaido to be in areas with slightly moving sand. In Nova Scotia the most luxuriant *Laminaria* beds are located in regions of swift tidal currents, in particular those west of Cape Sable in the Fundy Approaches. In that area *Laminaria* blades are large and thick, and with a high alginate content.

In addition to using concrete structures and ropes for the cultivation of *Laminaria*, ordinary stones may be set out as was frequently the practice in Ireland. In some areas rock ledges are blasted at suitable depths to provide new surfaces for *Laminaria* attachment.

PORPHYRA, UNDARIA AND GELIDIUM

Laminaria, being a cold water genus, occurs mainly in Hokkaido and northeastern Honshu. Hokkaido produces about 90% of the available crop. *Porphyra* on the other hand is of general occurrence. As an article of food it has been valued highly since ancient times. Its cultivation which began in Tokyo Bay three centuries ago has expanded and spread to many regions until now its industrial cultivation is the largest of all marine products. More than 300 miles of nets are spread over several thousand acres of sea. By 1952 the growing areas had been extended to 16,000 acres. By 1959 the total area under cultivation was estimated at 155,000 acres of which about 8,000 acres consisted of brush-bamboo hibi. The value of the industry in 1965 was $11,000,000 U.S.

The life cycle of *Porphyra* is a complicated one with several types of spores and two types of vegetative structures, a larger leafy thallus attached to rocks or other substrata — even coarse seaweeds — and a filamentous shell-boring stage known as *Conchocelis* (Fig. 5).

As so often happens with many discoveries, the cultivation of *Porphyra* had an accidental beginning. A tree branch with leafy *Porphyra* plants attached was discovered floating in the sea. The finder stuck it into the sandy bottom. The plants grew and flourished. Subsequently cultivation was carried on using branches of bamboo or bushes which were placed in the sea in areas which proved suitable for collecting the spores.

Spores from the *Conchocelis* phase are buoyant. Dense masses of conchospores, noticeable by their reddish colour, appear in the water about September 22 or thereabouts, the time of the autumnal equinox.

The best locations for spore-collection vary somewhat with the direction of winds and currents.

The origin of the spores was a great mystery and gave rise to much speculation. Ueda reported that the spores originated from a "summer form" of the leafy thallus. Kunieda believed them to arise from a "resting spore" on the sea bottom. The two theories resulted in a scientific controversy which lasted for fifty years or more until a brief account appeared in Nature (1949) of the work of Kathleen Drew who had germinated the so-called carpospores of Porphyra umbilicalis (L.) J. Ag. f. laciniata (Lightf.) Thur. (now called P. purpurea (Roth.) C. Ag.).

On germinating the spores at the University of Manchester, Drew obtained a shell-penetrating filament which she recognized to be the organism then known as the alga Conchocelis rosea Batt. In 1953 Kurogi reported similar results with P. tenera Kjellm. in Japan. Drew had also observed the buoyancy of the Conchocelis spores which floated to the surface in contrast with the heavier carpospores of Porphyra which sank.

The result of these discoveries was that many Japanese began to study how to collect the Porphyra carpospores on shells and to develop the Conchocelis phase in quantity in tanks. Thus began an industrial revolution in the Porphyra industry. Methods of cultivation are becoming more sophisticated and the area under cultivation has been increased 400 per cent.

The *Conchocelis* phase is now usually developed in oyster shells placed in sea water in shallow indoor tanks. Initially the cleaned shells may line the bottom of the tank and are "infected" with carpospores from fruiting *Porphyra* thalli. Following "infection" the shells are suspended in the tanks with occasional changes of sea water, remaining there through the development of the *Conchocelis* phase and until about 8 months or so later when the monospores (conchospores) of the *Conchocelis* phase have ripened (Plate 15).

Development and ripening of spores and their release are affected by length of day and by temperature of the water. Spores released from the *Conchocelis* phase as the days become shorter in September are collected on nets of nylon or other twine. Following attachment of the spores the nets are spread out in the sea, 5 or 6 together in a layer, fastened to bamboo poles which have already been pushed into the soft bottom. The system of nets and poles is known as "hibi". When first set out the hibi are usually placed near the mouths of estuaries where the water is rich in nutrients. Later the hibi are moved out toward the open sea a few nets at a time as the plants become ready. The *Porphyra* grows until winter when several crops are harvested, the largest plants being removed first. Following the harvest, nets and poles are taken up and stored until the next season.

The most suitable time for setting out or "spreading" the hibi depends on the location and the sea temperature. In northern Japan the operation usually begins in mid September and is finished by early

October. In Matsushima Bay, Miyagi Prefecture, it is from mid September to early November when the sea temperature falls from 25° C. to 15° C. In southern Japan it is mainly in October.

Of the Porphyra species under cultivation, some are characteristic of the "inner" seas (those almost surrounded by land) while others are adapted to less sheltered or "outer" seas of Japan. P. tenera, a popular commercial species abundant in the inner seas, has a relatively short growth period and is harvested in November and early December. P. angusta, with growth period and harvesting season much the same as P. tenera, is characteristic of the "outer" seas. P. kuniedai an inner sea species, and P. yezoensis more common in "outer" seas, have a longer growth period and are harvested from December to May. Leafy thalli of P. kuniedai may even be found in shore habitats during most of the year. P. pseudolinearis has the shortest growth period. Its harvesting is limited to November and December (Fig. 6).

By the first of October the water temperature in Hokkaido had cooled sufficiently for the rapid release of conchospores. At the time of the visit to Usu, the nets had already been set out. For study of the Conchocelis, however, and for a further supply of spores if needed, a quantity of oyster shells with Conchocelis were being maintained in a tank of sea water at the station (Plates 12-15).

In spite of the great success achieved in seaweed cultivation, which in the case of P. tenera has been carried on for 300 years, more knowledge is being sought by scientists who are constantly at work studying to improve the cultivation techniques. Much attention has been given especially to the biology of the Conchocelis stage of various species of Porphyra.

Seaweed investigations are an important part of the research and teaching programmes in Japanese universities as well as in numerous fisheries high schools. There are more than 200 fisheries and biological stations which are either attached to universities or are under government auspices — prefectural, municipal or national. The research programmes of nearly all these stations includes investigations of "useful" algae. Many fishermen's cooperative societies and even some individuals have their own private research stations. Japanese fishermen themselves have established a tradition as practical scientists and are eager for discussions of biological and other problems of cultivation. They show a deep interest in the latest scientific findings. The good relations between fishermen and scientists were evident everywhere.

The techniques of cultivation vary somewhat from district to district. Research projects also vary considerably among different institutions.

At the Tohoku Regional Fisheries Research Laboratory in Miyagi Prefecture, Munenao Kurogi is the "scientific leader" in charge of "studies on marine algae, especially on the culture of useful seaweeds". Kurogi is one of the outstanding seaweed scientists of Japan not only known for his corroboration of Kathleen Drew's findings of 1949 but also noted for studies in the life cycles of various species of cultivated Porphyra, the effects of light and of temperature, and ecological studies of the *Conchocelis* phase in the sea. It was regrettable that time did not permit a visit to the Tohoku Laboratory.

At the University of Hiroshima, as in other universities, scientists are deeply interested in problems of commercial seaweeds. In its Department of Fisheries and Animal Husbandry, Iwasaki is studying abnormal *Porphyra* plants growing with bacteria. Professor Torreya Fujiyama is cultivating a type of green "nori", *Prasiola japonica* Yatabe, a species difficult to culture. *Prasiola japonica* is a fresh water species of Japanese rivers, a full account of the life cycle of which Fujiyama published in 1955. (In our area we have *Prasiola stipitata* Suhr. a minute plant seen in many spots, especially cliffs, along the sea coast. It grows best with nitrogen and is often dense where droppings from sea gulls are plentiful. The life cycle of this species was published by Friedmann in 1959. Our minute *Prasiola* is insufficient in size and quantity for commercial harvesting.)

Industrial waste in many bays is seriously affecting commercial seaweeds. At the University of Hiroshima botanists are investigating what appears to be a crown gall disease in the tissues of *Porphyra* caused by *Pythium* sp. or spp., imparting a disagreeable flavour to the nori and even resulting in large scale death to populations of *Porphyra* in polluted areas.

Among the many important investigations which Iwasaki has made, his study of light and photoperiodism as they affect both the *Conchocelis* phase and the leafy thallus phase was of great significance. He obtained the complete life cycle in vitro in 5 to 6 months.

He found (1) growth of Conchocelis to be stimulated by high light intensities, (2) incandescent light to produce Conchocelis dark (brown-black) in colour and (3) fluorescent light to give a reddish colour. He found continuous illumination to favour growth of the Conchocelis.

Fluorescent light of 150 to 250 foot candles for 8 to 11 hours per day induced formation of monosporangia (conchosporangia) in 2 to 3 weeks. Provided the Conchocelis was subjected to this high light intensity, Iwasaki found little difference in the culture at the lower temperature of 13° to 15° C. or higher temperature of 18° to 20° C. Reduction of light intensity however to 30 to 50 foot candles delayed formation of monosporangia (conchosporangia), — and hence the appearance of young thallus germlings, — by a period of 84 to 163 days.

Maturation of monosporangia (conchosporangia) and release of the spores were induced by a short photoperiod and prevented by continuous illumination.

He found also that sporangia produced in continuous light (250 - 350 foot candles) were morphologically different from those produced under short-day conditions. The walls were thicker, the cells shorter and often of a different shape.

The variety of structures developing in different lights and temperatures illustrate the capacity for adaptation in this species.

Subsequent studies by Iwasaki and Matsudaira showed the behaviour of the "special sporangia" to vary with day length, the spores developing into two different types of plantlets, one under short-day and the other under long-day conditions.

In the leafy thallus phase Iwasaki and Matsudaira found: (1) the rate of growth to be higher in enriched sea water; (2) high intensity incandescent light to be good for vegetative growth but natural sunlight to be better; (3) fluorescent light to sustain life in young plants for only a few days; (4) young plants to grow well in 8 to 10 hours daily illumination but in continuous illumination to die off quickly.

In nature the Conchocelis phase grows in spring and summer, the long-day seasons, and the leafy thallus phase in autumn, the short day season. The transition between the two phases is almost exactly at the equinox. The photoperiod governs not only growth of the two phases but also the formation of the spores which produce the next phase of the life cycle (Fig. 5).

It is evident that some seaweeds, like some land plants are long-day or short-day plants. It is evident also that as a result of Iwasaki's work it is possible under the right conditions to raise Conchocelis and to obtain conchospores in any desired month.

A report on a study of the relation between nori production and sea water temperature was presented at the sessions of the Pacific Science Congress held in Tokyo in August 1966. Korean botanists Moonki Chyung and Sun-Myo Kim had made a study of crops and sea temperatures with special emphasis on the temperatures at critical periods in the life cycle of Porphyra. They reported that 1962 was a year of ordinary harvest, 1964 was a year of great abundance but 1963 and 1965 were years of very poor crops. They stressed that there are three critical periods in the life cycle of Porphyra:

(1) the time of adhesion of "conchospores" to the hibi.

(2) the initial stage of growth after "budding" of the spores.

(3) the initial period of harvest.

On consulting temperature records they found the following interesting data:

(1) Period of spore adhesion

The highest sea water temperature during these four years was 23.04° C. in the late September 1965, the year of the poorest harvest, while temperatures of other years were below 21.74° C. This high temperature was in the hibi construction period, i.e. the period of spore adhesion.

(2) Initial period of growth after budding

(early November to early December)

1962: 9.72° C. - 16.72° C. (an ordinary harvest)

1963: 10.47° C. - 17.10° C. (a bad crop year)

1964: 8.21° C. - 13.18° C. (a very abundant crop)

1965: 12.22° C. - 19.93° C. (a bad crop year)

(3) Initial period of harvest (Middle of December)

1962: 8.91° C. (ordinary harvest)

1963: 9.77° C. (meagre harvest)

1964: 8.05° C. (abundant harvest)

1965: 9.52° C. (meagre harvest)

Chyung and Kim concluded that for a good harvest favourable temperatures in the "initial period of growth after budding" must be below 13.10° C. and that temperatures over 13.22° C. will result in a poor yield.

Various systems are in use for collecting conchospores on the nets. Sometimes advantage is taken of the buoyancy of the spores when first released from the *Conchocelis*. Frequently the water is stirred by some means in order to move the spores to the nets.

At Minoshima Estuary close to the Biological Field Station of the University of Hiroshima two groups, one private, the other belonging to a fishermen's cooperative society, were observed turning nets in tanks using a special rolling device designed by Professor Fujiyama. Rolling machines are used in many areas. The one designed by Fujiyama is more elaborate than those in general use. His has an elaborate system of rollers over which the nets pass. A chamber on the side of the tank holds shells with *Conchocelis* through which water is forced to distribute the spores over the rolling net (Plates 16-22).

A group of ten biology students were spending a week at the field station. They were observing *Porphyra* culture methods in the field and in the culture sheds and making microscopic examination of spore attachment on nylon twine. Counts were being made of the number of spores per centimetre which had adhered to the twine. Overcrowding the nets is undesirable as crowded plants are more subject to disease and may lead to loss of the crop. The students were also studying the conditions and techniques for cultivation of the brown alga *Undaria*, the early stages of which were being grown in the culture shed.

At Minoshima 40,000 *Porphyra* nets are set out annually. Each net is about 4 ft. by 60 ft. with 6 to 10 in. meshes. Several nets are attached together in the hibi when set at the mouth of the Estuary, the number diminishing as nets are removed gradually to locations nearer to the open sea (Plate 14).

The hibi are arranged with nets at the proper level to allow several hours daily exposure of the plants to the air. 3 to 4 hours per day is the average exposure time. If a disease appears the exposure time is increased to 5 or 6 hours. Under exceptionally good conditions exposure may be reduced to one hour or to no exposure. It is often necessary therefore to raise or lower the nets on the bamboo poles.

In areas with a hard bottom poles cannot be pushed into the ground.

In these areas floats and anchors are substituted for the upright poles.

Hibi are tended daily by the fishermen who watch the growth of the plants and shake the nets to remove accumulations of silt, diatoms or other unwanted material (Plate 23).

Light rains are not injurious but heavy rains may damage the crop. Porphyra tolerates considerable dilution of seawater. (In October 1967, following a summer of unusually high precipitation, the growth of Porphyra in a small bay in Eastern Halifax County, Nova Scotia, was unusually profuse near the outlet of a small freshwater lake. At Low Water much of it was being completely submerged in the stream draining the lake. In average years the stream diminishes to a trickle and the Porphyra population in the area is usually sparse. In 1967 however, no doubt in part as a result of the added nutrients draining from the land as well as its tolerance of dilution of the sea water, the Porphyra population was luxuriant.)

Drew's discovery and the subsequent spore culture made possible an increase of 100 - 150% in cultivated Porphyra crops, and led to numerous studies in this connection. Efforts are being made now to improve the techniques of cultivation and to stabilize the crop as well as to maintain a stock of young stages. Temperature changes in the sea can damage the plants. Spores which are liberated often fail to germinate. Laboratory control is therefore very important for maintaining a supply in good condition. Some fishermen stock germlings by rapid freezing (to -30° C.)

to keep on hand a supply of young leafy thallus stages. At some research stations the liberation of monospores (conchospores) is controlled by temperature or by photoperiodism.

For culturing germlings the temperature should be under 22° C., making it necessary either to wait until the temperature falls below this point or to employ photoperiodism which is very costly for commercial use. Both temperature control and photoperiodism are now being tried (using less than 13 hours of light) to induce development and release of spores. To liberate spores the temperature is lowered. To reduce the number of spores being released the temperature is raised.

The largest production of Porphyra is in Kyushu. In the Kumamoto Prefecture alone 10,000 people are engaged in the industry. The Nori Research Laboratory of Kumamoto Prefecture is located in the Uto Peninsula, the oldest district for nori in Japan. The former research building has recently been replaced by a large modern station for seaweed research. In this laboratory as elsewhere the aim of research is to stabilize the crop to give a constant yield. The particular field of inquiry here is a study of the diseases of seaweeds especially those affecting Porphyra, the most troublesome in this district being a "red rot" caused by a fungus.

In the laboratory, Mr. Ohta, the chief of agriculture, was cultivating the leafy-thallus phase of Porphyra suborbiculata f. latifolia to obtain spores. No sexual plants have been reported for forma latifolia. The leafy thalli produce monospores in great numbers. Thalli gathered in March had been air dried to 20% moisture and fast frozen to -20° C. P. suborbiculata f. latifolia is a robust seaweed which remains viable in this frozen state for at least six months. At the time of the visit, seven months after the plants had been collected, small thalli or portions of thalli were being cultured in aerated solutions in pyrex containers. The culture jars were placed near the windows, the leafy thalli growing in natural daylight but protected from direct rays of the sun by curtains of white cotton hanging at the windows. The plant material was kept in constant tumbling motion by the air stream. Monospores released from the thalli and settling in the lower part of the culture jar were drawn off daily through an outlet at the base and transferred to shells in another container (Plate 24).

As spores are collected and attached to twine an effort is made in the case of this form of P. suborbiculata to limit spore density to 10 spores per centimetre.

For culture of the Conchocelis phase at this laboratory the sea water is heated to 70° C. for 30 min. before being used to fill the larger culture tanks. The culture tanks here at Misumi were very large and with a very white interior to give good light reflection (Plate 25).

In the office of the Director, Dr. Masuda, was a chart of the area and an interesting model of a "bamboo blind" hibi field. The chart indicated the many little rivers of the area the fertile estuaries of which showed bamboo blinds hibi. The hibi model illustrated such a field. Both chart and model were made in the days when the "bamboo blinds" were in vogue. Nowadays nets are more common than the bamboo blinds. Nets are easier to move and whole fields can be transferred quickly to escape from a polluted area if disease becomes noticeable (Plates 26, 27).

In the all bamboo hibi (all bamboo except for the fastenings) the net is replaced by parallel bamboo slats stretched across two bamboo supports. The whole structure is agitated by the motion of the water, removing the silt and thus requiring less attention from the fishermen than the more modern nets.

The model of the hibi field showed the arrangement of bamboo blinds which allows sufficient space between each two rows for the passage of the narrow boats used by fishermen when hibi-tending. In the model were also miniature fertilizer containers of the type used in that Prefecture. The fertilizer in use is an inexpensive one with 90% N and 10% K salts. Pellets of this fertilizer are placed in the containers in amounts to last 10 days to 2 weeks (Plate 28). It was interesting to learn that at least in some regions fertilizer is used during the pre-harvesting period. At this time it gives to the Porphyra the good colour desirable in such a commercial crop. (In the summer of 1965, a season of much sunshine in Nova Scotia, most of the Rhodymenia harvested near Digby was pale in colour and hence less desirable than usual for the commercial market. At the Seaweeds Laboratory of the Research Foundation it was felt that some remedial measure should be attempted. Rhodymenia cultured in our laboratory under unshaded fluorescent light lacked the usual characteristic pigmentation. Addition of $NaNO_3$ to the culture medium developed plants of a healthy appearance and with the dark red colour familiar to the consumer.)

At the time of the visit to Misumi the laboratory staff there were making preparation for an official visit of His Imperial Highness Emperor Hirohito who was expected in a few days. The Emperor is a biologist greatly interested in fisheries and seaweed developments and was coming to view the Porphyra cultivation in the area and the facilities of the new Nori Research Laboratory.

Gracilaria sp. is harvested in Kumamoto Prefecture but because the price is low its commercial cultivation is carried on only to a limited extent. Rocks with attached plants are collected and placed together in convenient locations.

The great activity in the Porphyra industry in this region can be seen clearly from a vantage point at Uzuchi not far from Misumi. Looking from Sumiyoshi Hill as the tide ebbs one can see many acres of hibi with fishermen and fisherwomen tending some of the 40,000 nets in the bay, some from boats, some wading. As the tide recedes one is surprised to see gradually uncovered a specially built concrete roadway with trucks moving down the gently sloping shore carrying people and gear of various types for use in the hibi fields. Without the road fishermen in that bay using boats alone would have to leave shore several hours before low water. Some fishermen without trucks were seen walking (Plates 29-30).

This place overlooking the bay with its extensive cultivation of Porphyra was chosen as the site of a monument in memory of Kathleen Drew whose work was of such importance to the fishermen of the area. Each year on April 15, many fishermen and others interested in nori culture meet there with Mr. Ohta and other scientists to honour her memory and to discuss problems relating to the cultivation (Plate 49).

The next places visited were in Mie Prefecture. Following a day spent with Professor Segi and others at the Faculty of Fisheries of the Prefectural University of Mie at Tsu, visits were made with Dr. Uyeno and Dr. Kida to seaweed farms and culture stations at Yonezu and Ohguchi, both on Ise Bay.

For the culture of Conchocelis oyster shells are used at Yonezu as at stations elsewhere. Ten cleaned shells (the flat, thinner valve only) are threaded back to back on strings through two hores bored in the shell. The strings of shells are hung from bamboo poles placed close together across the tank which at Yonezu is 50 cm. in depth (Plate 15). When tanks are used also for nets for spore collection and adhesion they are usually deeper. The twine used for the nets here is made from hemp palm, or yarns of synthetic fibre manufactured in Kurashiki, Okayama Prefecture.

The sea water used in the tanks at this station is not subjected to previous heating. Formerly it was the custom to heat the water and to sterilize the shells before infection for Conchocelis. Both practices were abandoned about seven or eight years ago. Shells are now washed in a special cleaning machine and suspended in the tanks at a density of 800 shells per square metre of water surface (Plates 32, 33).

Although most nets at Yonezu had already been set out in the hibi, the Director of the station at the request of Professor Segi had very kindly allowed the winding machines on one tank to be left in place until after the visit. These net winders were less complicated than the ones designed by Fujiyama in use at Minoshima Estuary. The concrete tanks at Yonezu were built with removable sections near the ends of a lengthwise partition to allow thorough circulation. Two large net winders were placed in the tank, one in each section. Agitation of the water by the turning wheels and nets distributes the conchospores for collection on the net (Plates 34, 35). In this area in 1966 the endeavour was to limit the attachment to 10 to 50 spores per centimetre. In 1965 the allowance of 60 to 100 spores per centimetre had proved to be too many. If spore density is too great the population, further increased by the second germination of neutral spores released from monosporangia of juvenile plants, is likely to suffer the disease caused by Pythium. This disease causes much damage, sometimes even wiping out entire crops. When Conchocelis is too dense it also may suffer from diseases, in this case either caused by or associated with bacteria. Cl_2 is used to counteract this condition. Some shells with Conchocelis are maintained in culture at all stations for study and periodic examination (Plates 15, 36).

At this station two news reporters who had come to interview the writer were greatly surprised and even perplexed that seaweeds are not a regular item of the Canadian diet, and sought earnestly to know the reason. With some embarrassment they were told that it might be that as most Canadians live inland they do not fully appreciate the dietary value of seaweeds, although a great many enjoy "dulse" and others enjoy desserts and other foods containing carrageenan or alginate.

In the culture shed at Ohguchi *Undaria* was being cultivated. The technique for cultivating *Undaria* (Wakame) is much the same as for *Laminaria*. Ripe or nearly ripe sporophylls had been placed in containers in the spring and after release of the zoospores the sporophylls were discarded. Lengths of twine, each 150 metres, are then immersed into the dense suspension of motile spores so obtained. The twine is allowed to remain in the suspension of swarming zoospores for two or three hours until about 100 spores per cm. have settled and become attached to the twine. *Undaria* spores are motile. There is no production of neutral spores producing additional plants of the same type. Hence it is not necessary to restrict the spore attachment to 10 or 50 per cm. 100 spores per cm. is considered to be a satisfactory number in this locality. (To determine the density of attachment, samples of twine must be examined under a microscope.) The twine is wound on the frames immediately and hung in tanks of running sea water (running for about one month) for the development of gametophytes and young sporophytes. By November when the young sporophytes are about ready to set out running sea water is used again for some time. The lengths of twine are then wound about ropes 3 metres in length, many ropes attached to a horizontal bamboo pole which is anchored in a suitable place and kept afloat by buoys.

In winter pearl oysters are moved south to escape the cooler water temperatures on the Mie coast. The pearl culture rafts are then often used in this region for the Wakame rope cultivation (Plate 37).

The sea temperature at Ohguchi at that time was 20° C. In the sea 16,000 nets with Porphyra tenera had been set out in hibi, the upright poles being pounded into sandy or muddy bottom. In harder bottom a jet pump is used for making holes for insertion of the upright bamboo poles.

The fishermen of 6 unions share the hibi ground. Each fisherman marks his hibi sections with his distinctive pennant. Not all locations in the ground are equally good. In order that an equable distribution of choice and less choice sites be shared by the members, it is customary for union officials to assign several locations to each fisherman. In many regions, for protection of all the union members, each fisherman is required to notify official guards when he goes to the hibi. Often both the guards employed by the unions and the director of the local biological station must be informed.

The nets are tended every day for close examination of the Porphyra plantlets and to raise or lower the level of the nets according to the phase of the moon and the tidal amplitude. In this region nets are exposed to the air for 4 or 5 hours per day. After transferral to an exposed area the exposure is reduced to 2 hours (Plates 38, 39).

Through the kindness of the Director a tour of the hibi grounds was made at low tide in a power boat supplied to the station by the government for the application of fertilizer to the *Porphyra*. Like the boats of the fishermen it was narrow and could pass easily among the rows of hibi. A field microscope (X 150) carried in the cabin was used for noting the progress of the juvenile plants and their density on the twine. Microscopic examination indicated the *Porphyra* plantlets to be overcrowded and the station biologists were apprehensive of the outcome. Several months later, the writer learned that the crop unhappily had been a failure. Perhaps in spite of the reduction in numbers per cm. in 1966 too many conchospores had been allowed to attach to the nets during the period of spore adhesion. Perhaps production of neutral spores by the juvenile plants had been more prolific than usual. The crop failure was a bitter disappointment and a great loss to the fishermen.

Not all conchospore-collecting in Mie Prefecture is carried out in indoor tanks. Advantage is taken also of highly productive locations, the "natural hibi grounds". Hibi spread in such areas for spore-setting are usually moved later to other locations. Field-collection is often beset by difficulties related to weather conditions. In rough weather spores adhere only to the outside of the twine. On calm days (and indoors) spores can penetrate further into the twine. In field-collection as well as in tank-collection indoors, inspection of spore adhesion is made by use of the microscope.

In former years — about forty years ago — the hibi grounds at Ohguchi, now given over to production of *Porphyra*, were used for commercial net-cultivation of Monostroma. Although cultivation of Monostroma has been reduced with the increased production of Porphyra, some natural hibi grounds are still being maintained for Monostroma and Enteromorpha. These green algae are dried and ground to be eaten on rice or blended with other ingredients for making "green nori pastes" used on special occasions. Such a "natural" hibi ground was observed in a sheltered cove not far from Toba (Fig. 8. Plates 41, 42).

Two species of Undaria are used for "Wakame", U. pinnatifida and U. undarioides. Natural hybrids of the two species occur near the biological station at Hamajima. U. pinnatifida in this area occurs mainly just inside Ise Bay from Morozaki to Toba, with some populations also within the inner reaches of the Bay. U. undarioides in this area occurs on the coast from Ise Shima west. Not many naturally occurring hybrids have been seen here — and no reports of hybrids have been made in other districts, although their occurrence is likely elsewhere. The hybrids must result from some unusual combination of environmental factors. The water west of Morozaki is neritic. Ise Bay is considerably diluted by water which empties from three large rivers. Oceanic water does not penetrate far into the bay. Offshore are many ledges and skerries probably reached by Ise Bay water. Mixing of the two bodies of water occurs here. It is evident that gametes of the two species are also mixed and a few hybrids result from successful fusions.

At the Research Station at Hamajima the cultivation of Undaria of both species and their hybrid is very successful and is most interesting to observe. In April zoospores are collected on twines in density sufficient to produce about three gametophytes per cm. (If every gametophyte were to complete its development fewer than this number would be required.) By November there is a mixture of sporophytic plants of both species and the hybrids (Plate 43).

Water temperature is not particularly controlled. Light intensity, however, must be controlled, the requirement being governed by the temperature of the water. Undaria gametophytes are more tolerant of high light intensities than gametophytes of Laminaria and can withstand higher intensity in the culture shed than is suitable for Porphyra. Special fluorescent "Plant Lux" light tubes were being used having a wave-length approximating that of chlorophyll and giving a faintly violet or pinkish colour (Plates 44, 45).

At	23° C. :	2,000 lux is required
	23° - 25° C.:	1,000 lux is required
Above	25° C.:	intensity must be reduced to less than 500 lux.

Seawater temperatures at Hamajima do not exceed 28° C. A temperature of 17° C. is best for gametophytes and very young sporophytes.

All water used in the culture procedures is filtered. Fresh ripe sporophylls collected in April are first washed in filtered sea water to remove as many adherent diatoms as possible. Washing helps to keep the diatom population in the cultures to a minimum. To increase the rate of release of zoospores the sporophylls are then dried slightly in air — away from direct sunlight — and immediately placed in filtered sea water. No separation is made of U. pinnatifida and U. undarioides. Sporophylls of both species are placed together in the same container and are removed after release of the zoospores.

As is usual for rope cultivation, twine is wound on frames of non-toxic firm vinyl tubing and suspended in tanks of filtered sea water. Even with careful washing of sporophylls and using only filtered sea water in the culture tank there will still occur on the twine quite a few diatoms and many colonies of bluegreen algae. The water is changed every month or every two months. Containers of many sizes may be used, from small boxes to large culture tanks of 9 sq. metres bottom surface and 50 cm. in depth. Other tanks are half this size.

At Hamajima the culture medium is filtered sea water alone. Addition of hormones, vitamines, and chelators has been tried but as there was no noticeable difference in the result their use was discontinued. The added nutrients produced larger gametophytes but had no apparent effect on the sporophytes.

For rope cultivation to obtain a field harvest, no attempt is made to separate the hybrids from the specific plants. For future study of the F_2 generation, however, all plants of U. pinnatifida and U. undarioides are removed leaving only the hybrids on the twine. For setting out in the sea in November, lengths of twine bearing the young sporophytes are wound around "growth" ropes 3 m. in length a number of which have already been attached to a heavier supporting rope anchored in a suitable place and kept afloat by several polyethylene buoys each 30 cm. in diameter. Growth of Undaria is more luxuriant in the upper part of the rope thus making it unnecessary to have the "growth" rope longer than 3 m. The heavy rope holding buoys and "growth" ropes is usually also about 3 m. in length.

At Hamajima also an experimental programme has been undertaken on field-cultivation of the agarophyte Gelidium, the regenerative properties of which had been known since early in the century. Gelidium cultured on twine is attached closely to a specially designed concrete structure by threading the twine through eyebolts inserted in the concrete. Attachment of plant fragments is also made in this manner. Fragments held close to the concrete develop branching creeping rhizomes which produce attachment organs at intervals on the under side and send up profusely branching upright shoots above (Fig. 9, Plates 46, 47).

Fertilizers for Gelidium are also being investigated, the main components of which are urea and water soluble phosphate with some hormones including I.A.A. To apply the fertilizer, several 50 gram pellets (Plate 48) are placed in a perforated vinyl basket and set on the bottom among the seaweeds. As the Gelidium populations at Hamajima are not in pure stands but in mixed populations, the effect of the fertilizer was less evident than in the more concentrated populations of Gelidium near Tokyo.

The success of the "rope-concrete cultivation" has been difficult to assess with accuracy as natural growth and rope-attached plants have been harvested together. Harvests of Gelidium by the fishermen's union in the area, however, had increased. Elsewhere production had declined. At the time of the visit "rope-concrete cultivation" and the use of fertilizer had been going on for only two years. The continued decline of Gelidium has seriously jeopardized the future of the agar industry. Its successful cultivation is therefore of very great importance not only in Japan but also in other countries dependent largely on the Japanese supply of agar for their requirements.

Seaweed diseases, especially those associated with Porphyra are troublesome and their control is difficult. Scientists at most universities and research stations are studying many of the disease-causing organisms and are making a great effort to develop means of control. Pollution from industrial waste in particular has become a very serious problem. Tokyo Bay, formerly the site of luxuriant Porphyra cultivation, has become greatly polluted. Hibi grounds successful for centuries in the Bay have had to be abandoned and the Porphyra cultivation moved further out to the coasts of the Prefectures of Chiba and Kanagawa. Since before 1960 Arasaki has been involved in the investigation of diseases of cultivated Porphyra and especially with a Chytridean parasite which attacked the crops in Tokyo Bay in epidemic proportions in 1959-60.

Research in connection with Porphyra both in amount and in variety is very extensive. At the Prefectural Fisheries Station at Okayama experimental work is particularly concerned with the effects of various fertilizers on the flavour and colour of Porphyra. Applying the results of research in photoperiodism by Kurogi and Iwasaki and the completion in vitro by the latter of the Porphyra life cycle, ecologists at Yamomoto near the Haneda airport and at a few institutions in other areas are attempting "greenhouse culture" of Porphyra on a larger scale. At Dr. Arasaki's suggestion and accompanied by him, an interesting visit was made by the writer to the Agricultural Station at Abiko, near Tokyo to observe the "greenhouse" operation on a small scale. The effects of such research offer many favourable possibilities to the industry.

SOME POSSIBLE APPLICATIONS IN THE ATLANTIC PROVINCES

Several genera of seaweeds which are cultivated in Japan occur in the Atlantic Provinces of Canada: Laminaria, Porphyra, Gracilaria, Ulva, Monostroma and Enteromorpha. Of these all except Gracilaria have been grown from spores in the Seaweeds Laboratory of the Nova Scotia Research Foundation. Rhodymenia and Chondrus have also been cultured here from spores. Chondrus germinated in the laboratory and set out in the sea continued growth for three years before being washed from the substratum in a winter storm. Substrata employed in the laboratory included glass, granite, slate, stones, shells and various types of twines. Laminaria, Chondrus, Gigartina and Rhodymenia have been grown in the sea on concrete blocks and other substrata.

Concrete cylinders as used in Japan would be useful for extending many of our Laminaria beds. Many Laminaria beds east of Cape Sable could be extended by removal of Echinus. The density of this heavy grazer severely limits the beds in such areas as Lockeport Harbour, coastal areas near the mouth of Mahone Bay, and other places east of Sable.

Rope cultivation as used in Japan for Laminaria and Undaria would be suitable for Laminaria here and would eliminate contact with most grazers. With suitable provision for shade from strong sunlight this method should be suitable also for Rhodymenia. Successful applications of fertilizer shortly before the harvesting season might obviate the necessity of such shade.

Asakusa nori prepared near Tokyo from Porphyra tenera is considered the nori of best quality in Japan. Its great popularity is due largely to the special processing procedures employed in the preparation. Several species of Porphyra are abundant in certain regions of Nova Scotia and New Brunswick and probably are abundant also in Newfoundland. There is no local market for this genus. If texture and flavour meet Oriental requirements, a market could be found in Japan. If texture and flavour are not quite desirable then these could be improved by developing required processing techniques. Cultivation on nets as in Japan would be suitable.

Areas with good currents provide favourable conditions for growth of algae. Regions with very hard substratum would present difficulty for placement of upright poles which are usually required in large numbers. In some cases, however, a jet pump could be employed to prepare holes for insertion of the poles. Floats and anchors could be employed in areas where the degree of exposure to wave action is not too great and/or the current not too strong.

Gracilaria could be grown on rope in the warm summer waters of the bays of the Gulf of St. Lawrence and Northumberland Strait. The Ceramium sometimes associated with it might be somewhat troublesome, if separation is necessary. On the other hand, if the extract of the Ceramium is compatible with that of Gracilaria, as is quite possible, the epiphyte would be an added benefit to the harvesters.

Furcellaria fastigata Lamour., another commercial seaweed, is also found in the comparatively sheltered waters of the southern Gulf of St. Lawrence and Northumberland Strait — the only known location for this genus in North America. It occurs on rocks and ledges of friable sandstone from just above Low Water of lowest spring tides to depths of 30 ft. often in association with Chondrus or Fucus serratus.

Because of its habit of growth and delicate organs of attachment, harvesting by raking — generally satisfactory for the more strongly attached Chondrus — is not suitable for Furcellaria. Careful investigation by workers in our laboratory and by scuba divers in the field has shown raking to be a ruthless method of harvesting. Even cutting with great care removes whole clumps of plants from the substratum leaving no portion for regeneration. Austin has found this plant to require five years from germination of the spore to maturity. Many tons are gathered from beaches after late summer and autumn storms which remove chiefly the older and heavier plants. Raking removes plants of all ages and would soon deplete the supply. To maintain conservation only drift weed should be harvested.

In Europe much of the Furcellaria of commerce occurs in the "free-floating" or drifting form and grows well in areas with a sandy bottom and where the sea water, like that of the St. Lawrence Gulf, has been somewhat diluted by inflow of freshwater. It would be of great ecological interest and possibly also of eventual commercial value to introduce Furcellaria to some biologically suitable body of water, preferably one with an eddy, where it could become established by increasing vegetatively in the "free-floating" form.

"Rope-stone" cultivation which appears to be successful with Gelidium in Japan should be attempted for our Furcellaria.

If either or both of these attempts were successful additional supplies of this valuable seaweed would eventually become available to industry.

The demand for Rhodymenia palmata exceeds the supply. It has long been the opinion of the writer that cultivation of this seaweed should be undertaken in our area. Studies are in progress at the Seaweeds Laboratory of the Research Foundation to determine conditions and techniques suitable for various phases of such cultivation. Although not yet far advanced, both laboratory and field studies show promise and it is hoped to set up more extensive field experiments in Nova Scotia and Prince Edward Island in 1968. It is planned to grow Laminaria on the upper part of the rope in an attempt to provide a sunshade.

Hybridization offers interesting possibilities. In this connection it should be noted that Suto was able to produce hybrids from crosses between monoecious species of Porphyra and between dioecious species, but that attempted crosses between monoecious and dioecious species resulted in high mortality among the F_1 generation.

A successful hybrid of Laminaria digitata and L. longicruris might produce a very desirable commercial alga possessing the best features of each. L. digitata has a stronger holdfast, a heavier stipe, and a shorter but broader blade. It has greater longevitity and a higher alginate content. L. longicruris grows to a greater length in a short period of time. Plants of L. longicruris more than 40 ft. in length have been collected from swift currents in southwestern Nova Scotia. New growth in length of the blade between late October 1952 and early June 1953 was as much as ten feet in plants on a ledge in Yarmouth County.

Although hybrids of these species have not been recorded in our waters, it must be kept in mind that in spite of the many harvesters and scientists working in the field, few natural hybrids of Undaria have been reported in Japan, and these from a single location.

The seaweed with the greatest present demand in the Atlantic Provinces is *Chondrus crispus*, large harvests of which come chiefly from Nova Scotia and Prince Edward Island. The demand for extracts from red seaweeds continues to increase. Successful large scale cultivation of *Chondrus* would enable crops to be taken in areas not now producing this seaweed. The strongly adhesive spreading perennial holdfast requires a broad surface for growth and attachment. Near Halifax a period of three to five years is required after spore germination before upright shoots are of sufficient size for harvesting. Rope cultivation is unlikely to be satisfactory. Blocks of concrete or of concrete faced or studded with granite on the surface are suitable for small scale cultivation. Large scale cultivation would present some engineering problems. If engineering costs were not too great a large scale cultivation could be profitable. Cultivation techniques suitable for *Chondrus* would be suitable also for *Gigartina*. Our native species, *G. stellata*, however, is less in demand than *Chondrus crispus*. The introduction of other species of that genus which are in greater demand might be possible.

In many seaweed populations noticeable differences are frequently evident among plants of the same species growing in close association at the same or almost the same level. Some plants or clumps of plants, displaying strong evidence of immediate common ancestry, are more robust and vigorous than others. It is possible that special strains could be developed from these which would yield a higher grade or greater quantity of extract or which in some other way would enhance the value of the crop plant.

Most of these possibilities would involve projects of fairly long term. Increased production of Laminaria by extension of existing beds, however, could begin at once. Cultivation of Rhodymenia hopefully could be undertaken within a reasonably short period of time. If desired, Porphyra could also be cultivated.

A pilot project to demonstrate procedures would be required to introduce large scale rope- or net-cultivation to the fishermen of the area.

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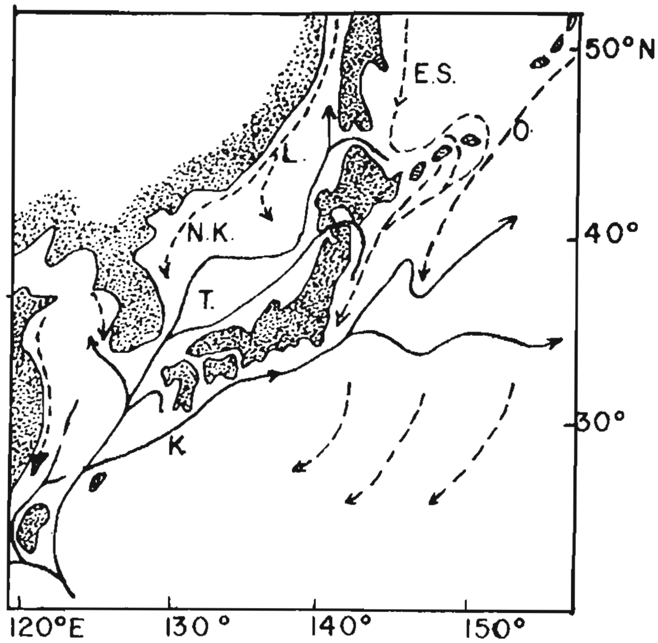


CURRENT-SYSTEM IN THE WATERS ADJACENT TO JAPAN

after Uda, 1966

Fig. 1.

E.S. = East Saghaline Cold Current

K. = Kuroshio Warm Current

L. = Liman Cold Current

N.K. = North Korean Cold Current

O. = Oyashio Cold Current

T. = Tsushima Warm Current

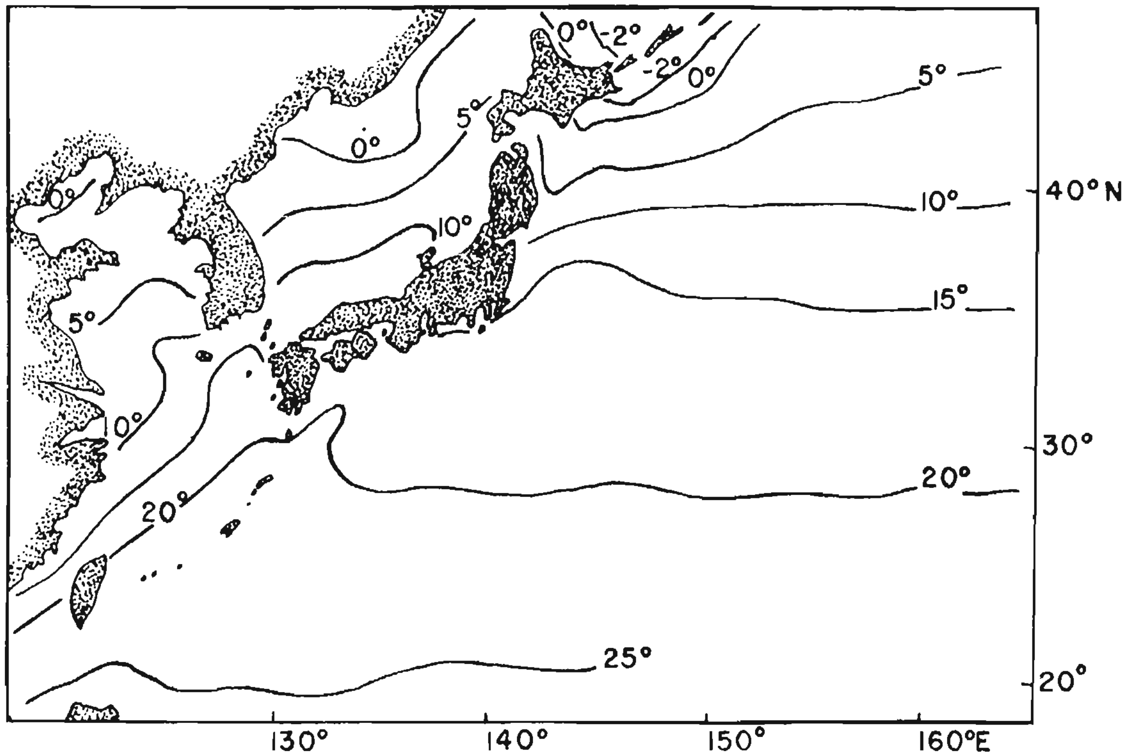


Fig. 2- SURFACE TEMPERATURE in FEBRUARY
after Horikoshi

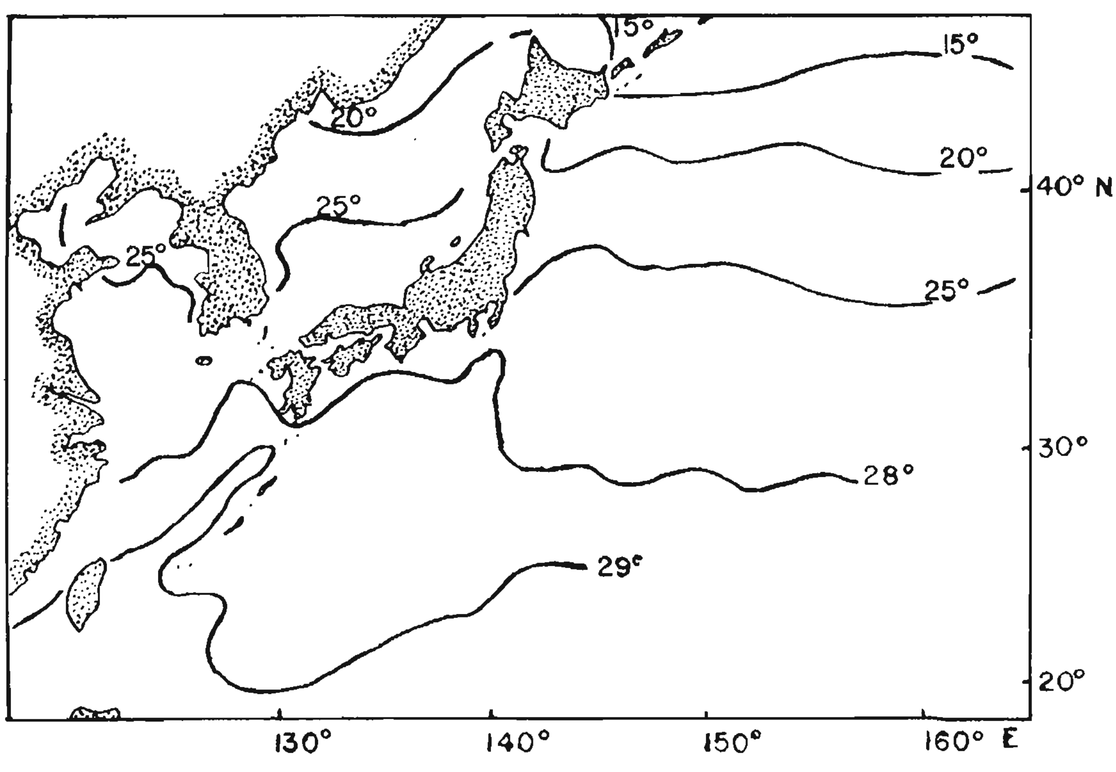
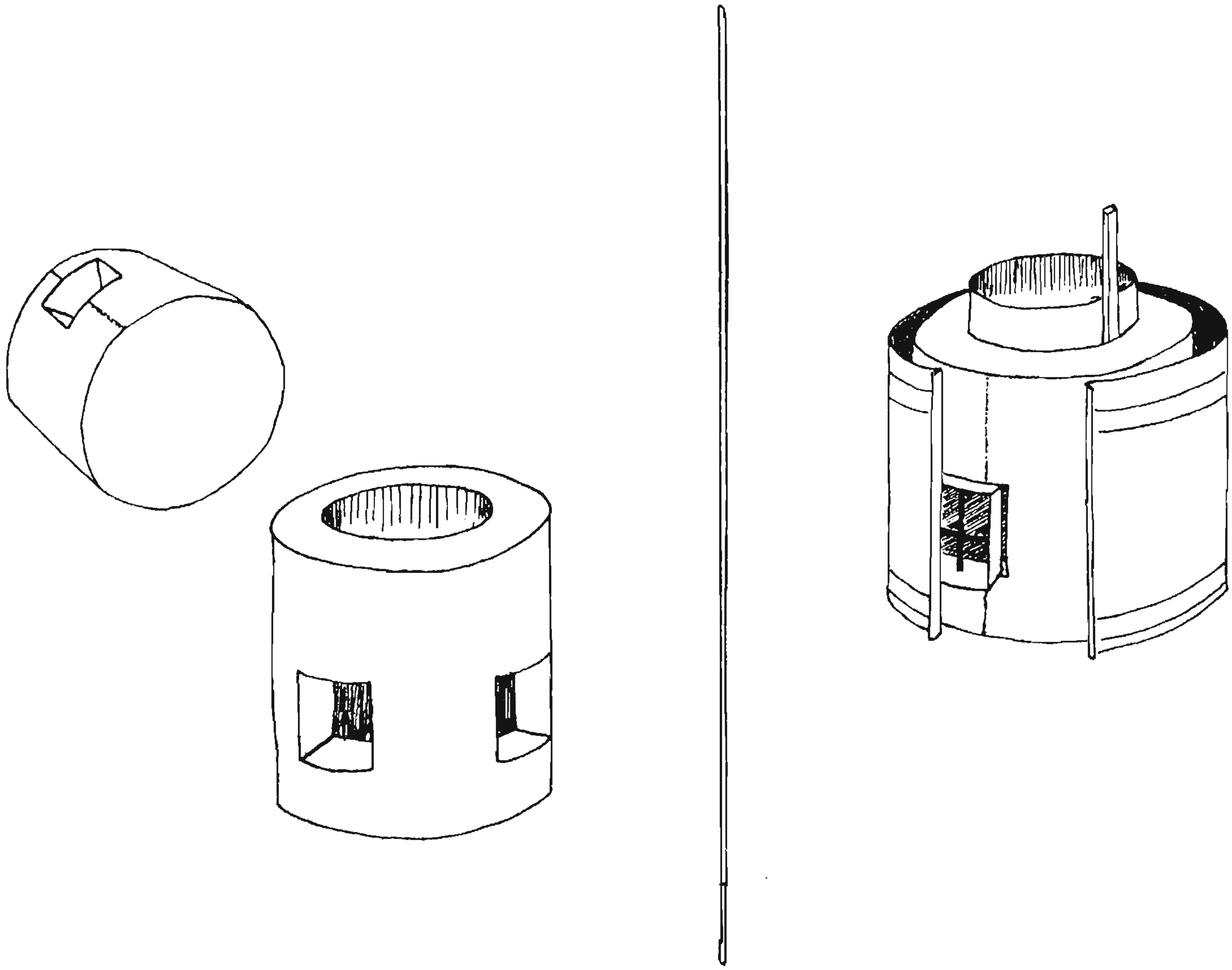


Fig. 3- SURFACE TEMPERATURE in AUGUST
after Horikoshi



1. 2.

Fig. 4. 1. Concrete Laminaria planters.

2. Concrete planter in mould of metal and wood.

Usu, Hokkaido, 1966.

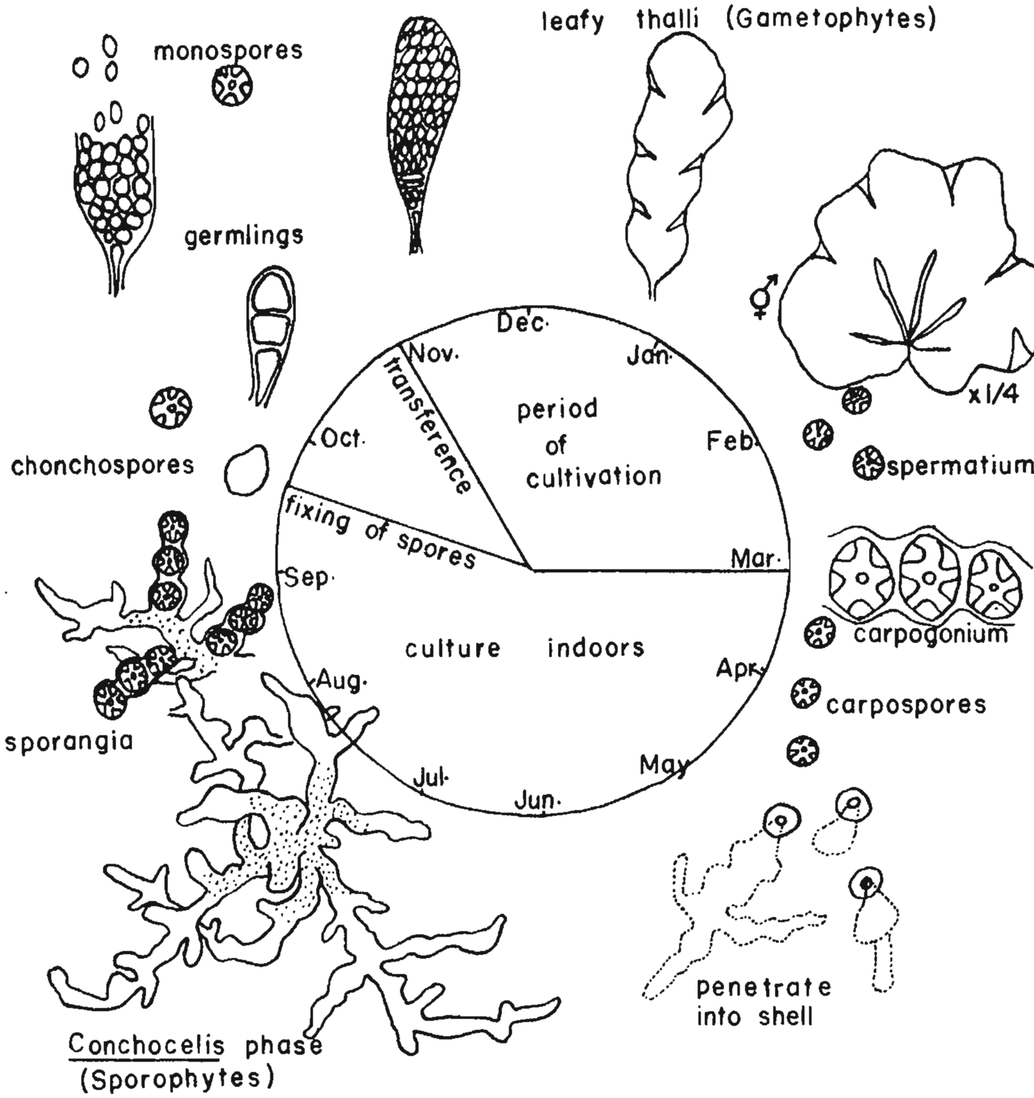
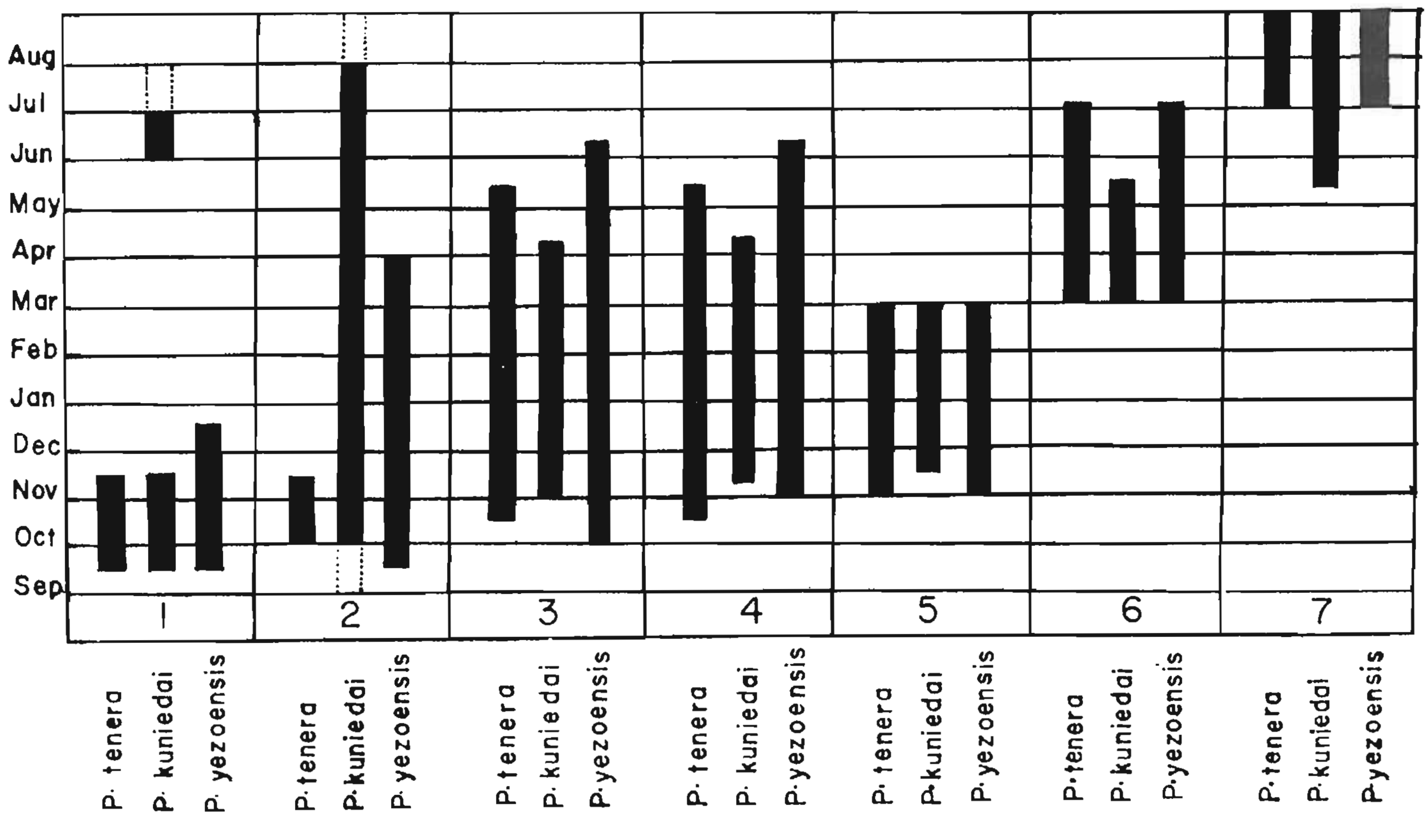


Fig.5- LIFE CYCLE OF PORPHYRA TENERA KJELLM. OR PORPHYRA YEZOENSIS UEDA

from a diagram by T. Segi



1. Period of monospore (conchospore) liberation from Conchocelis-phase

2. Period of monospore liberation from leafy Porphyra thallus

3. Period of spermatangium formation and release of spermatia

4. Period of 'carpogonium' formation and release of 'carpospores'

5. Early growth of Conchocelis-phase in mollusc shell matrix

6. Period over which Conchocelis-growths become visible in shell

7. Period of formation and maturation of monosporangia in Conchocelis-phase

Fig. 6- SUMMARY OF SEASONAL FRUITING BEHAVIOUR OF SOME PORPHYRA SPECIES CULTIVATED IN JAPAN. (After Boney, 1965, from data in Kurogi, 1961).

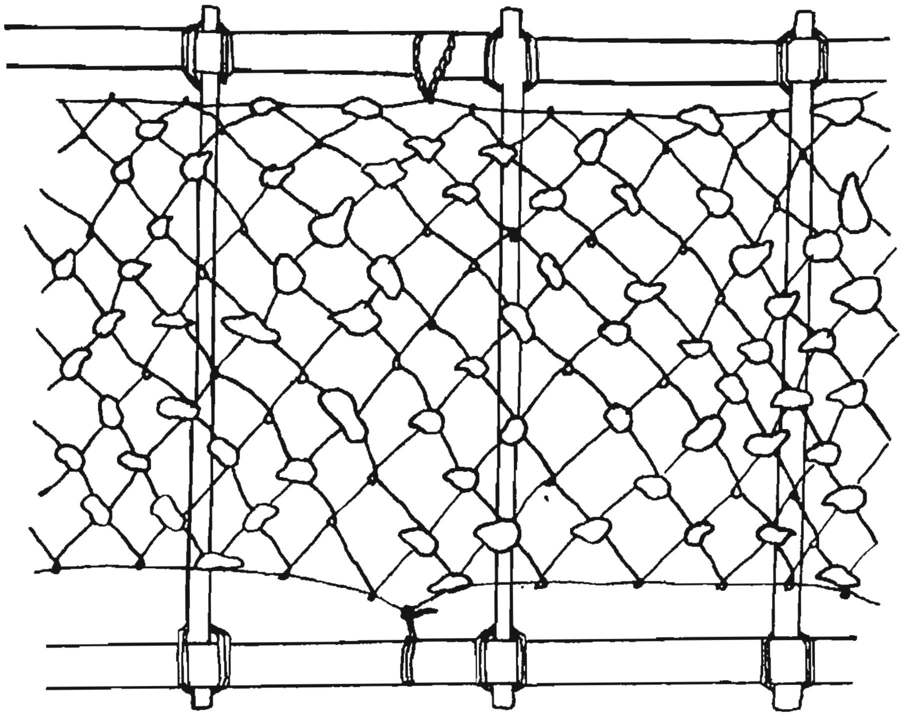


Fig.7- Section of bamboo frame with attached net with shells. Used occasionally in the field where it is placed below Porphyra nets:

1) to catch spores released from mature leafy thallus phase (Jan. to March, depending on species and location.)

2) to allow liberated buoyant conchospores from Conchocelis-phase to rise to hibi nets.

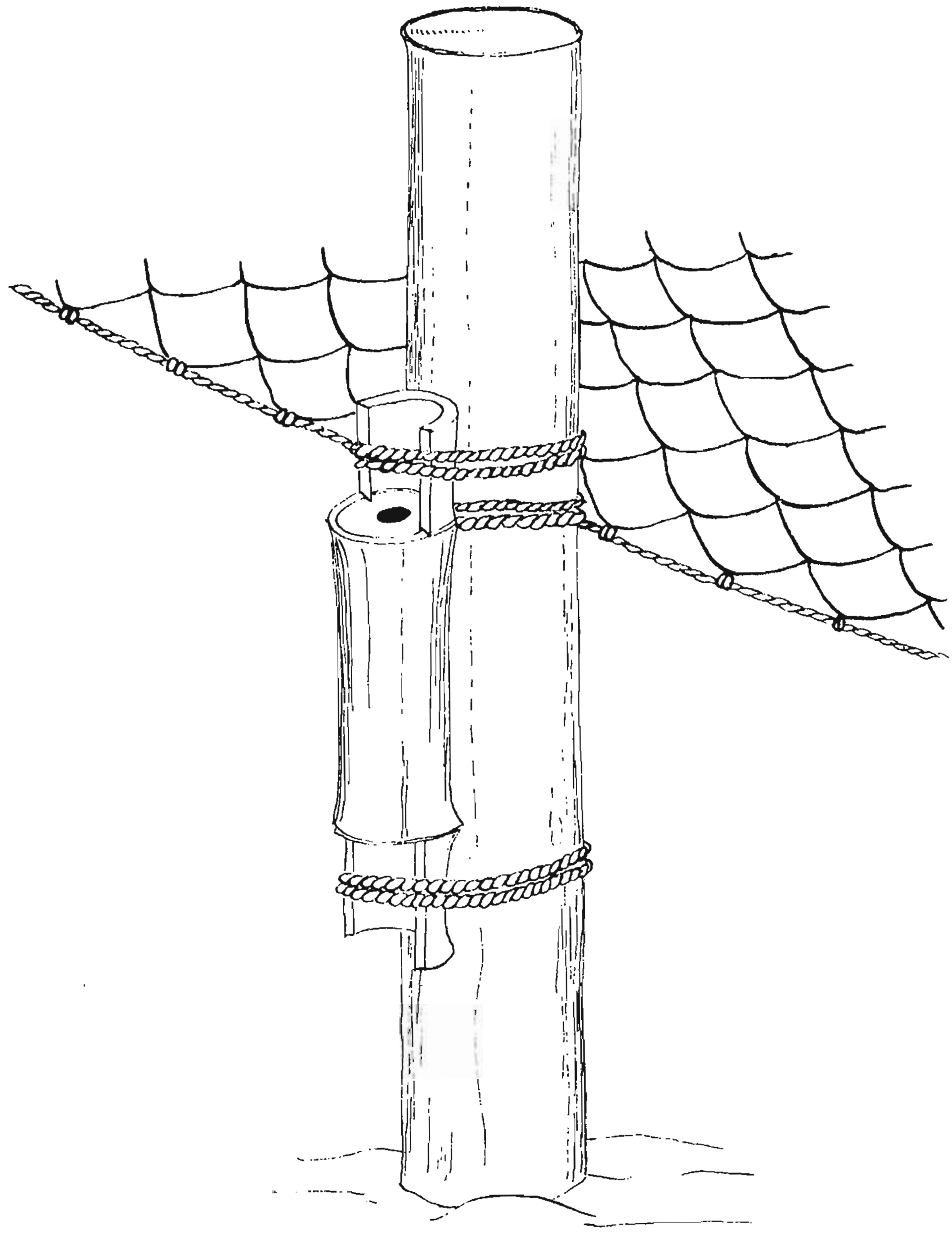


Fig.8 Section of bamboo used as holder for fertilizer in Monostroma hibi in Mie Prefecture.

after Segi.

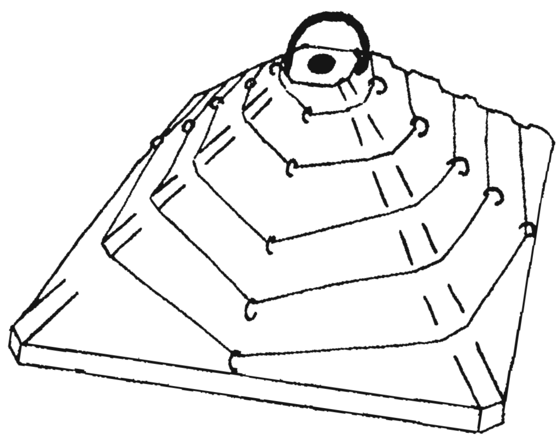


Fig.9- Concrete structure with embedded eyebolts used for cultivation of Gelidium at Hamajima. Oct., 1966.

Plate 1. Fisherwoman collecting <u>Laminaria</u> by hand at Muroran, early morning, low water. Oct., 1966.

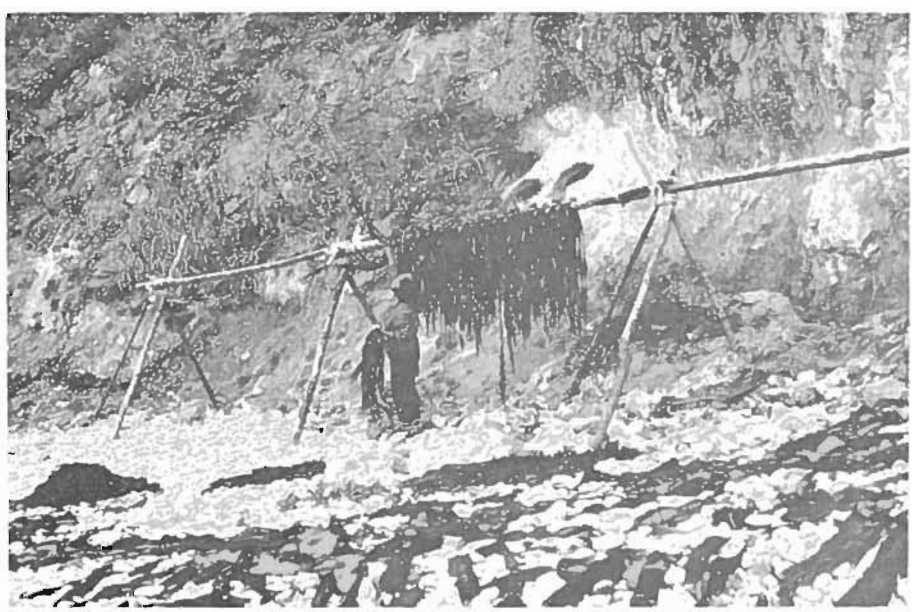


Plate 2. A good <u>Laminaria</u> drying location at Muroran, Oct., 1966. Note pebbles and cobbles on sloping beach.

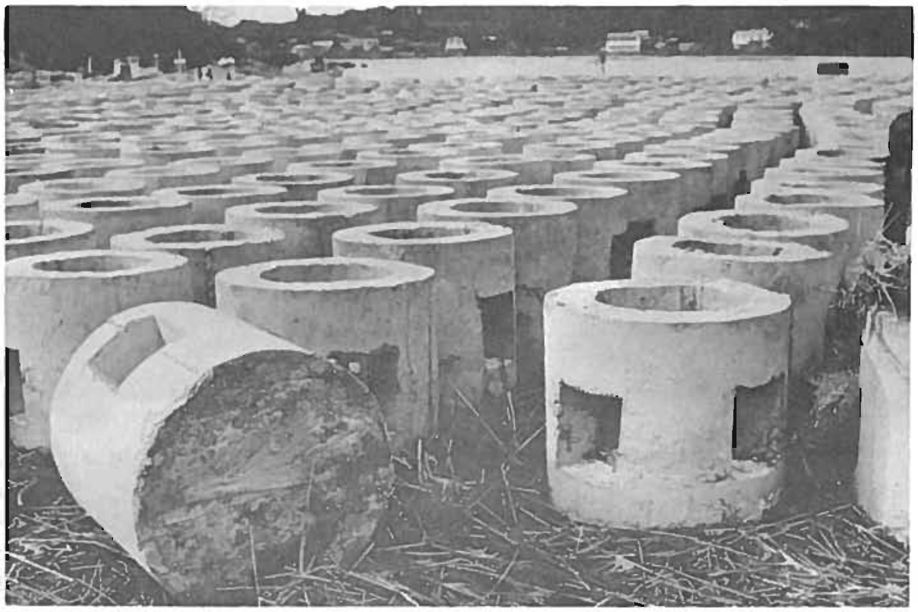


Plate 3. Concrete structures used to extend Laminaria beds. Usu, Hokkaido. Oct., 1966.

Plate 4. Concrete "planting stones" for Laminaria and moulds of metal and wood used in their manufacture. Usu, Hokkaido. Oct., 1966.

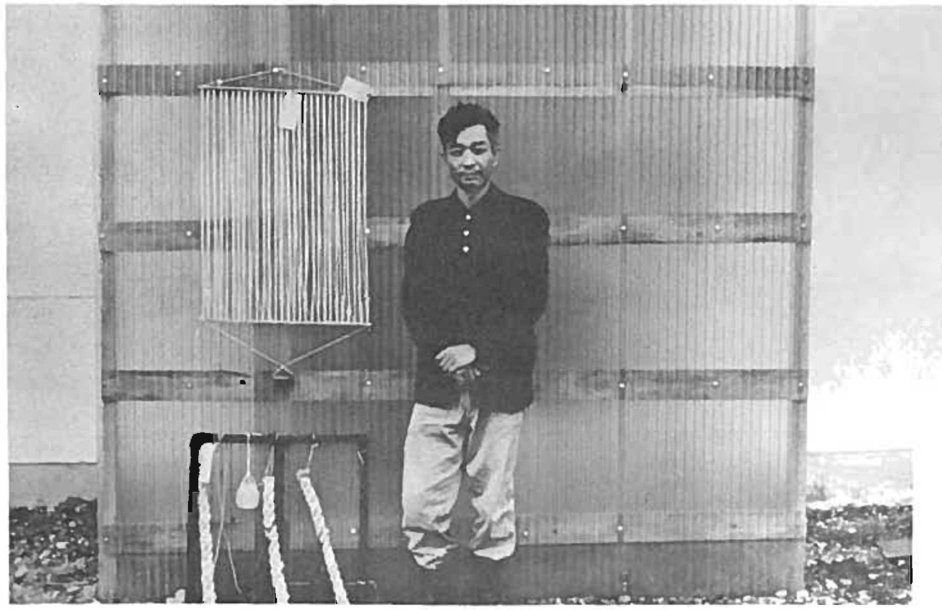


Plate 5. Upper frame with twine is used for spore attachment and growth of early stages of *Laminaria*. Lower frame shows samples of ropes about which are wound the twine with attached young *Laminaria* sporophytes. Polyethylene container is used to hold fertilizer. Usu, Hokkaido. Oct., 1966.

Plate 6. Preparation of heavy ropes for continued cultivation in the sea. Usu, Hokkaido. Oct., 1966.

Plate 7. Laminaria bed, low water, Digby Neck, Nova Scotia. July, 1965.

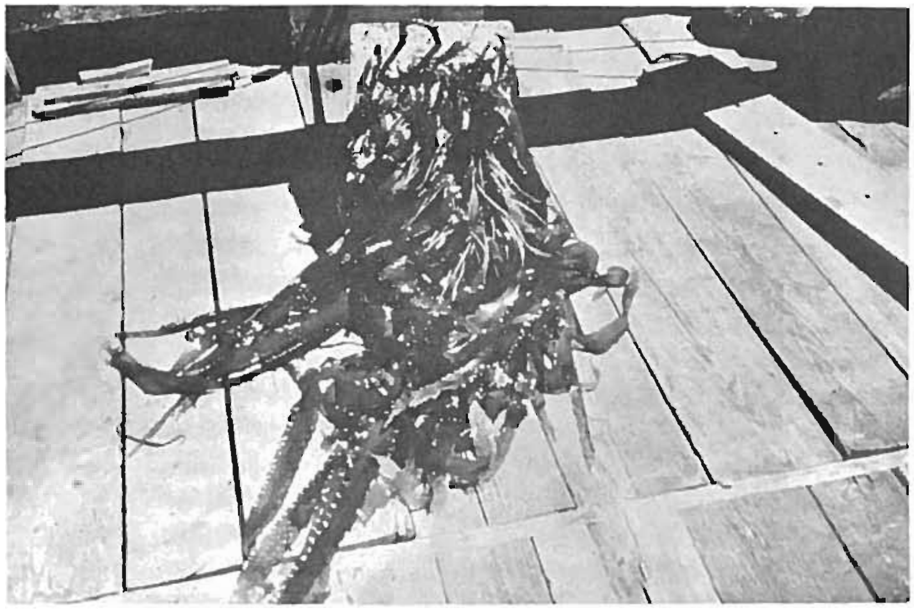


Plate 8. Young Laminaria longicruris on concrete block. Southwestern Nova Scotia, Summer, 1950. Block placed in sea, Oct., 1949.

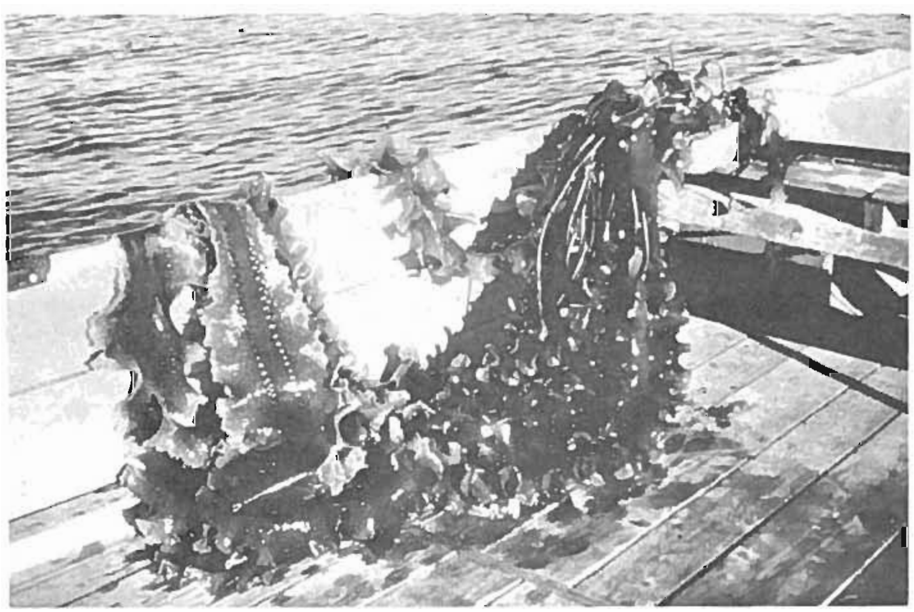


Plate 9. Same block, Summer, 1951.

Plate 10a. 1949 test block with single remaining plant of Laminaria longicruris, Laminaria digitata, Corallina and Chondrus. Summer, 1952.

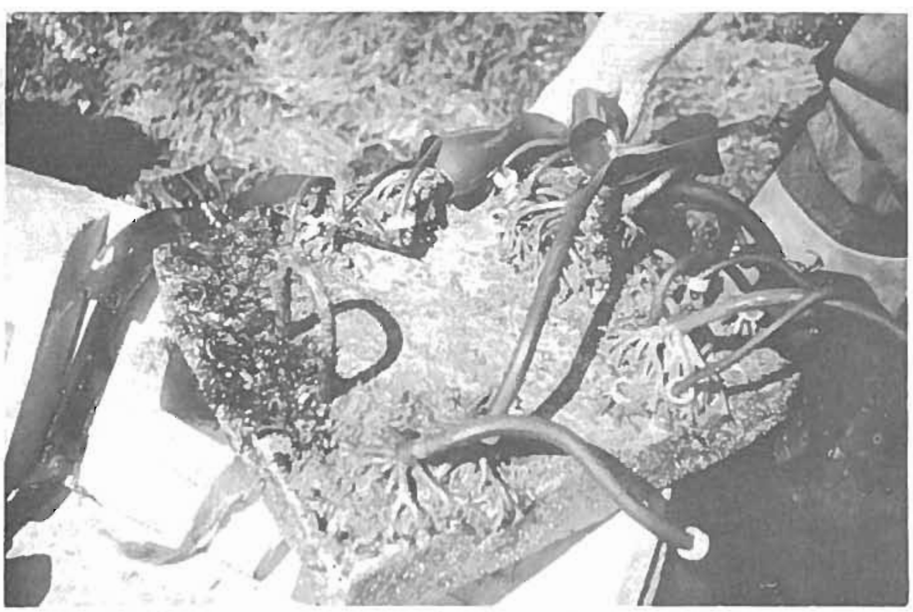


Plate 10b. Same block showing stipes and strong spreading holdfasts of Laminaria digitata. Summer, 1952.

Plate 11. Plant succession as shown on concrete block. Corallina and Chondrus carpeting the block and covering holdfasts of Laminaria digitata.

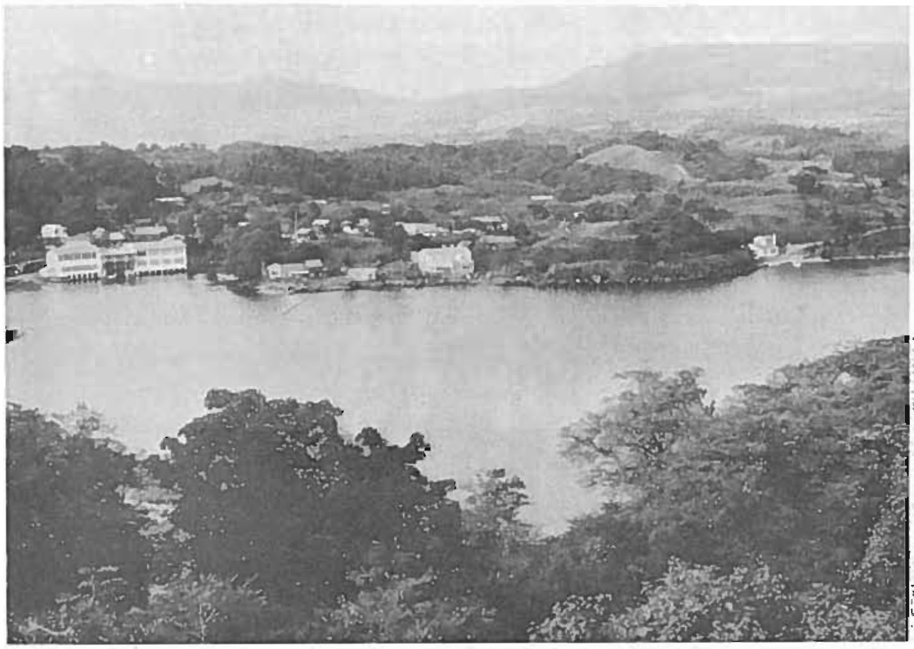


Plate 12. Porphyra hibi at Usu on Uchiura Bay, Hokkaido. Oct., 1966.

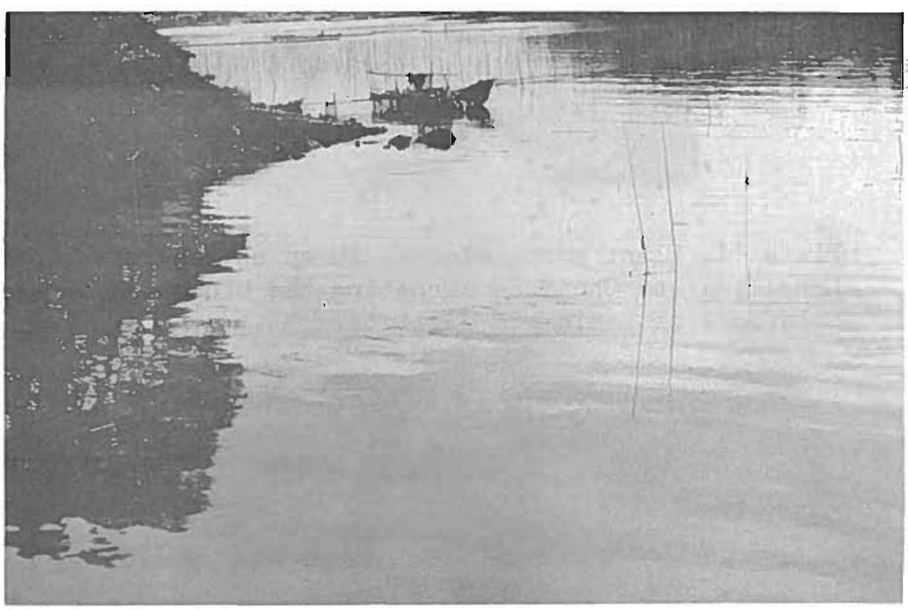


Plate 13. Porphyra hibi at falling tide, Usu on Uchiura Bay, Hokkaido. Oct., 1966.

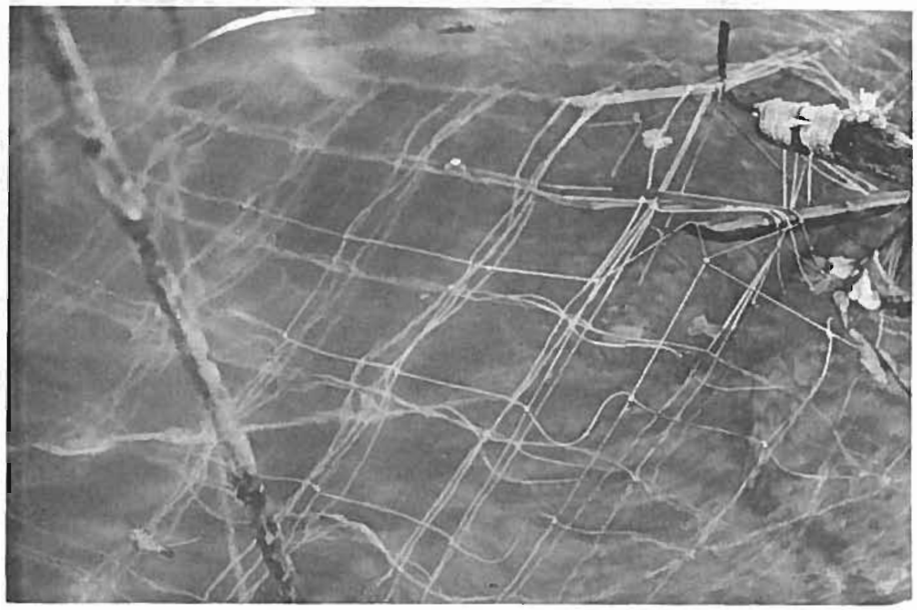


Plate 14. Detail of four nets placed at same level in hibi near Usu, Hokkaido. Oct., 1966.

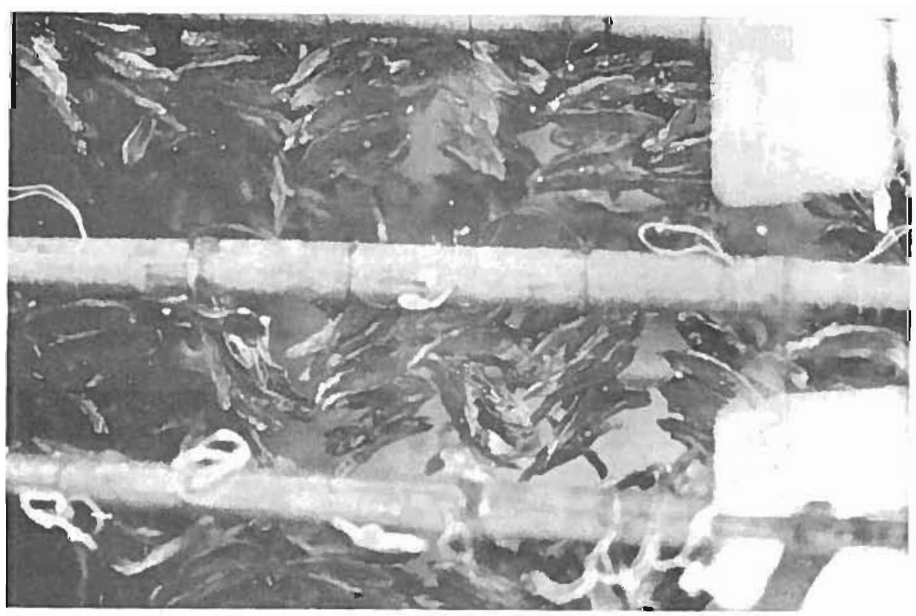


Plate 15. Oyster shells suspended in tank of seawater from bamboo poles for culture of Concocelis phase of Porphyra. (white rectangles on right are reflections of windows.) Oct., 1966.

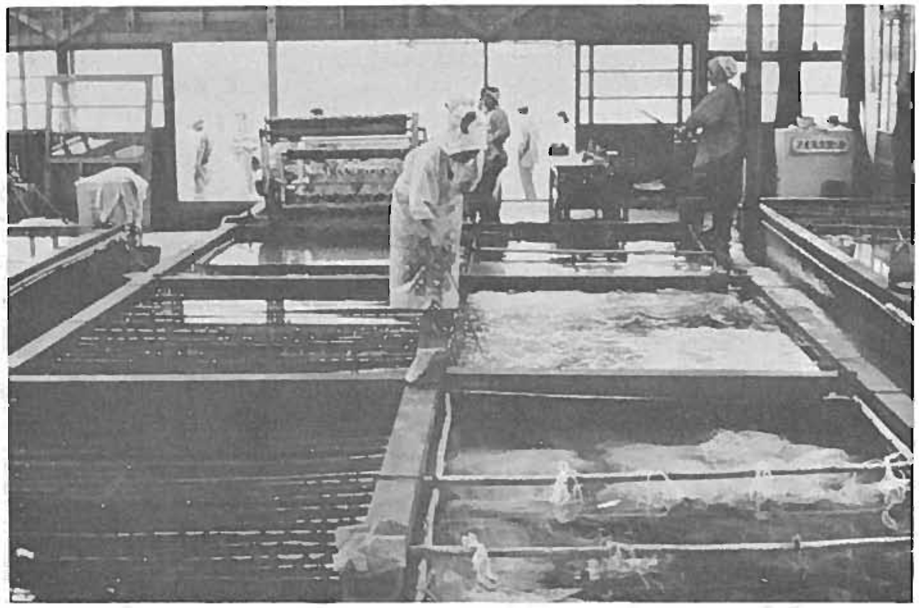


Plate 16. Fishermen's Cooperative Station, Minoshima Estuary. Spore-collection machine designed by Fujiyama in background. Tanks, left foreground, have bamboo poles suspending shells with Concocelis. Tank, right foreground, contains nets with developing sporelings. Net with newly attached spores is being arranged in tank right centre. Oct., 1966.

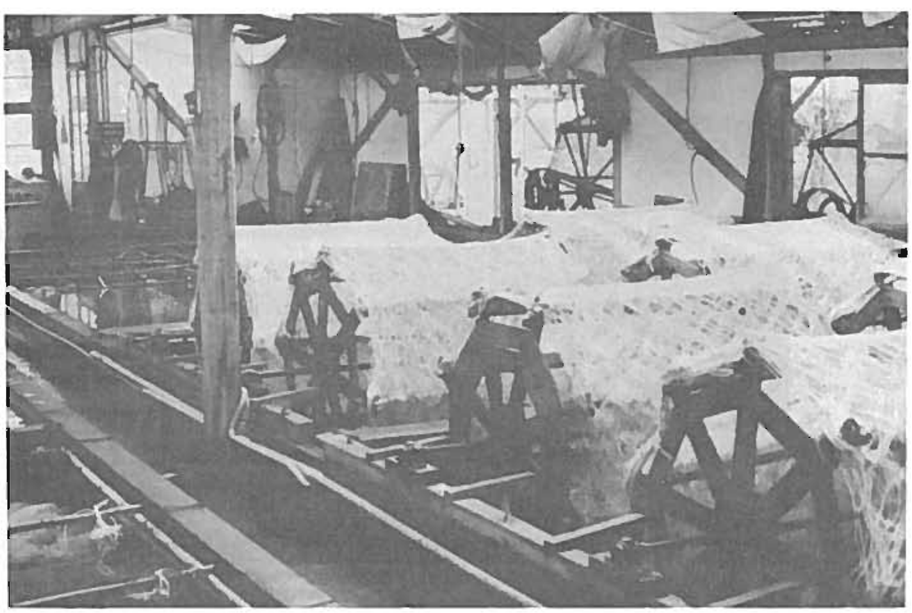


Plate 17. Older type turning devices with nets for collection of conchospores. Minoshima Estuary, Oct., 1966.

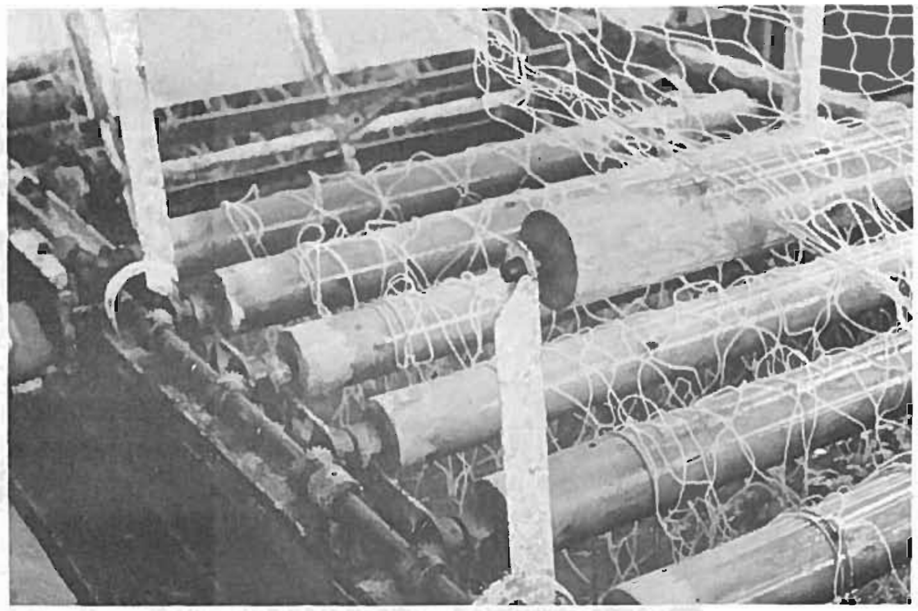


Plate 18. Part of a special rolling machine devised by Prof. Fujiyama, showing rollers and side chamber for holding Conchocelis. Minoshima Estuary. Oct., 1966.

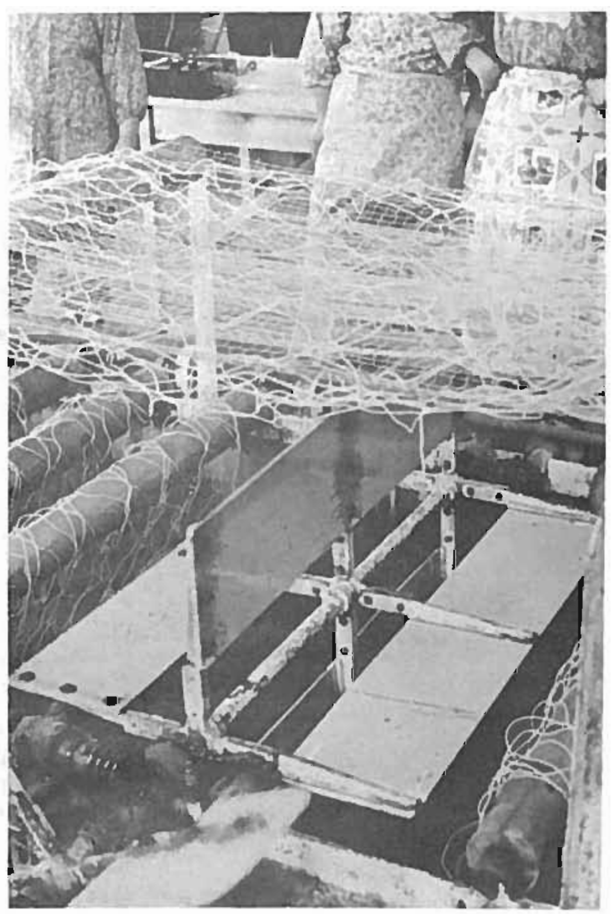


Plate 19. Part of special machine showing net, rollers and paddle. Minoshima Estuary. Oct., 1966. Small paddle (foreground) forces water through side chamber with Conchocelis to facilitate distribution of spores.

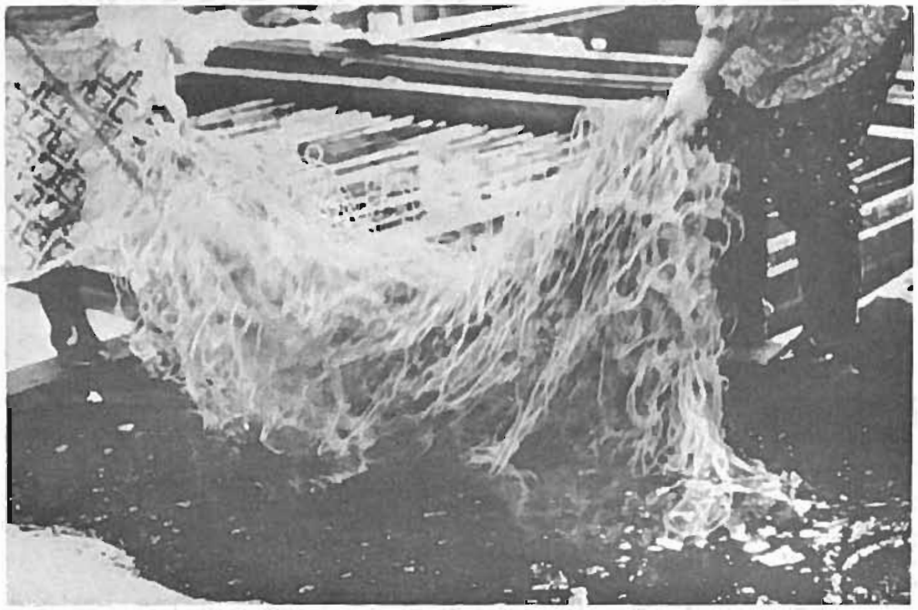


Plate 20. Net with Porphyra germlings being removed from tank for transfer to hibi field. Minoshima Estuary. Oct., 1966.

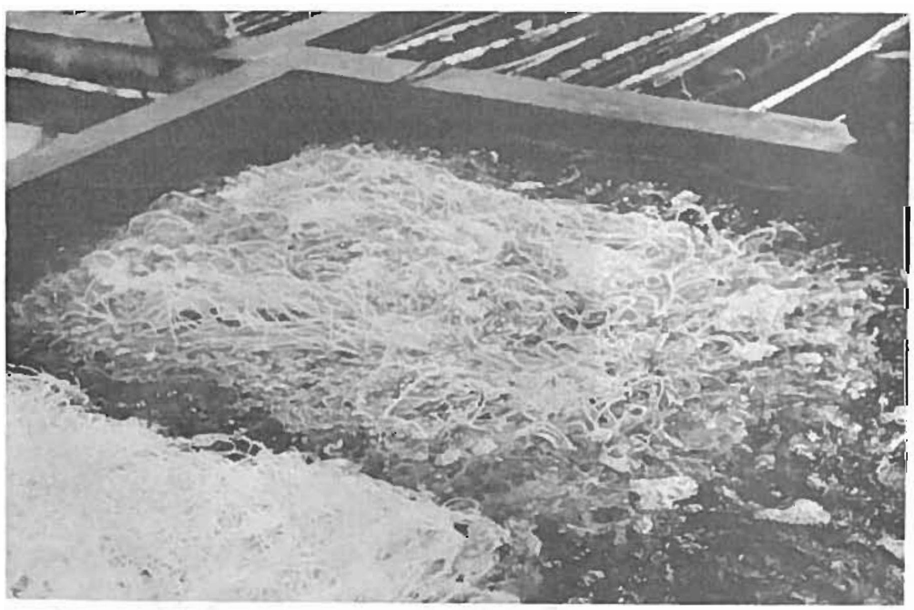


Plate 21. Two nets: net on left with recently attached spores has been placed in tank for spore setting and initial development of Porphyra germlings; net on right is ready for transfer to hibi field. Minoshima Estuary, Oct., 1966.

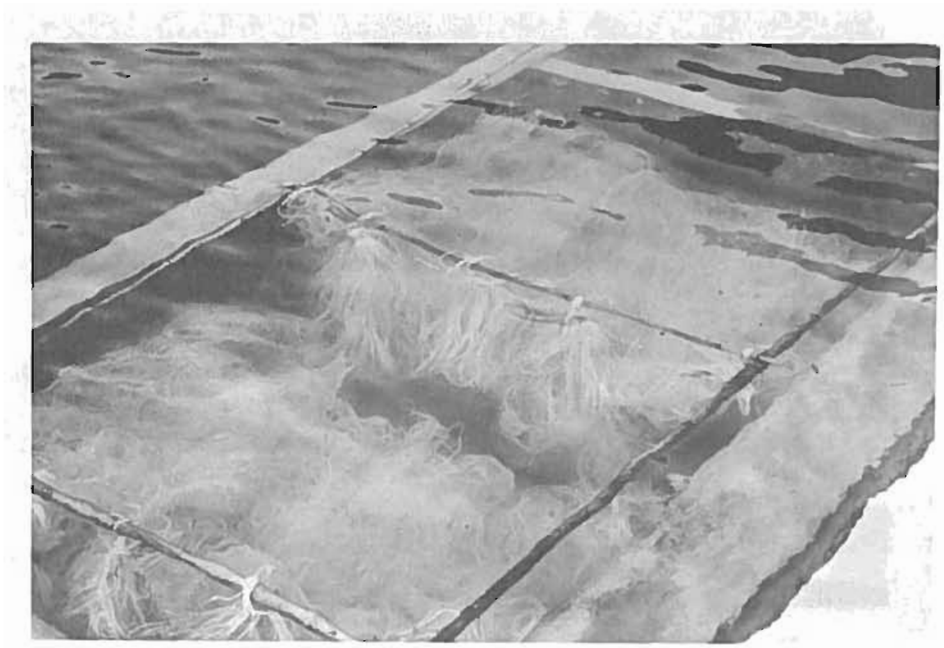


Plate 22. An outdoor tank. Minoshima Estuary. Oct., 1966.

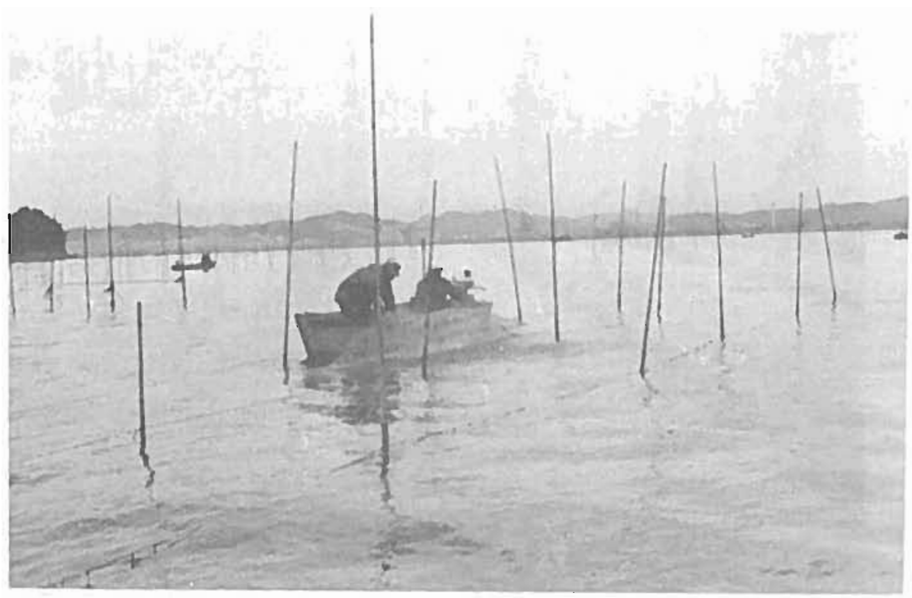


Plate 23. Hibi tending. Minoshima Estuary, Oct., 1966.

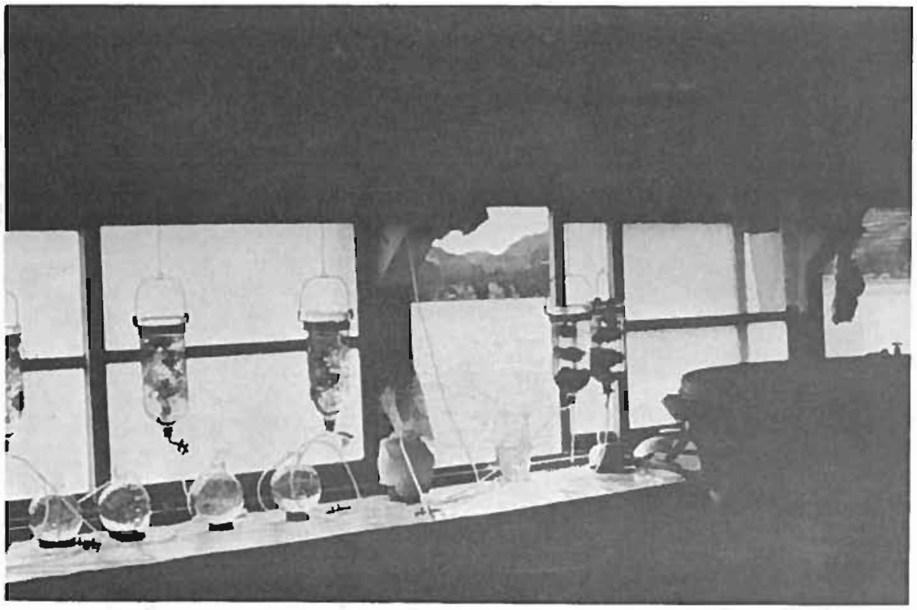


Plate 24. Culture of Porphyra suborbiculata forma latifolia at Nori Research Laboratory of Kumamoto Prefecture. Near Misumi, Oct., 1966.

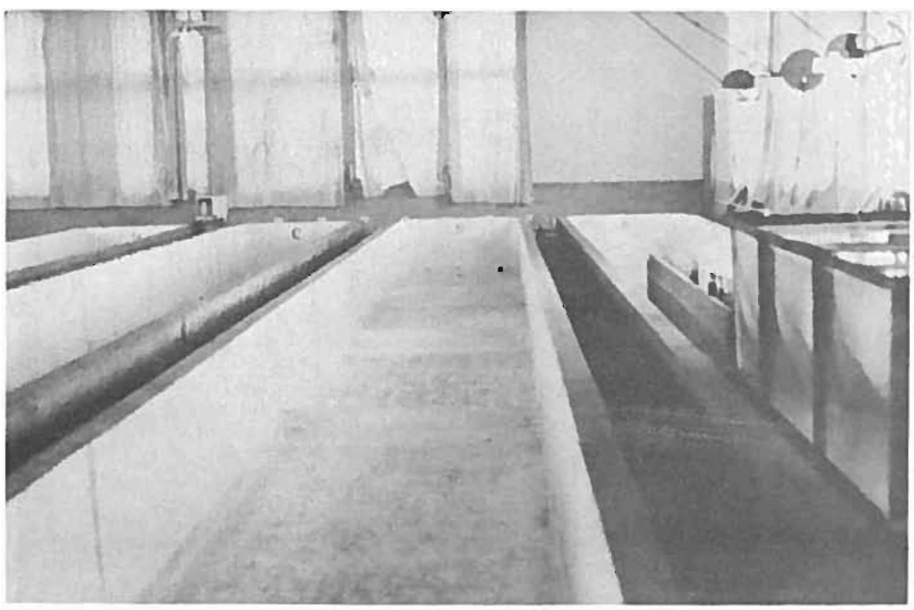


Plate 25. Culture tanks at Nori Research Laboratory of Kumamoto Prefecture. Tank may be subdivided to form smaller units. Note protective window curtains of white cotton. Oct., 1966.

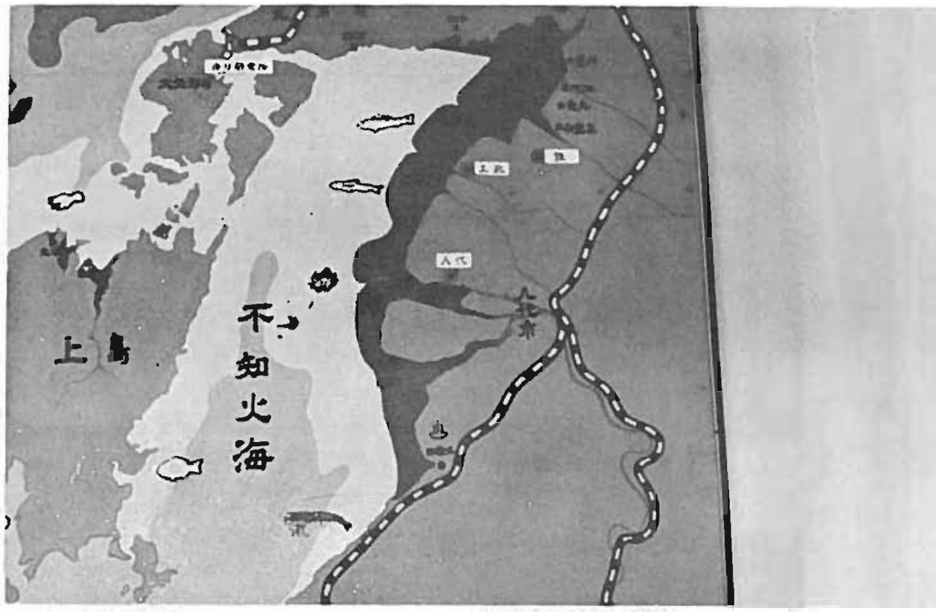


Plate 26. Portion of chart showing coast and location of bamboo blinds hibi in fertile estuaries of the many small rivers of the region near Misumi. Oct., 1966.

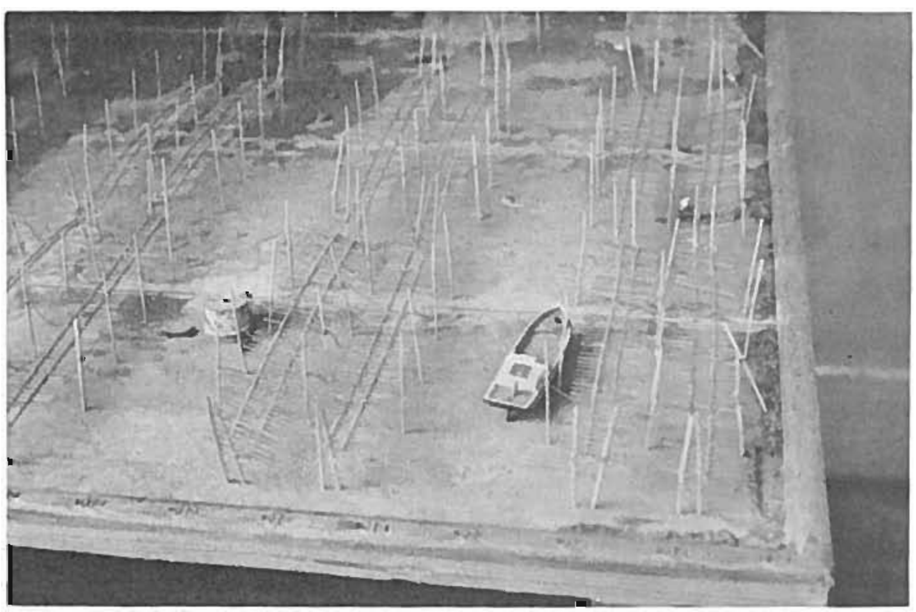


Plate 27. Model of all bamboo hibi with bamboo blinds, boat and container for fertilizer. Misumi, Oct., 1966.

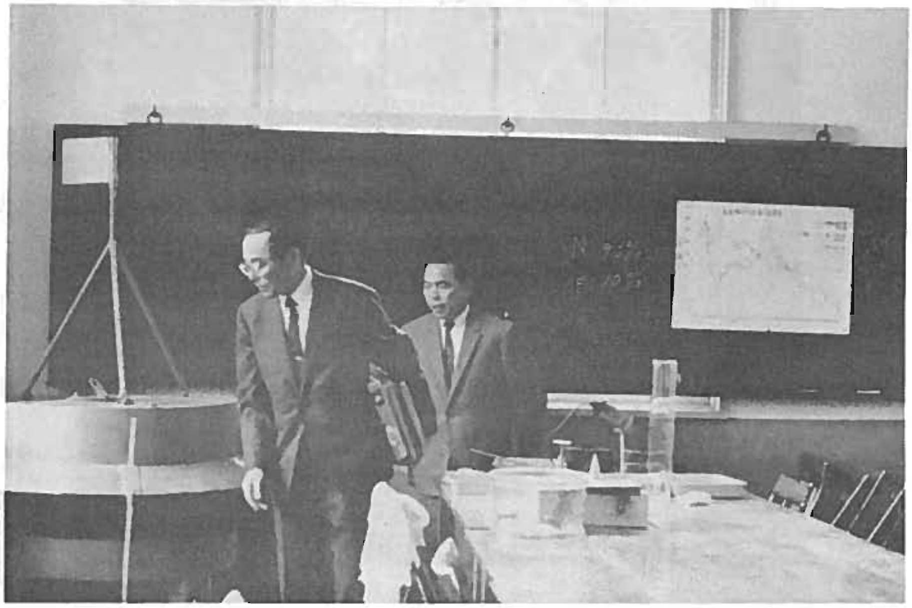


Plate 28. Mr Ota, Chief of Agriculture (left) at the Nori Research Laboratory of Kumamoto Prefecture, beside full size fertilizer container of a style used in Kumamoto. Stiff pennant attached to container marks its position in the sea. (Note yellow metre stick measuring height of container.) Oct., 1966.

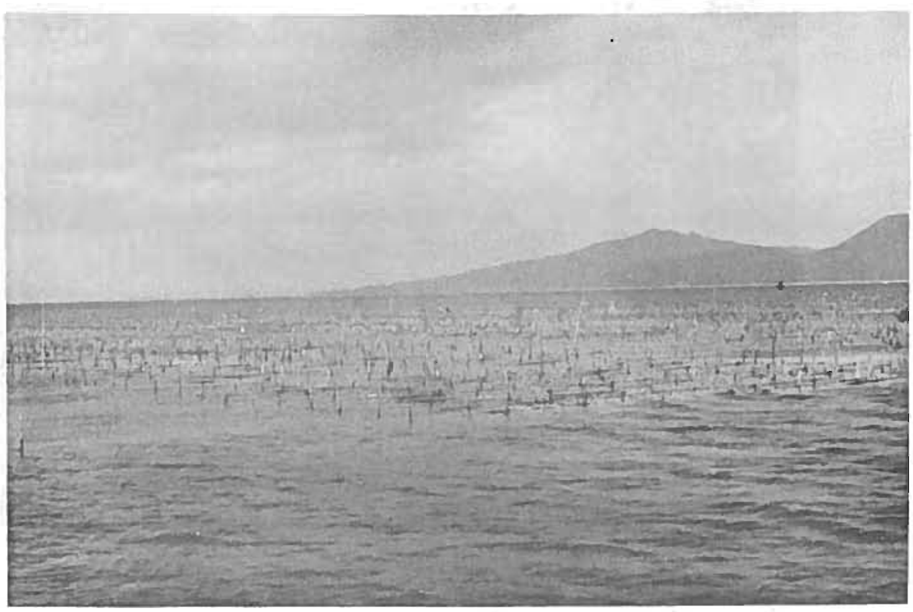


Plate 29. Some of the 40,000 nets in the bay below Sumiyochi Hill not far from Misumi. Oct., 1966.

Plate 30. View from Sumiyochi Hill at ebb tide showing hibi field and concrete roadway with trucks and pedestrians. Near Misumi, Oct., 1966.

Plate 31. Hibi and concrete roadway with trucks and pedestrians. Both hibi and roadway will be covered by the rising tide. Near Misumi, Oct., 1966.

Plate 32. Oyster shells, cleaned and washed. Yonezu, Ise Bay, Mie Prefecture. Oct., 1966.

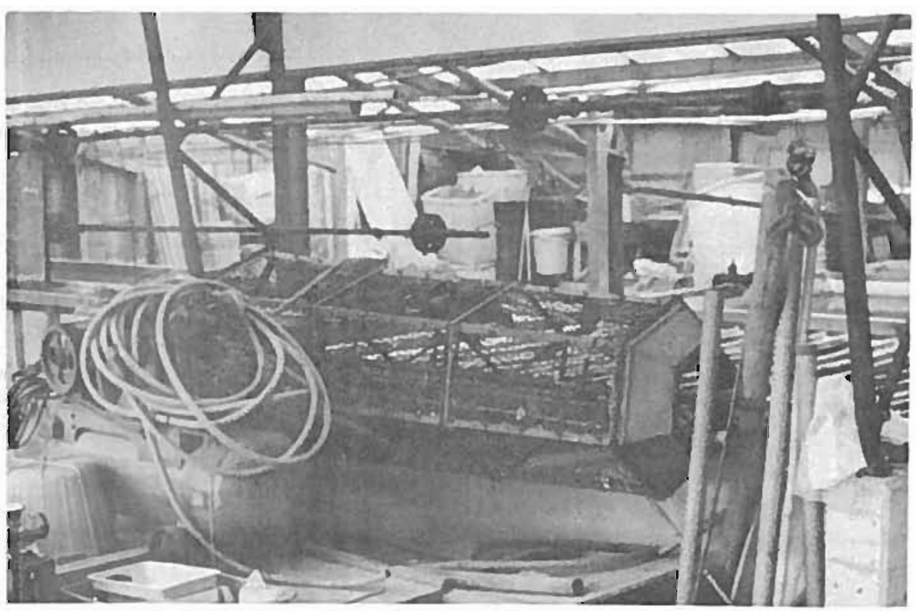
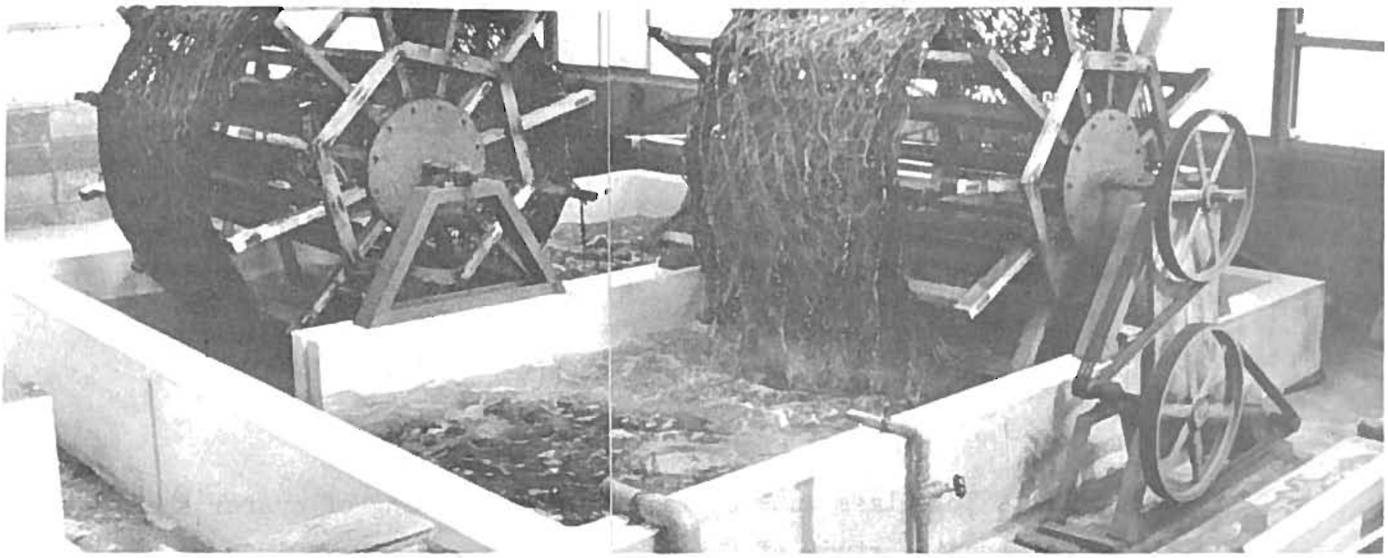


Plate 33. Shell washing machine.used at Yonezu, Ise Bay. Oct., 1966.



Plates 34 & 35. Double tank with net-winders and nets. The end portions of the lengthwise partition of the tank have been removed to facilitate circulation of water and distribution of conchospores. Yonezu, Oct., 1966.

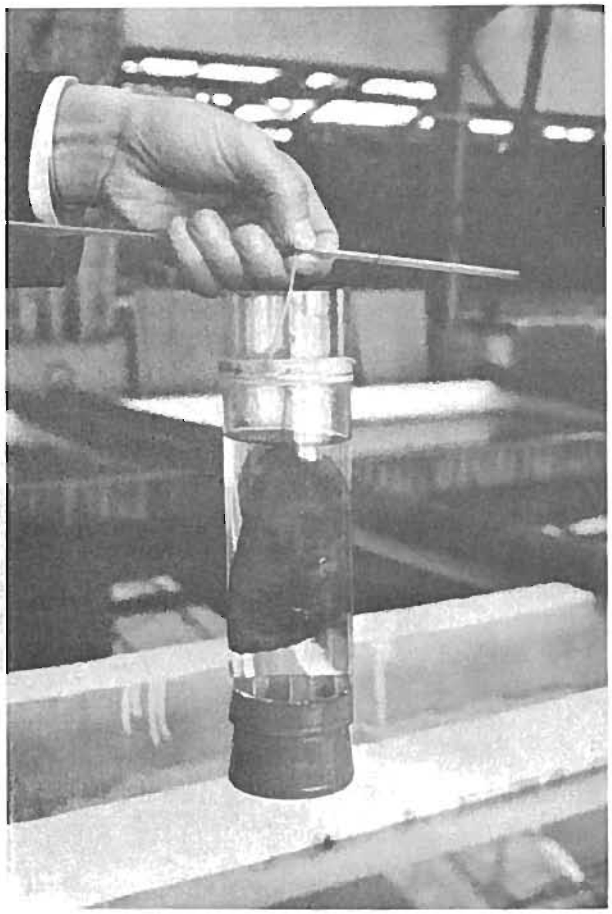


Plate 36. Glass tube containing short string of oyster shells for special study of Conchocelis. Yonezu, Oct., 1966.

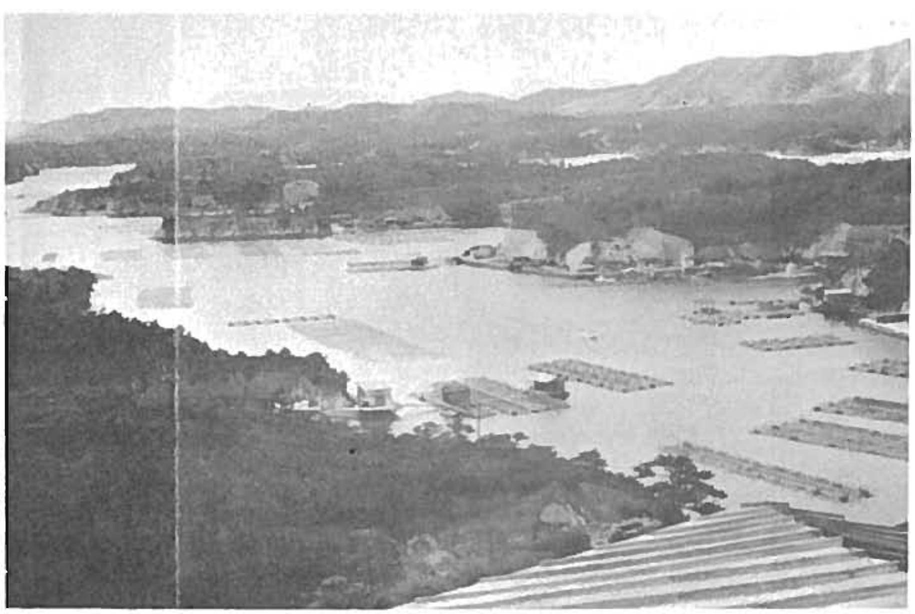


Plate 37. Pearl culture rafts near the mouth of Ise Bay, not far from Toba. Oct., 1966.

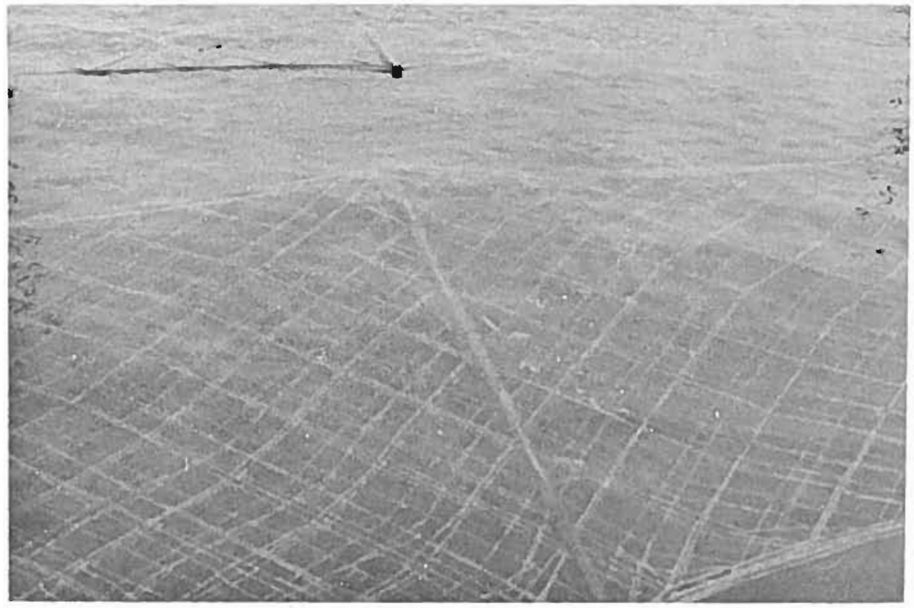


Plate 38. Porphyra hibi at Ohguchi, Mie Prefecture, Oct., 1966. Five nets attached in hibi. Later, three of these will be moved to more open area reserving two against accident or disease. Note bamboo stretcher.

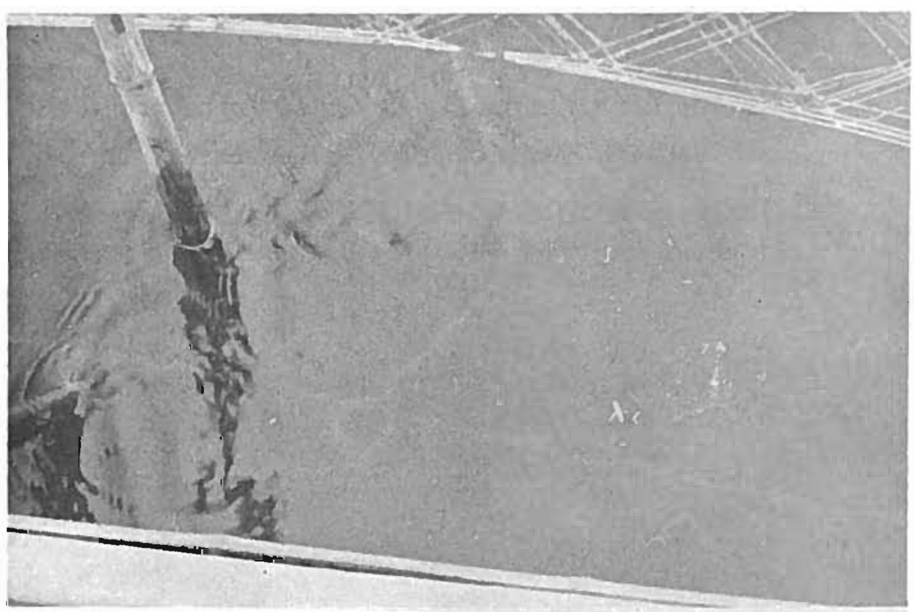


Plate 39. Attachment of nets in hibi and means of changing net level. Ohguchi. Oct., 1966.

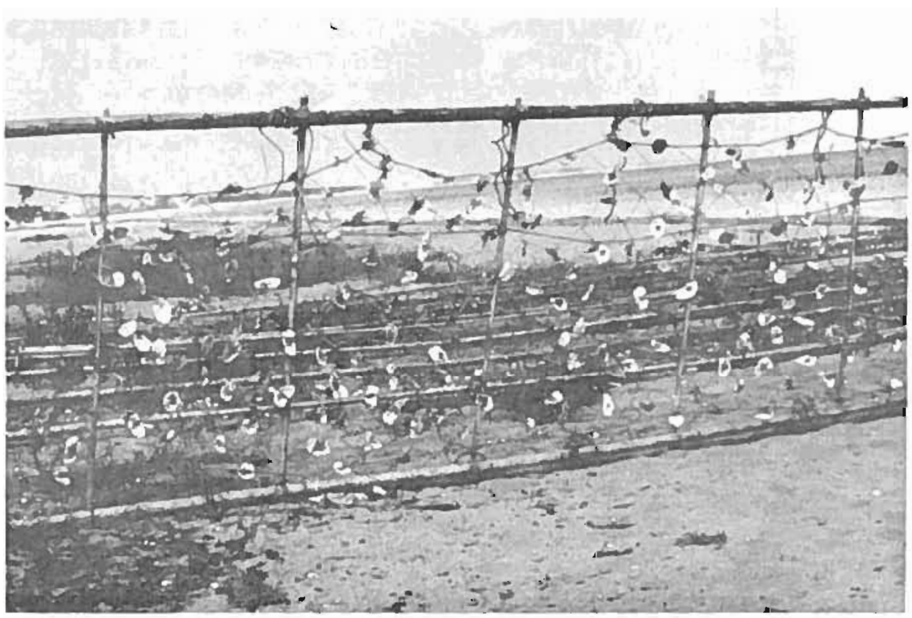


Plate 40. Net with shells attached to bamboo frame. May be placed beneath hibi to catch carpospores from leafy *Porphyra* phase or to allow buoyant conchospores to rise to hibi nets. Ohguchi, Oct., 1966.

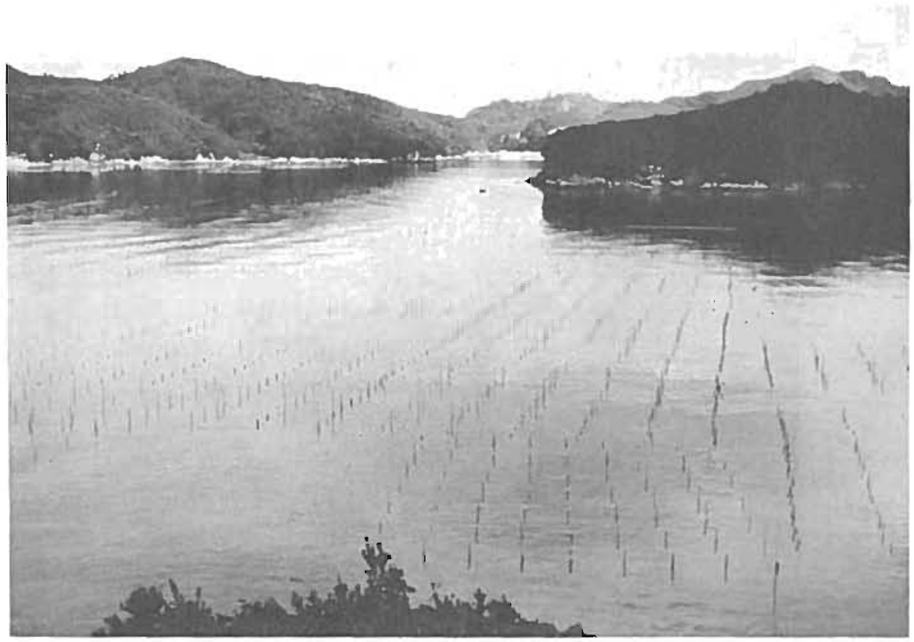


Plate 42. A natural Monostroma hibi ground maintained in a sheltered bay not far from Toba. Oct., 1966.

Plate 42. Monostroma and Ulva washed up from natural hibi ground in a small cove near Toba. Oct., 1966.

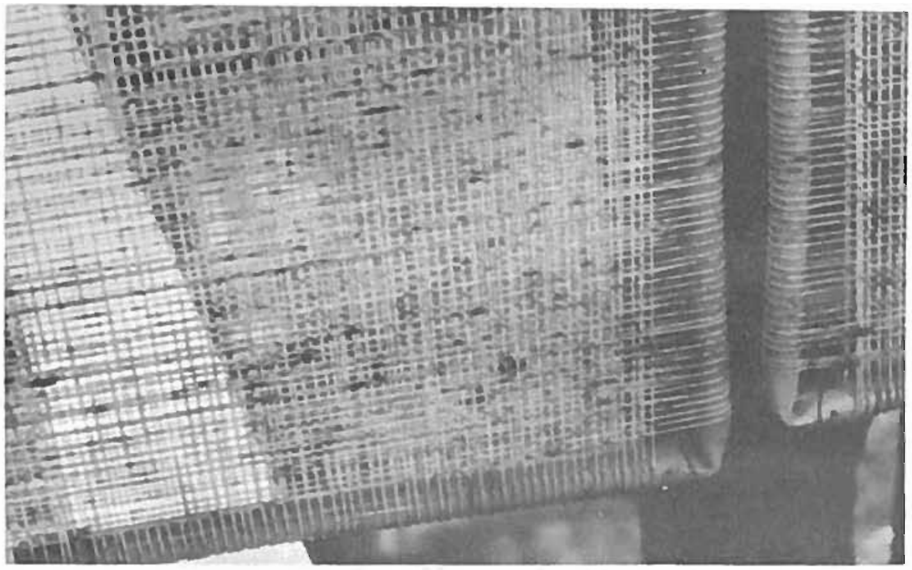


Plate 43. Frames with attached minute Undaria sporophytes. Research Station, Hamajima, Ago Bay, Mie Prefecture. Oct., 1966.

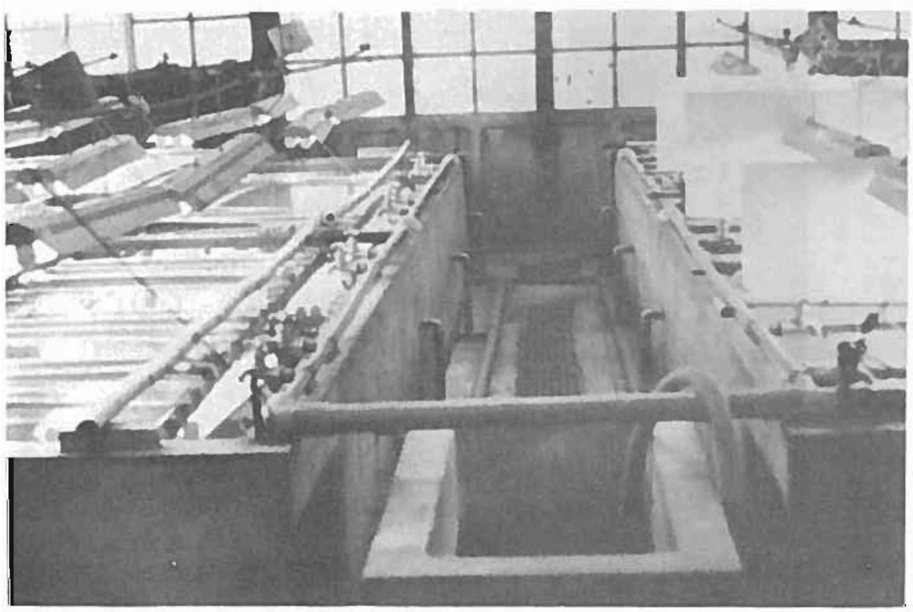


Plate 44. Tanks for culture of Undaria at Research Station, Hamajima. Plastic fittings are in use in all Japanese seaweed culture stations. Oct., 1966.

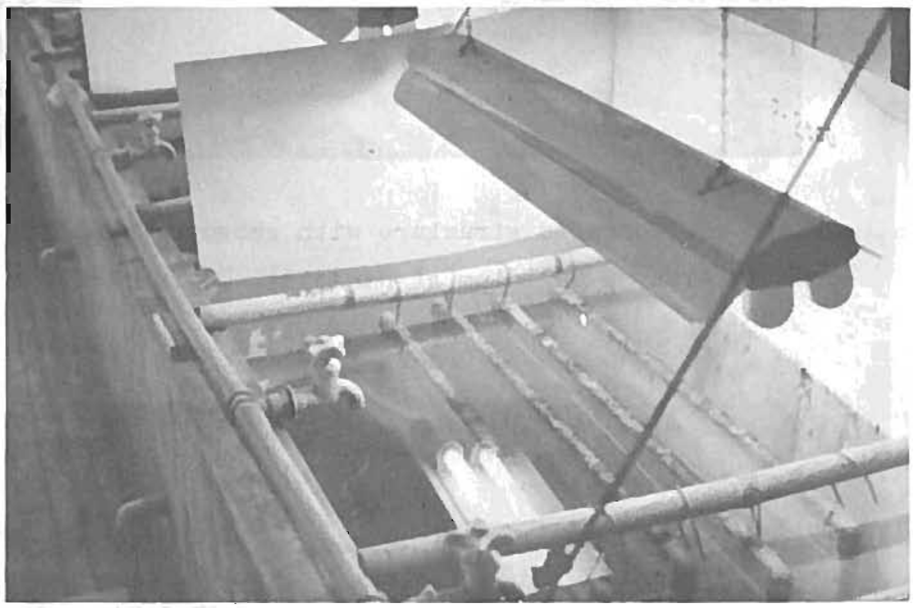


Plate 45. Close-up of section of culture tank with Undaria on frames strongly lighted by fluorescent "plant lux" tubes. (Light tubes reflected in water) Hamajima, Oct., 1966.

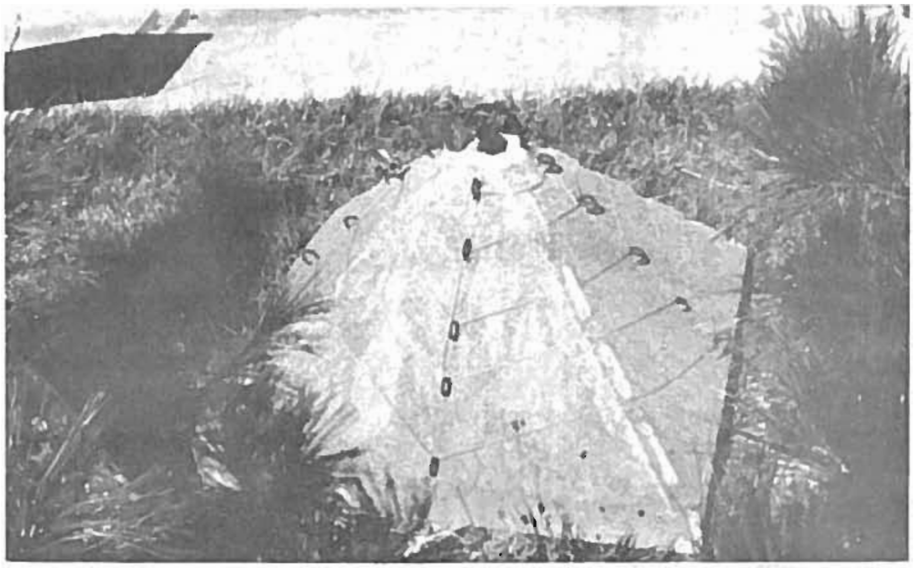


Plate 46. Concrete structure with embedded eyebolts used for cultivation of Gelidium at Hamajima. Oct., 1966.

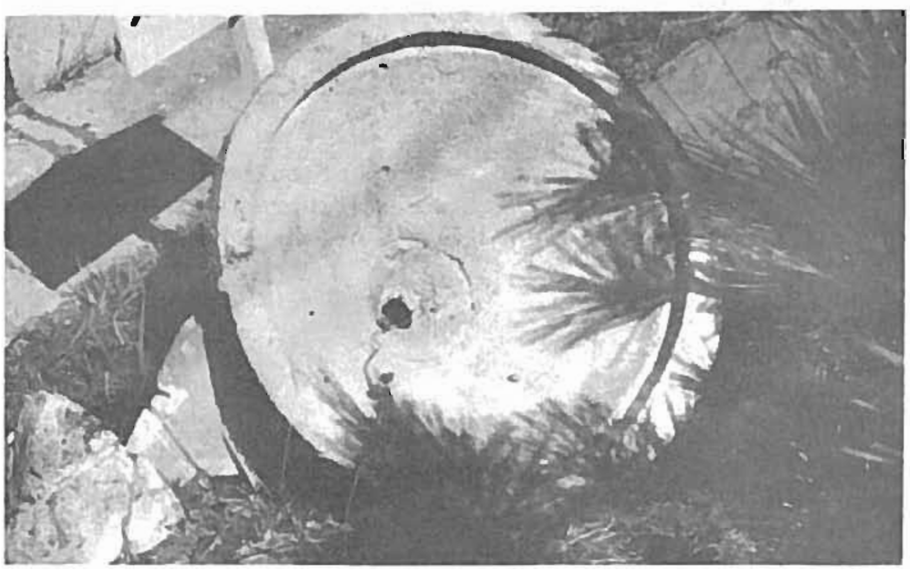


Plate 47. Interior of a somewhat similar Gelidium "stone-planter". Hamajima, Oct., 1966.

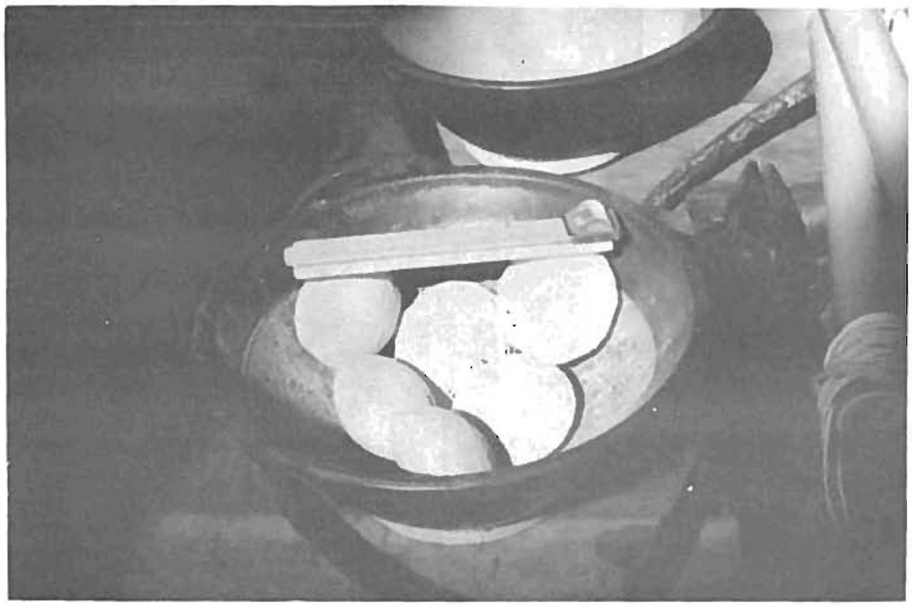


Plate 48. Several of the 50 gm. fertilizer pellets used for Gelidium. Hamajima, Oct., 1966.

Plate 49. Memorial to Kathleen Drew at Uzuchi, not far from Misumi, Kumamoto Prefecture. Oct., 1966.