OYSTER CULTURE IN JAPAN

UNITED STATES DEPARTMENT OF THE INTERIOR

FISH AND WILDLIFE SERVICE

FISHERY LEAFLET 383

NATURAL RESOURCES SECTION

SHUCKING OYSTERS

UNITED STATES DEPARTMENT OF THE INTERIOR, Oscar L. Chapman, Secretary
FISH AND WILDLIFE SERVICE, Albert M. Day, Director

FISHERY LEAFLET 383

Washington 25, D.C. October 1950

OYSTER CULTURE IN JAPAN

By

A. R. CAHN

Fishery Leaflet 383 is a republication of Report No. 134 of the Natural Resources Section, Supreme Commander for the Allied Powers, Tokyo, issued in September 1950. Republished with the permission of the United States Department of the Army.

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OYSTER CULTURE IN JAPAN

by
A. R. Cahn 1/

SUMMARY

1. Oysters are a valuable food item, for they provide many of the elements essential to a balanced diet. They are especially important to the Japanese, who lack adequate protein foods.

2. Seventeen species of oysters have been recognized in the waters of Japan Proper. Five species are used as food (Ostrea gigas, O. rivularis, O. denselamellosa, O. nippona, and O. echinata), but only O. gigas and O. rivularis are cultured commercially. O. denselamellosa has been cultured experimentally but not commercially. O. gigas is by far the most important of Japanese food oysters.

3. The culture of oysters in Japan started in the early 17th century, in Hiroshima Prefecture, which remained the center of oyster culture for nearly 300 years. Early culture procedures were simple, consisting of the sowing, stone, and bamboo stick methods. Although these methods are still used to some extent in various places, they have been largely supplanted by the modern hanging culture methods.

4. The hanging methods consist of the raft, long-line, rack, and umbrella modifications, each of which has its special advantage and is adapted to specific purposes or conditions. The hanging methods have proved much more efficient than any of the earlier systems, in growth rate and quality of the oysters and in total production per unit area. Because these methods utilize the middle stratum of water between the bottom and the surface where food organisms are especially abundant, the growth rate of the oysters has been greatly accelerated. When the oysters are hung vertically, the number that can be raised per unit area of sea bottom is greatly increased. Because contact with the sea bottom is avoided and the vertical position can be maintained at any desired level, many areas previously considered unsuited to oyster culture because of bottom type, water depth, or the abundance of parasites, become available and highly productive. Also quality of oysters raised in clear sea water is better.

5. The export of spat of O. gigas from Japan is the basis for the oyster industry of the Pacific coast of the United States and Canada. The export of spat on a commercial scale began in 1925 and continued until 1941 when World War II stopped the shipments. Export was resumed in 1946. During 1925-49, 585,156 cases of spat were exported. The United States and Canada have been the principal recipients of these shipments, with a total of 581,907 cases valued at $1,869,285. The center of the spat export trade is Miyagi Prefecture, especially the Ishinomaki Bay area.

1/ This report was prepared by Dr A. R. Cahn, aquatic biologist, Fisheries Division. Mr T. Ino, Fisheries Division, gave invaluable assistance in translating and briefing a large number of source Japanese publications. The illustrations were prepared by Mr K. Kita, draftsman, and Mr S. Satouchi, artist, both of Fisheries Division.

6. For domestic consumption the Japanese oysters are available on the market either raw or canned; the canned oysters are sometimes smoked. Domestic consumption during 1908-45 was 2,063,311 metric tons. By-products of the oyster industry are confined to the utilization of the shell, as chicken feed, paint, slaked lime, fertilizer, and medicines.

7. Both elemental and biological factors cause damage to the oyster. Elemental enemies are changes in water temperature, wind, and floods. Biological enemies are the red tide, oyster drills, starfish, internal parasites, and fouling organisms.

INTRODUCTION

To a nation critically in need of food, any item which can be produced in quantity and which has high nutritive value is of great national importance. Japan has always looked to the sea for a considerable proportion of its food requirements, and the sea has seldom failed to produce it. While fish have always been the major aquatic item of the Japanese diet, other marine products, although produced in much less quantity, are of immense importance to the native food requirements. Among these lesser contributers from the sea the native oysters stand very high. They are produced in considerable quantity--2,063,311 metric tons 2/ during 1908-45, an average annual production of 54,297.6 metric tons. This annual yield affords a substantial quantity of very nutritious food, high in essential minerals, proteins, and vitamins, with useful by-products. In addition, the greater part of an industry on the Pacific coast of the United States and Canada was founded upon and is kept alive by seed oysters imported from Japan, so the Japanese oyster culture industry is a matter of international interest. That this relatively young American oyster culture industry has grown to large-scale proportions is illustrated by the fact that the 1949 oyster crop from the Pacific coast of the United States was estimated at about 1,000,000 gallons of shucked oysters, with a value, when processed, of more than $5,000,000.

Because of the direct interest of the United States, Canada, and other nations in Japan's oyster production, this report will discuss the Japanese procedures in some detail. The Japanese have been exceedingly efficient in the culture of both edible and pearl oysters, and their methods are therefore of more than passing interest to the occidental world. Because the methods employed today are the result of many hundreds of years of culture experience and experiment, this report traces the history of oyster culture in Japan from its misty beginning to the present-day techniques.

The literature concerning the various phases of Oyster culture in Japan is voluminous but almost entirely in the Japanese language. Preparation of this report necessitated translation and study of hundreds of publications to select those facts which were considered important to the general story of the industry. This report also describes the life history of the oyster, as its culture is based upon a knowledge of its life history; indeed, the importation of seed oysters to the United States is based upon an understanding of the early stages of the Japanese oyster's personal history. The author traveled extensively throughout the oyster culture areas of Japan to study these cultural methods in operation. Successful accomplishment of this mission would not have been possible without the cooperation of innumerable oyster culturists and scientists, who submitted quantities of unpublished data for examination and placed every facility possible at the author's disposal. For all of this assistance the writer expresses his appreciation.

HISTORY

Like many other human activities which have roots in the distant past, the origin of the cultivation of the edible oyster in Japan is shrouded in legend. From this nebulous beginning, the more tangible facts of modern oyster culture methods gradually emerge into sharper focus. Where legend ends and fact begins is difficult to determine, for the legends are so plausible and are endowed with so much of the authenticity of truth that their factual classification is frequently puzzling.

2/ Unless otherwise specified, weights given are gross, including shell. See glossary for conversion of metric terms used in this report.

That whatever people inhabited Japan in the far-distant past depended largely on the sea for their subsistence is amply illustrated by the contents of the prehistoric shell mounds and kitchen middens (refuse dumps) which have been excavated in many parts of all the major islands of Japan. Many of these mounds, some of which are estimated to date back several thousand years, show a profusion of marine shells as well as the remains of other marine invertebrate (e g, sea urchins) and vertebrate animals. Among the mollusk remains, oyster shells are definitely common in many localities, indicating the utilization of those animals as an item of food. The Chiyama shell mound in Kanagawa Prefecture shows a layer of shells of the native oyster Ostrea gigas averaging three meters in thickness (Naora, 1941 3/).

Although the story of the utilization of the oyster in Japan thus starts with tangible facts, the story of the culture of the native oyster emerges from three separate legends, all of which are so realistic in the details of names, dates, and places that they may well be fact. These legends (Seno, 1938) are:

(1) When Lord Nagaakira Asano moved from Wakayama Prefecture in 1620 to establish his home in Hiroshima Prefecture he brought with him the native Wakayama oysters and transplanted them in the waters of Hiroshima. Thus the first step in oyster culture was taken.

(2) Heijiro Yoshiwaya, who lived in Fuchizaki, Hiroshima Prefecture, sometime between 1624 and 1643, one day noticed an oyster attached to a rock. He placed rocks in the shallow water to see if oysters would attach to them. They did. He also observed oysters attached to bamboo branches which were being used in the construction of fish traps. These two observations by Yoshiwaya are supposed to be the basis of the stone and bamboo culture methods still used in some localities today.

(3) In 1673 Gorohachi Konishiya (or Goroemon Kobayashi), who lived in Kusatsu, now the city of Hiroshima, planned to culture clams. To enclose his stock he constructed a bamboo fence in the water and unexpectedly found that many small oysters attached themselves to the stakes and grew there (Figure 1). This observation was the basis for his method of cutting bamboo brush two or three meters long and placing it in the water to collect oysters.

Whether these origins are fact or fiction, the Hiroshima methods of oyster culture are the oldest in Japan and have been in use for some 300 years. All versions concerning the early history of the edible oyster culture in Japan agree that it began in Hiroshima Prefecture. That this area should have been the scene of the birth of oyster culture is biologically sound, for ideal environmental conditions are extensive there today and probably have altered little since the time oyster culture was begun. Among the advantageous features are: (1) the sheltered nature of the region, producing a sea area that is normally calm; (2) the tidal differential of 2.5 to 3 meters, which exposes a wide shoreline area adaptable to oyster culture; (3) a firm sea bottom, composed mostly of finely worn granite and devoid of mud 4/. Furthermore a ready market was available in the nearby thriving city of Osaka. Starting in 1688 Nizaemon Kawamo sent an oyster boat, "kakibune" 5/, from Hiroshima to Osaka. From this floating sea food restaurant he served the people of Osaka deliciously cooked oysters, thereby stimulating both their appetites and the infant oyster industry. In 1708 a disastrous fire in Osaka ruined much of the city. The fishermen working on the oyster boats were so heroic in rescuing government property that the magistrate of Osaka rewarded them by giving all oyster men a special free business license in the tidal areas below the main bridge of the city.

3/ See Selected Bibliography.

4/ Japanese oyster culturists have avoided mud bottoms for culture areas whenever possible, whereas the ultilization of areas having a mud bottom is common practice in the United States.

5/ See glossary for translation of Japanese terms and definitions of technical terms.

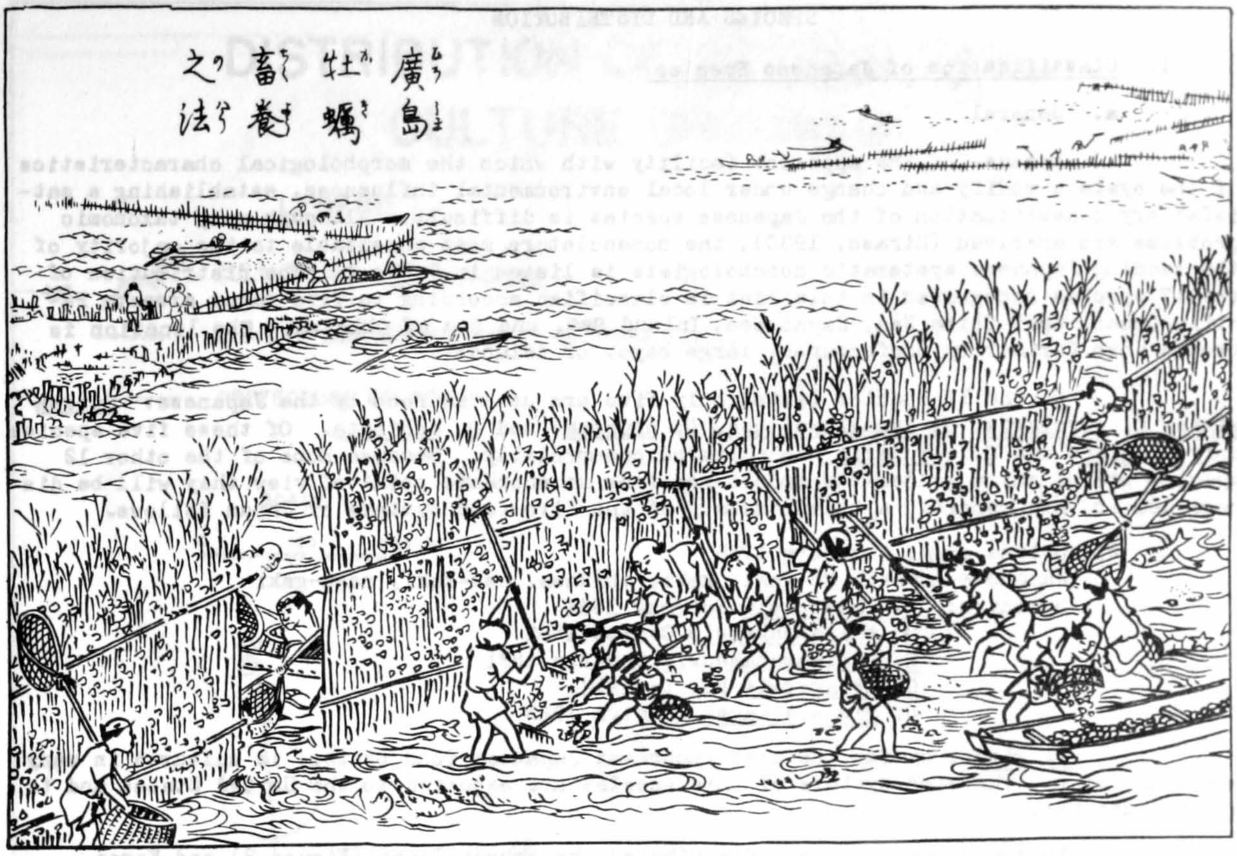

Figure 1. - Ancient method of oyster culture in Hiroshima Prefecture, from an old woodblock print.

Oyster culture in Japan followed the method developed at Hiroshima for more than two centuries without important modification. This method consisted essentially of driving bamboo sticks or tree branches in the ground within the intertidal zone of shallow water bays and inlets. Here the young, free-swimming oyster larvae attached in profusion and grew rapidly. Areas of muddy bottom, places of luxuriant growth of seaweeds, regions of pure sand, or deep water shores were regarded as unsuited to oyster culture, and the industry was not developed in such locations.

The picture changed radically in 1923. In that year H. Seno and J. Hori, studying oysters in the Kanagawa laboratory of the Tokyo Fisheries College, unexpectedly discovered the principle of the hanging culture method, which gave excellent results from the beginning. The following year the Kanagawa Prefecture Fisheries Experiment Station at **Moroiso-wan successfully adapted the hanging method. Following the proven success of the Kanagawa experiments, prefecture after prefecture adapted the hanging method, and many new and extensive oyster culture grounds were established in Hiroshima, Miyagi, Iwate, Shizuoka, Wakayama, Shimane, Kanagawa, Kumamoto, and Mie prefectures.**

Seed oysters of _Ostrea gigas_, cultured by this new method, were exported from Japan to America, forming the basis of the edible oyster industry of the west coast of the United States and British Columbia. Export of seed began commercially in 1925, ceased in 1941, and was re-established in 1946 after World War II hostilities ended.

SPECIES AND DISTRIBUTION

1. Classification of Japanese Species

a. General

Because of the apparent facility with which the morphological characteristics of the oysters modify and change under local environmental influences, establishing a satisfactory classification of the Japanese species is difficult. Although many taxonomic problems are unsolved (Hirase, 1930), the nomenclature most acceptable to the majority of the leading Japanese systematic conchologists is listed in Table 1. The distribution of the 17 species recognized in this list is classified according to five major areas: Pacific Ocean, East China Sea, Japan Sea, Inland Sea, and Sea of Okhotsk. The location is broken down further by prefectures, large bays, or islands.

Of the 17 species listed only five are used as food by the Japanese: Ostrea gigas, O. rivularis, O. denselamellosa, O. nippona, and O. echinata. Of these five species only O. gigas and O. rivularis are cultured commercially. Because none of the other 12 species are of any considerable importance from an economic point of view they will be disregarded in this report. A brief summary of the five food oysters of Japan follows.

b. Ostrea gigas Thunberg 1795

Japanese names: Ma-gaki, kaki, shikame, ezo-kaki, naga-gaki

Synonyms: O. laperousii Schrenk 1861
O. talienwakensis Crosse 1862
O. talienwahahensis Sowerby 1871
O. ariakensis Fujita 1913
O. gigas sikamea Amemiya 1928

O. gigas, by far the most important Japanese food oyster, is cultured in many parts of Japan. The seed oysters of this species are exported to the United States and to other countries.

This species is widely distributed throughout Japan (Figure 2) and Korea. Some authorities regard the Japanese and Korean species as belonging to different races or subspecies, while others regard them as one. The morphological variations of O. gigas are very great. A fossil shell bank at Noda-mura, Iwata Prefecture, yields specimens measuring as long as 50 centimeters. Living oysters from Tokoro, east of Abashiri on the Sea of Okhotsk side of Hokkaido, are enormous, measuring as much as 40 centimeters in length; they are very thick-shelled, heavy, and variable in form (Figure 3). Specimens from Sendai, Miyagi Prefecture, are large and flat, whereas those from Hiroshima are small, broad, and deep (Figure 4). Seki (1937) divides O. gigas into two types: (a) the northern (Sendai) and (b) the southern (Hiroshima). By inbreeding experiments Imai has shown that the morphological characters of the two forms remain fixed and can always be distinguished even through the third generation. The northern and southern forms are compared in Tables A and B (pp 12, 17).

TABLE A. - CHARACTER DIFFERENCES BETWEEN NORTHERN AND SOUTHERN TYPES OF OSTREA GIGAS

Character	Northern (Sendai)	Southern (Hiroshima)
Size	Large	Small
Form	Flat	Broad, deep
Growth	Rapid	Slow
Growth at 10°C	Rapid	Slow
Growth at 25°C	Slow	Rapid
Mortality rate	High	Low
Spawning season	Early	Late
Palatability	Inferior	Superior

SOURCE: Seki, 1937.

c. Ostrea rivularis Gould 1861

Japanese name: Suminoe-gaki

O. rivularis is a good-quality food oyster that is easily cultured. However, its economic importance is limited by its restricted range, which is western Kyushu. Its culture is carried on mainly in Ariake-kai. It is a round, flat, smooth-surfaced, oviparous species with a maximum length of 24 centimeters (Figure 5). Although this oyster was classified as O. gigas by Fujimori (1929), this synonymy with gigas has been denied by Taki (1933) and by Imai. Imai's opinion is based upon the fact that in repeated experiments he has been unable to cross gigas and rivularis.

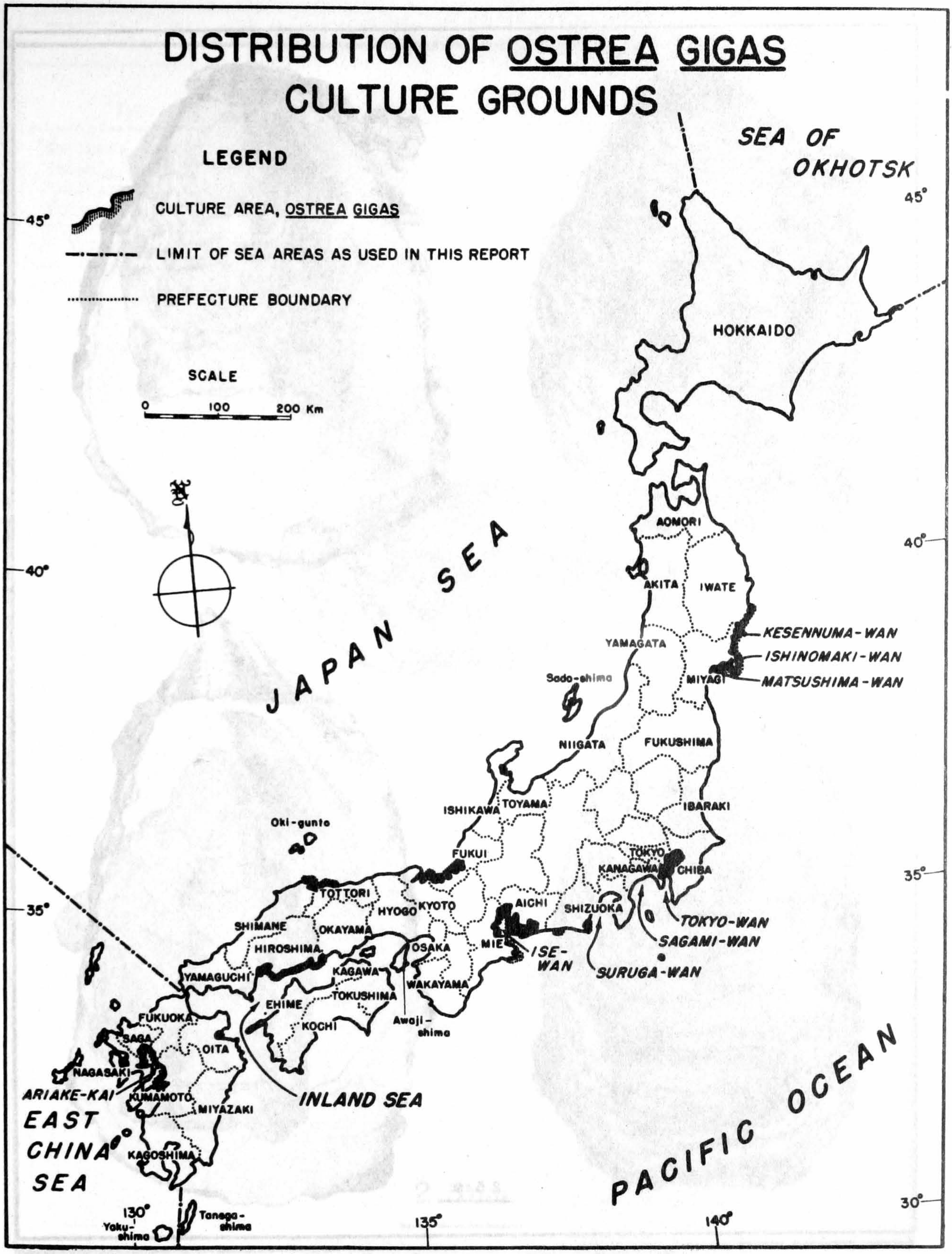

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Figure 2

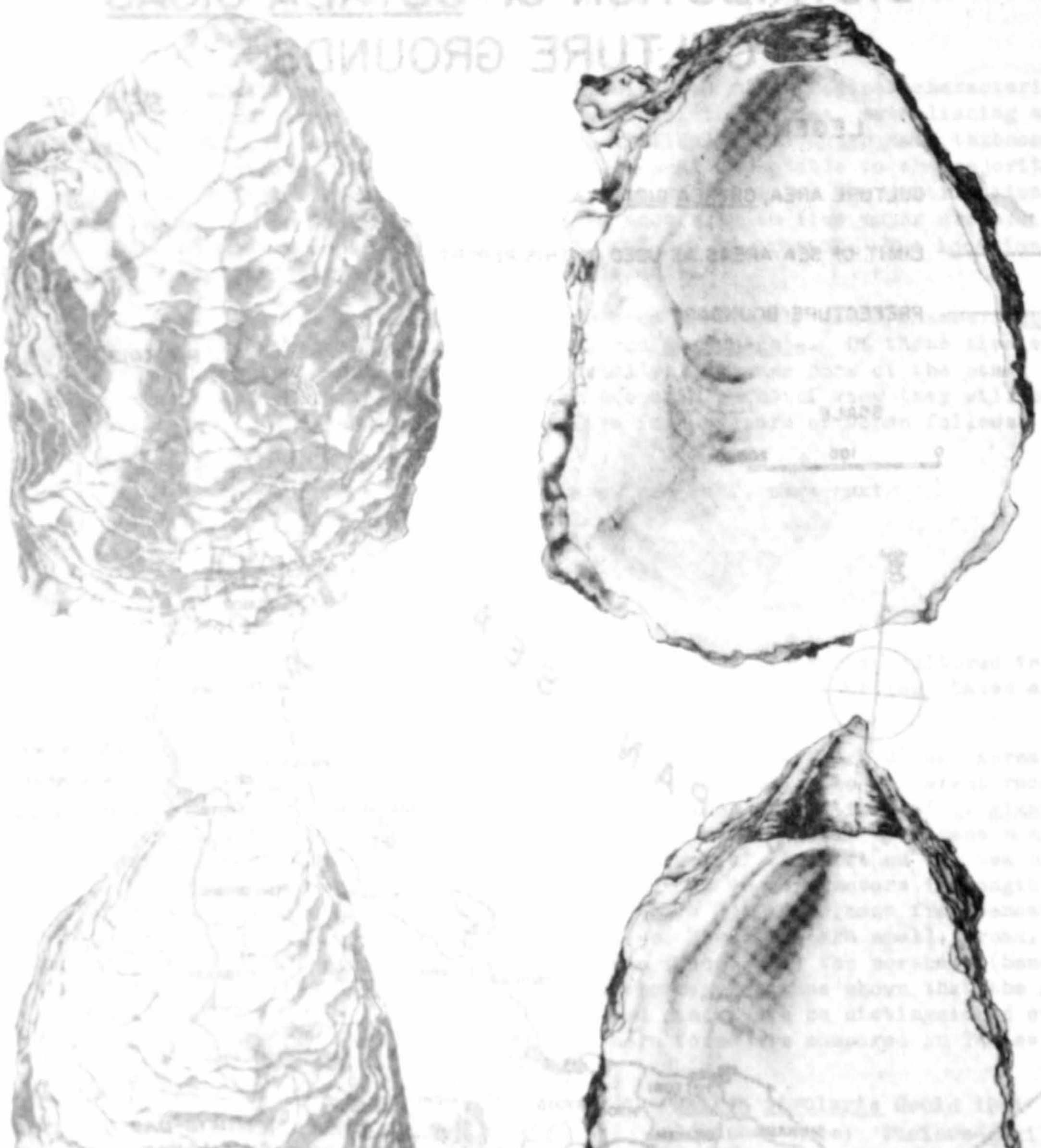

Figure 3. - Ostrea gigas from Hokkaido

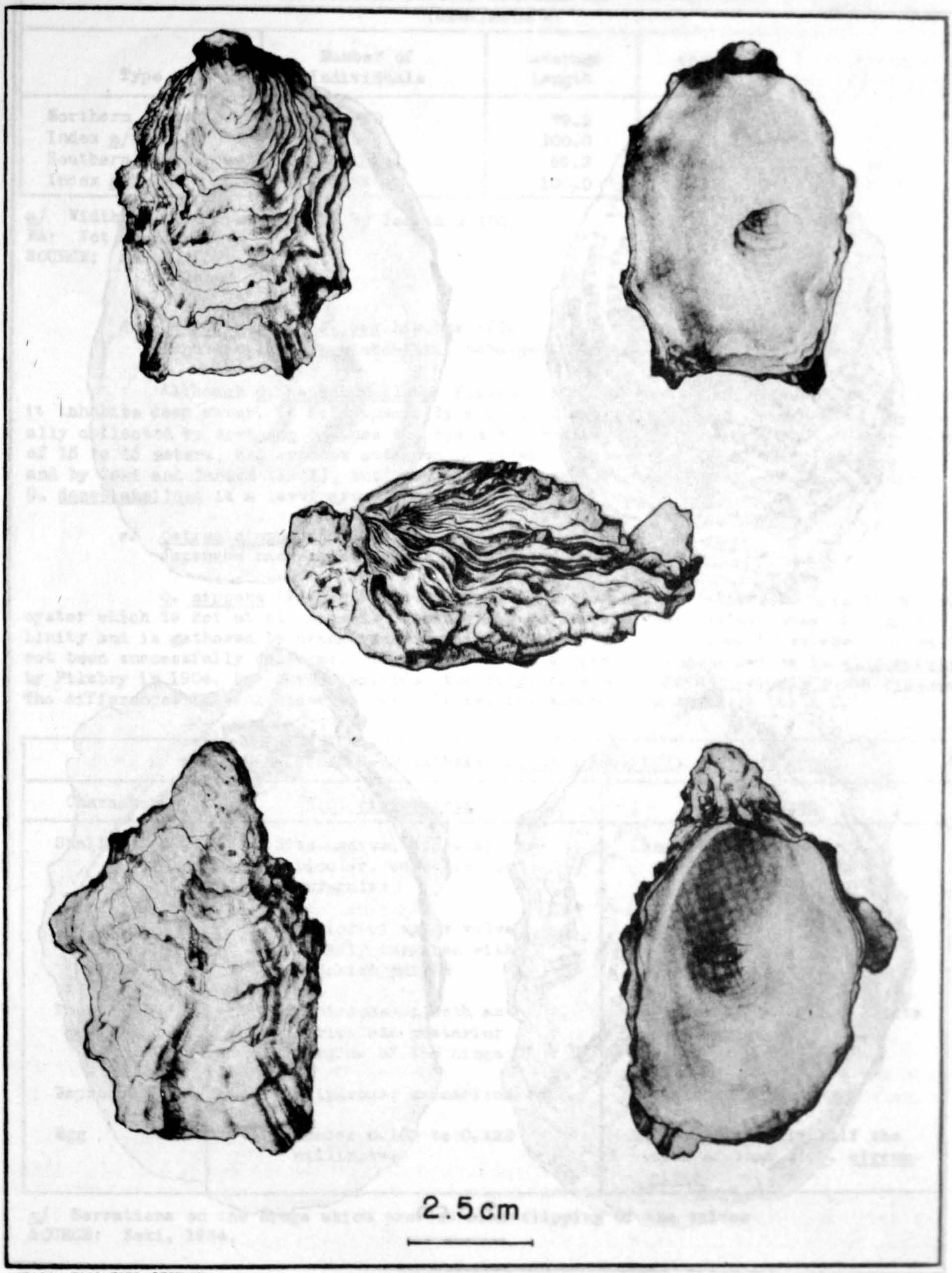

Figure 4. - Ostrea gigas from Hiroshima

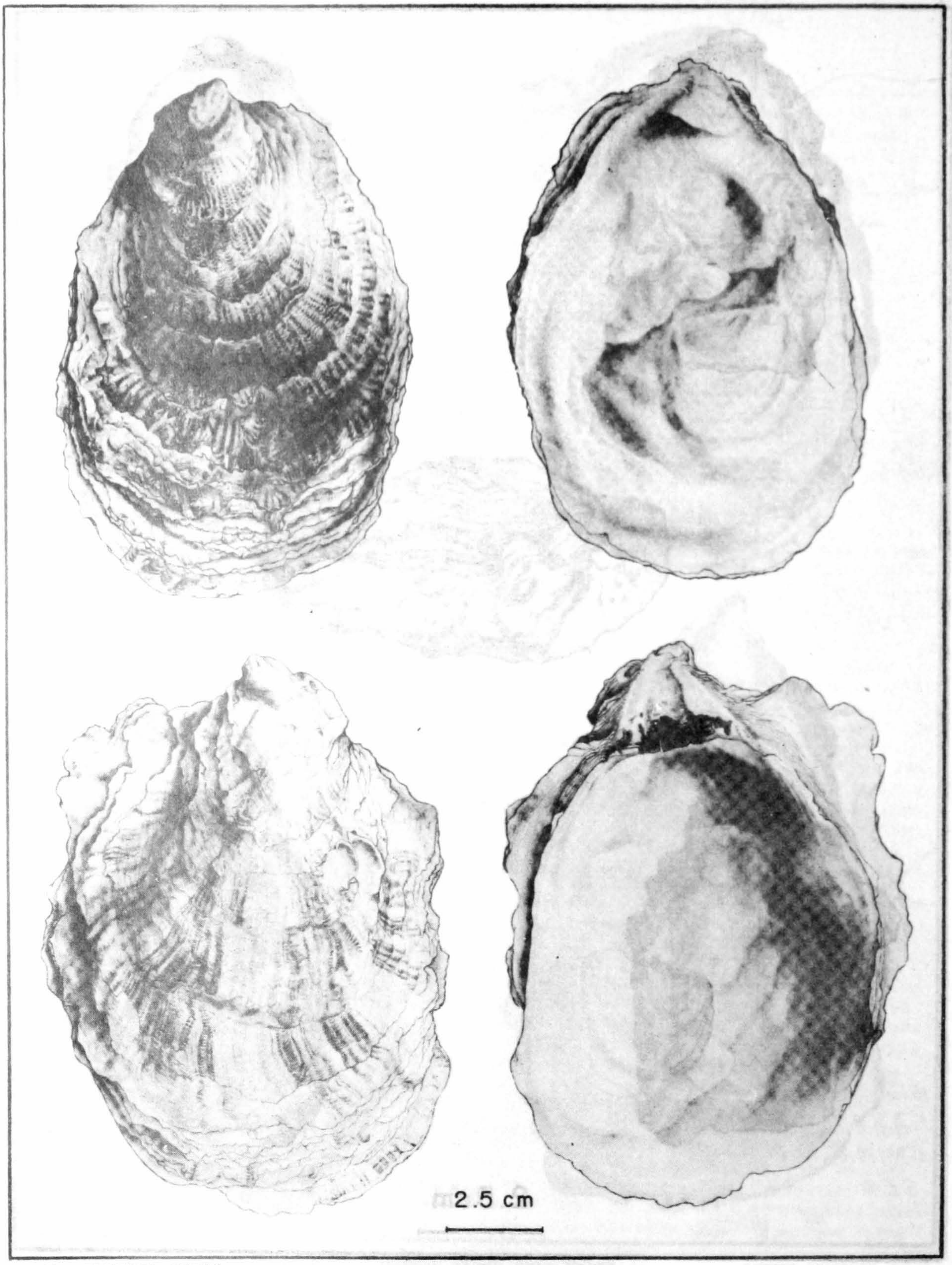

Figure 5. - **Ostrea rivularis**

TABLE B. - SHELL FORM DIFFERENCES BETWEEN NORTHERN AND SOUTHERN TYPES OF OSTREA GIGAS (centimeters)				
Type	Number of Individuals	Average Length	Average Width	Average Thickness
Northern (Sendai)	100	79.9	44.9	25.1
Index a/	NA	100.0	56.0	31.0
Southern (Hiroshima)	100	59.3	41.7	24.1
Index a/	NA	100.0	70.0	41.0

a/ Width or thickness divided by length x 100
NA: Not applicable
SOURCE: Seki, 1937.

d. Ostrea denselamellosa Lischke 1869
Japanese names: Itabo-gaki, baba-gaki, botan-gaki, nata-gaki, kobore-gaki

Although O. denselamellosa (Figure 6) is a useable and palatable table oyster, it inhabits deep water, is not especially abundant, and is difficult to gather. It is usually collected by dredging because the oysters occur loosely on the sea bottom, at a depth of 15 to 45 meters, and are not attached to rocks. Culture was attempted by Fujita (1888), and by Seki and Tanaka (1931), but results were unsatisfactory for commercial purposes. O. denselamellosa is a larviparous species.

e. Ostrea nippona Seki 1934
Japanese names: Iwa-gaki, kutsu-gaki, natsu-gaki

O. nippona (Figure 7) is a large, fast-growing, well-flavored species of food oyster which is not at all common. It inhabits relatively rough water areas of high salinity and is gathered by dredging or by diving from a depth of about 10 meters. It has not been successfully cultured. This species was originally identified as O. circumpicta by Pilsbry in 1904, but Seki subdivided the original species into circumpicta and nippona. The differences between these two closely related species are shown in Table C.

TABLE C. - COMPARISON BETWEEN OSTREA CIRCUMPICTA AND O. NIPPONA		
Character	O. circumpicta	O. nippona
Shell	Size medium; somewhat orbicular, subovoid, or irregular	Large, solid; elongate, subovate or oviform
Color	Interior of upper valve broadly margined with blackish purple	White
Teeth a/	Conspicuous on both anterior and posterior margins of the hinge	No teeth at any stage of its development
Reproduction	Larviparous; monoecious	Oviparous; dioecious
Egg	Diameter 0.103 to 0.122 millimeter	Egg approximately half the size of that of O. circumpicta

a/ Serrations on the hinge which prevent side-slipping of the valves
SOURCE: Seki, 1934.

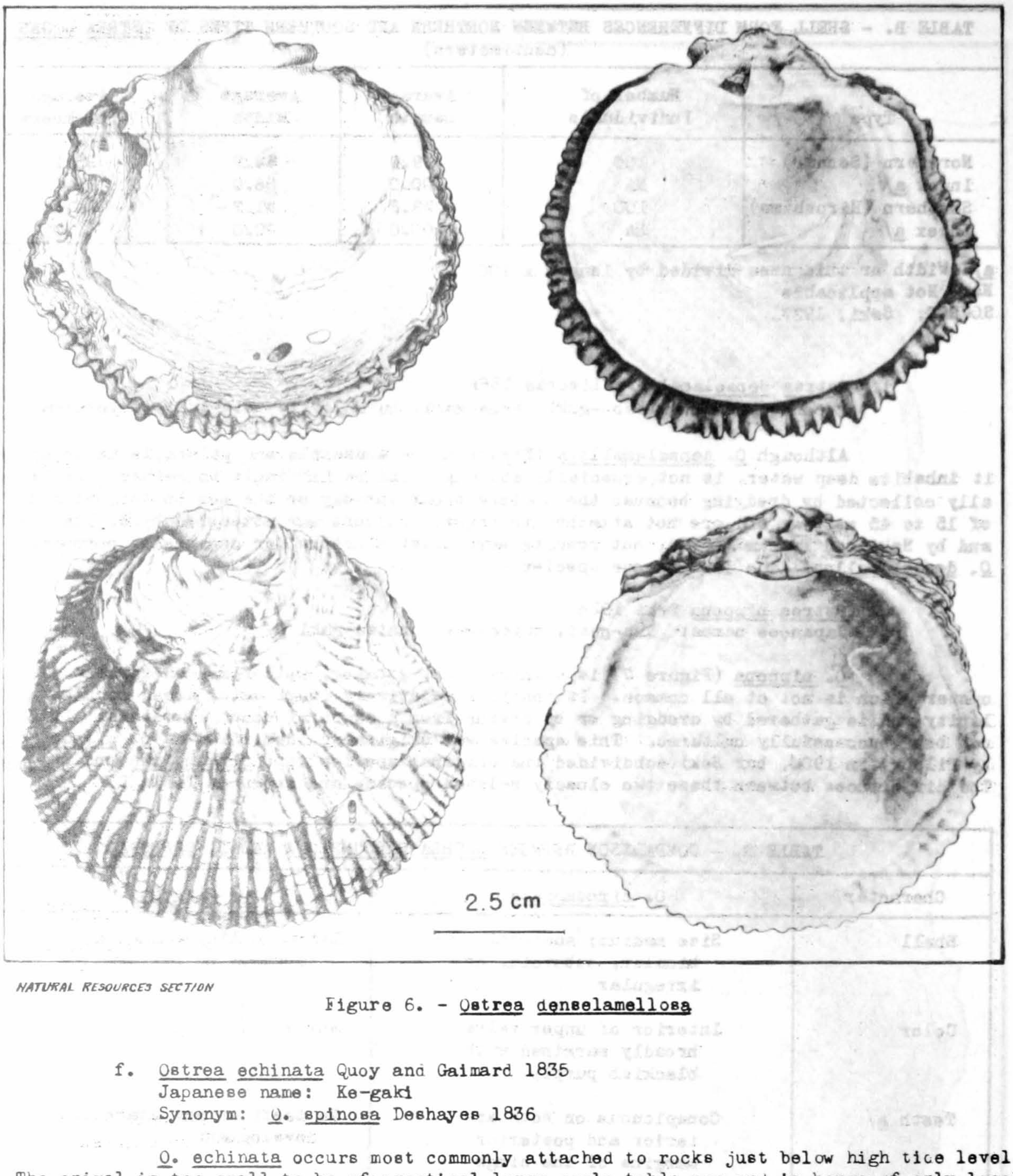

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Figure 6. - Ostrea denselamellosa

f. Ostrea echinata Quoy and Gaimard 1835
Japanese name: Ke-gaki
Synonym: O. spinosa Deshayes 1836

O. echinata occurs most commonly attached to rocks just below high tide level. The animal is too small to be of practical large-scale table use and is hence of only local importance as an item of food.

2. Comparison with Atlantic Coast Oyster

The three most important Japanese species of food oyster, O. gigas, O. rivularis, and O. denselamellosa, are compared with Ostrea virginica, the Atlantic coast oyster of America, in Table 2.

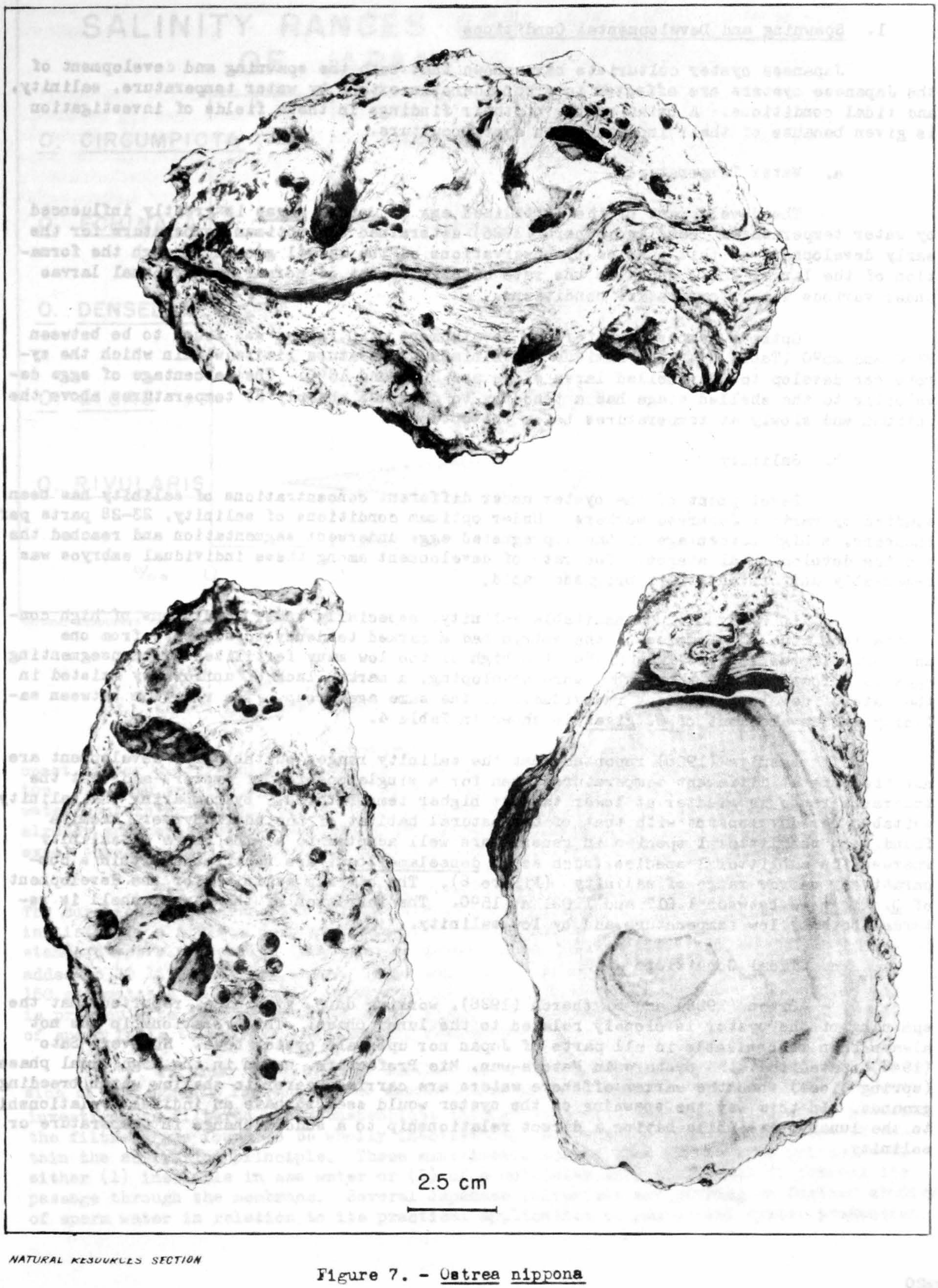


Figure 7. - Ostrea nippona

1. Spawning and Developmental Conditions

Japanese oyster culturists have shown that both the spawning and development of the Japanese oysters are affected to a considerable extent by water temperature, salinity, and tidal conditions. A brief review of their findings in these fields of investigation is given because of their importance in oyster culture.

a. Water Temperature

The development of the fertilized egg of *Ostrea gigas* is greatly influenced by water temperature. Seno and others (1926) determined the optimum temperature for the early development of this species by observations of the larval growth through the formation of the larval shell and also the rate of development of normal and abnormal larvae under various water temperature conditions.

Optimum temperature for the development of *O. gigas* was found to be between 23°C and 25°C (Table 3). The maximum and minimum temperature limits within which the zygote can develop to the shelled larva stage are 30°C and 15°C. The percentage of eggs developing to the shelled stage has a tendency to decrease sharply at temperatures above the optimum and slowly at temperatures below the optimum.

b. Salinity

Development of the oyster under different concentrations of salinity has been studied by various Japanese workers. Under optimum conditions of salinity, 23-28 parts per thousand, a high percentage of the impregnated eggs underwent segmentation and reached the ensuing developmental stages. The rate of development among these individual embryos was remarkably uniform and their progress rapid.

In water having unsuitable salinity, especially under conditions of high concentrations, the blastomeres of the embryo had a marked tendency to separate from one another. If the salinity was either too high or too low many fertilized but nonsegmenting eggs were found; among those that were developing, a marked lack of uniformity existed in the rate of development among individuals in the same age group. The relation between salinity and development of *O. gigas* is shown in Table 4.

Amemiya (1928) reported that the salinity ranges suitable for development are not the same at different temperatures even for a single species of oyster, and that the tolerance range is greater at lower than at higher temperatures. By comparing the salinity suitable for development with that of the natural habitat of the adult oyster, Amemiya found that the littoral species in general are well adapted to a wide range of salinity whereas the sublittoral species, such as *O. denselamellosa*, are restricted within a comparatively narrow range of salinity (Figure 8). The optimum salinity for the development of *O. gigas* is between 1.017 and 1.021 at 15°C. The formation of the larval shell is retarded both by low temperature and by low salinity.

c. Tidal Conditions

Orton (1926) and Prytherch (1928), working on *O. virginica*, reported that the spawning of the oyster is closely related to the lunar phase. This relationship has not always been recognizable in all parts of Japan nor upon all oyster beds. However, Sato (1948) stated that the oysters in Matoya-wan, Mie Prefecture, spawn in the high tidal phase (spring tides) when the warmer offshore waters are carried nearer to shallow water breeding grounds. In this way the spawning of the oyster would seem to have an indirect relationship to the lunar phase while having a direct relationship to a sudden change in temperature or salinity.

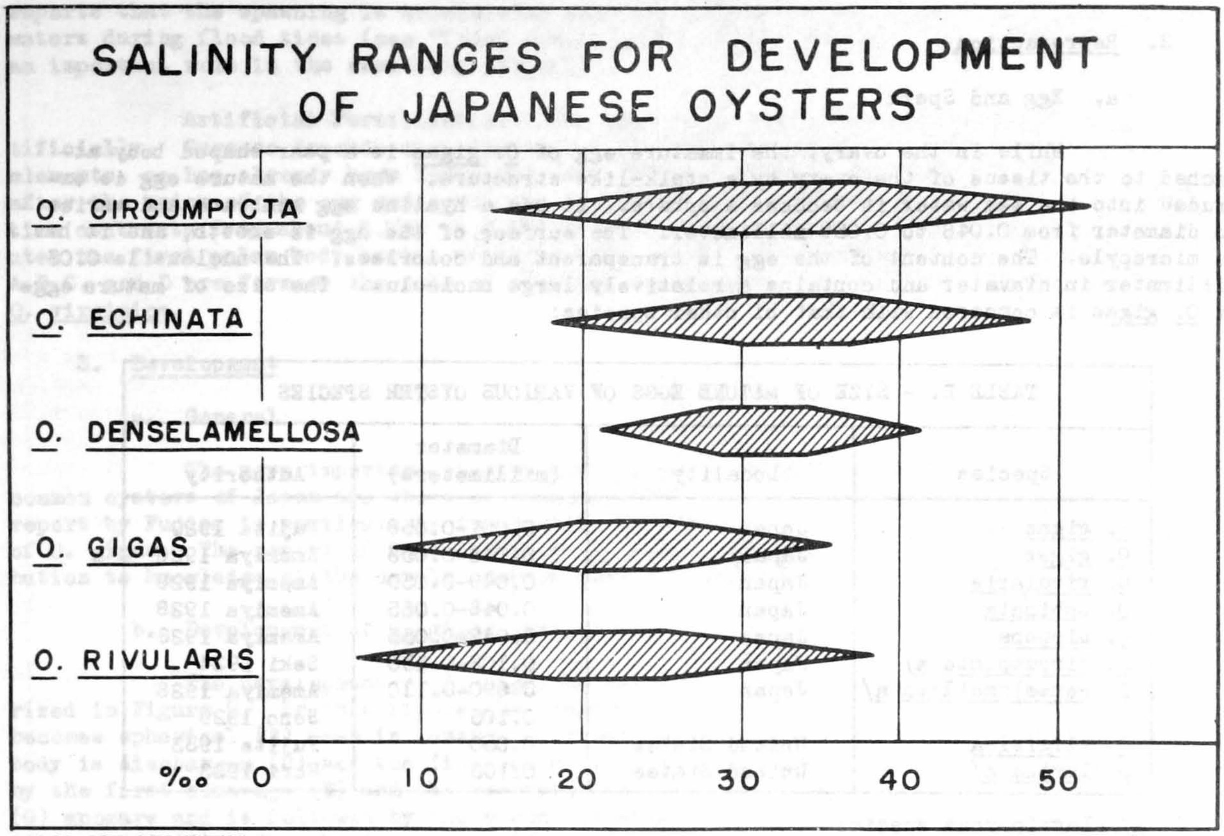


Figure 8

d. Effect of Sperm Water

Galteoff (1930) investigated two species of oysters, the common American east coast oyster O. virginica and the Japanese oyster O. gigas grown in Puget Sound, Washington. In both species spawning can be provoked by adding a small amount of sperm to the water containing gravid females. In several instances when the oyster was not ripe or had already spawned several times the characteristic contractions of the adductor muscle which expel the eggs resulted, but the activity was not accompanied by the discharge of eggs.

The latent period of this reaction in O. gigas varies from 9.5 to 17 minutes. The duration of the reaction varies from 13 to 64 minutes. This spawning reaction can be initiated by a minimum dose of sperm which was found to equal 0.03 cubic centimeter of standard sperm suspension (one gram of gonad tissue in 100 cubic centimeters of sea water) added to 30 liters of sea water. This represents an approximate concentration of only 150 spermatozoa to one cubic centimeter of water. A water temperature of 25°C or higher is prerequisite for the spawning of O. gigas. If the water is below 25°C the presence of sperm fails to provoke the spawning reactions.

In order to determine whether the active principle which induces the extrusion of the eggs is located in the spermatozoan or is present in the solution, Japanese investigators filtered sperm suspensions through collodion membranes. In every instance the filtrate was found to be wholly inactivating, whereas the residue was found to contain the activating principle. These experiments showed that this active principle is either (1) insoluble in sea water or (2) of a molecular size sufficient to prevent its passage through the membrane. Several Japanese culturists are working on further studies of sperm water in relation to its practical application to commercial oyster production.

2. Reproduction

a. Egg and Sperm

While in the ovary, the immature egg of O. gigas is a pear-shaped body attached to the tissue of the ovary by a stalk-like structure. When the mature egg is extruded into the sea water it becomes a sphere. It has a hyaline egg membrane and varies in diameter from 0.046 to 0.058 millimeter. The surface of the egg is smooth, and it has no micropyle. The content of the egg is transparent and colorless. The nucleus is 0.03 millimeter in diameter and contains a relatively large nucleolus. The size of mature eggs of O. gigas is compared with that of other species:

TABLE D. - SIZE OF MATURE EGGS OF VARIOUS OYSTER SPECIES

Species	Locality	Diameter (millimeters)	Authority
O. gigas	Japan	0.051-0.058	Fujita 1929
O. gigas	Japan	0.046-0.053	Amemiya 1928
O. rivularis	Japan	0.049-0.050	Amemiya 1928
O. echinata	Japan	0.048-0.065	Amemiya 1928
O. nippona	Japan	0.047-0.055	Amemiya 1928
O. circumpicta a/	Japan	0.102-0.130	Seki 1934
O. denselamellosa a/	Japan	0.090-0.110	Amemiya 1928
		0.105	Seno 1929
O. virginica	United States	0.050	Fujita 1933
O. lurida a/	United States	0.105	Hori 1933

a/ Larviparous species

Considerable disagreement is apparent in literature as to the number of eggs laid annually by O. gigas. According to Fujita this species lays from 30,000 to 200,000 eggs, but Galtsoff believes the number to range from 500,000 to 100,000,000. Age of the oyster and its degree of fattening may affect the number of eggs laid. The general belief in Japan seems to be that Galtsoff is closer to the truth than is Fujita. O. denselamellosa lays eggs from one to four times a year, and each spawning produces about 2,000,000 eggs for a total annual production of from 2,000,000 to 8,000,000 (Seki 1930).

The eggs can live in sea water for a brief period without being fertilized, the viability depending upon the water temperature and salinity. Fujita (1929) found the viability of such eggs of O. gigas to be greatest in salinities of from 1.014 to 1.016 at a temperature of 27°C. Under these conditions he reports the life span of the unfertilized egg to be at least 15 hours after discharge.

The spermatozoan of O. gigas is 0.075 millimeter in total length; the rounded head has a diameter of 0.0073 millimeter. When fully active, the sperm cell darts through the water at a rate of approximately 0.05 millimeter a second, but this period of maximum activity is not of long duration. When activity ceases death follows immediately. In densities of 1.012 to 1.016 and at a temperature of 29°C the sperm can live as long as 15 hours without union with an egg.

b. Spawning

Natural Spawning: The eggs are discharged from the ovary into the mantle cavity. This cavity is formed by the touching of the edges of the opposite sides of the mantle, leaving only one small opening between them. The adductor muscle undergoes a series of rhythmic contractions, causing the discharge of the eggs into the sea through the opening in the mantle. The spermatozoa are extruded from between the partially opened valves of the shell as a white, smoky stream apparently under slightly greater pressure than that under which water is extruded under normal, nonbreeding conditions. Sato (1948) reports that the spawning is accelerated when the offshore water mingles with the coastal waters during flood tides (see "Tidal Conditions"), and he believes that temperature plays an important role in the resulting activity.

Artificial Fertilization: The eggs of O. gigas can easily be fertilized artificially. Success depends upon the use of at least approximately mature reproductive elements, as has already been indicated (see "Effect of Sperm Water"). Within 20 minutes after the union of the egg and sperm the zygote assumes a spherical form and at the same time contracts from about 0.058 to 0.053 millimeter in diameter. Within the next 15 minutes the first polar body begins to appear (Figure 9) and from then on the blastomeres A,B,C, and D are formed, the mode of cleavage being quite like that of the American oyster, O. virginica.

3. Development

a. General

The more important studies dealing with the embryological development of the common oysters of Japan are those of Amemiya (1929), Fujita (1929), and Hori (1926). The report by Fujita is particularly instructive in regard to the early phases of development of O. gigas. The report of Seno (1929) on O. denselamellosa is the only important contribution to knowledge of the development of that larviparous species.

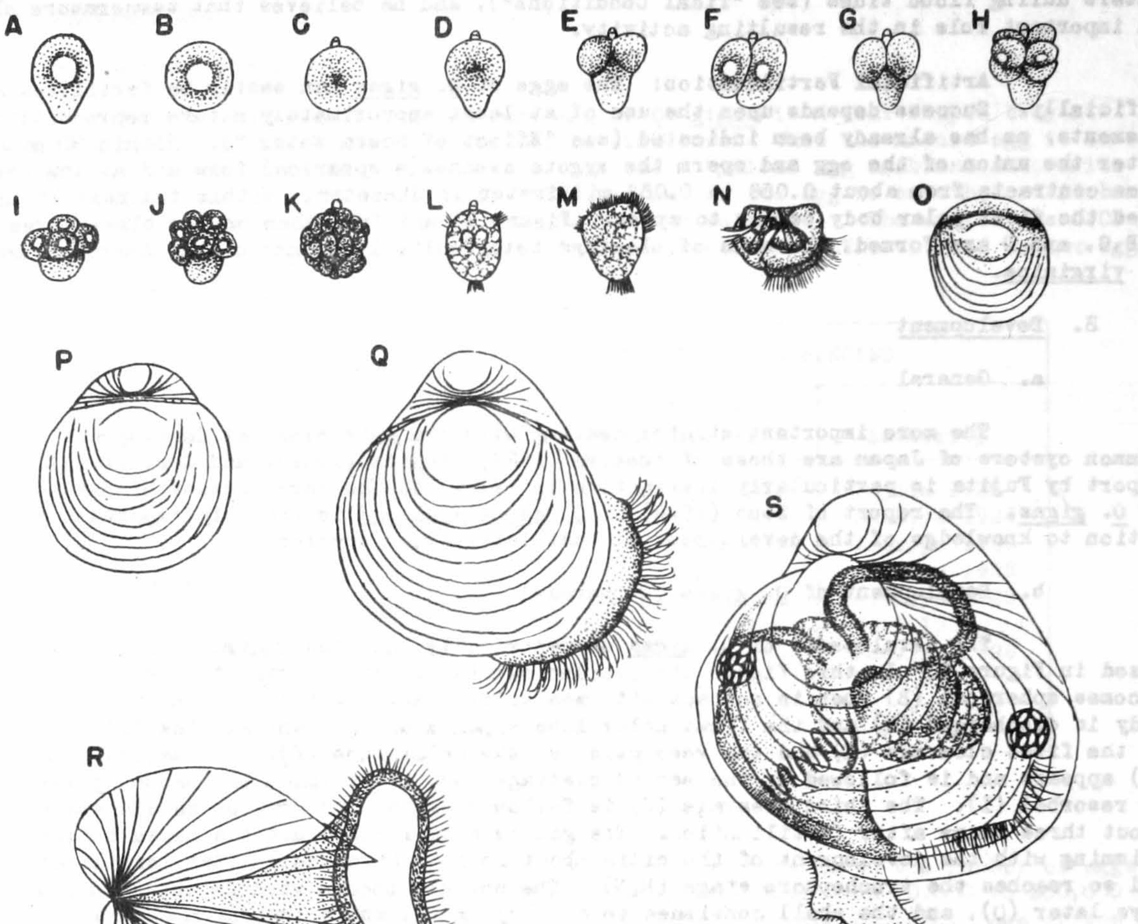
b. Development of O. gigas (Oviparous)

The development of O. gigas as reported by Icho and Oshima (1938) is summarized in Figure 9. In this figure the ovarian egg (A) is shown prior to discharge; this becomes spherical (B) when in contact with sea water. After fertilization the first polar body is discharged (C) and the first polar lobe appears on the ventral side (D), followed by the first cleavage (E) and the resorption of the polar lobe (F). The second polar lobe (G) appears and is followed by the second cleavage (H), after which the second polar lobe is resorbed (I). The third cleavage (J) is followed by the mulberry or morula stage (K) about three hours after fertilization. The gastrula is reached and the larva becomes free-swimming with the development of the cilia about four to five hours after fertilization (L) and so reaches the trochophore stage (M,N). The umbones become visible three to four days later (O), and the shell continues to develop (P)(Q) while the velum (R) is used as the organ of locomotion. About 10 days after fertilization the larva has grown sufficiently to reach the fixation stage (S) with a shell about 0.3 millimeter long. By using the foot, which extends beyond the shell, the oyster creeps over objects on the sea bottom and finally fixes itself permanently by discharging a secretion. From then on the spat grows by peripheral additions to the shell valves as indicated by the spat one day after fixation (T). This process of accretion continues as the young oyster continues to grow (U). The rate of development of O. gigas at a water temperature of 25°C is as follows:

TABLE E. - DEVELOPMENT OF OSTREA GIGAS AT WATER TEMPERATURE OF 25°C

Time After Spawning	Developmental Features
50-60 minutes	First polar body extrudes.
1 hour, 10 minutes	Second polar body extrudes.
1 hour, 40 minutes	First cleavage of zygote occurs.
2 hours	Second cleavage of zygote occurs.
6 hours	Blastula begins to move.
8 hours	Blastula begins to swim.
24 hours	Shell appears (trochophore stage).
48 hours	Shell covers the body (veliger stage).
3-4 days	Larval shell increases to 0.1 mm diameter.
14 days (approximately)	Shell increases to 0.33 mm diameter; larva ceases swimming and sinks to bottom where it attaches.

SOURCE: Amemiya, 1931



NOTE: SEE TEXT SECTION ON "DEVELOPMENT OF O. GIGAS" FOR IDENTIFICATION OF STAGES.

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Figure 9. - Development of *Ostrea gigas*

c. Development of _O. denselamellosa_ (Larviparous)

Seno (1929) first presented the details of the embryology and early life history of _O. denselamellosa_ which are summarized in this section and in Figure 10.

This species is closely allied to the European oyster (_O. edulis_) in shell and sexual characteristics (both are hermaphroditic). The ripe eggs are discharged from the ovary into a branchial cavity between the folds of the mantle, where fertilization takes place and where development progresses to the young shell-bearing stage capable of locomotion. The spermatozoa produced by other individuals are introduced into the branchial cavity with the incoming respiratory water currents. The species is not self-fertilizing.

In the Inland Sea near Hiroshima the breeding season begins early in June and lasts until mid-September. The most active spawning period is from the end of June to mid-July at a water temperature of 21°C to 23°C. The egg is spherical and white, has a large nucleus, and is opaque; the diameter is 0.105 millimeter. All the eggs carried by one individual apparently ripen at one time and all are discharged in one act. The sperm are very different in shape from those of the dioecious oysters. The cells when newly discharged from the gonaducts appear as opaque, nearly sperical bodies called "sperm balls" (A, Figure 10). They execute a rolling motion due to the active vibration of the tails of the ripe spermatozoa at the surface. The ball is composed of spermatozoa of different sizes, from 20 to 80 microns in diameter. When the sea water touches this ball the motion of the tails accelerates more and more until the ball is shattered and the component individual spermatozoa liberated.

In the mantle cavity all developmental stages from the unsegmented egg (B) to the shell-bearing larvae may be found, but stages of the 16-cells or later are the most numerous. Unsegmented zygotes are very rarely found. Seno was fortunate in finding a few of these rare stages and thus was able to follow the early cleavage through the eight-celled stage. After giving off the first two polar bodies (C,D) the egg divides into two unequal spheres (E). The second cleavage results in one large and three small cells (F), the third cleavage in one large and seven small blastomeres (G). The sixth cleavage produces the blastula (J) which is sperical and has a shallow invagination at one pole. This process of invagination continues and produces finally a typical gastrula which is somewhat heart-shaped (K,L) and ciliated and which swims in the characteristic manner. This stage ends the embryonic period. The tucked-in ectoderm becomes the lining of the mouth and esophagus; the cavity and its walls become the stomach and intestine, the latter being formed by a posterior outgrowth of the stomach which meets the ectoderm at the posterior end to form the anus. In the formation of the shell, each valve first appears as a small spot near the dorsal surface of the soft larval body. This grows, covering more and more of the body, until it meets its mate from the opposite side along the hinge line. Both valves then develop downward until they enclose the entire body except the velum. At this time the shell measures 0.15 millimeter in length and 0.14 millimeter in depth and has an almost straight hinge line (M). In this stage the larva leaves the branchial cavity to begin its pelagic plankton life.

As growth continues, the color changes from white in the early shell-bearing stage to gray in the straight hinge stage, and finally through pinkish-gray and purplish-black, to black. Small serrations (teeth) appear at each end of the hinge. The full grown larva (O,P), with a shell length of 380 microns, are most common from the end of July to mid-August, at which time they begin to attach themselves to stationary objects. This fixation occurs about four weeks after spawning.

4. Food

a. Larval Food

In nature oyster larvae consume many small plankton organisms having a diameter of less than 10 microns, including diatoms, flagellates, and bacteria (Figure 11). For organisms up to this size they have no discriminatory mechanism, hence innumerable forms are found upon stomach examination. Exactly which of these many forms function as food and which merely chance to be present, to be passed through the digestive system without undergoing digestion, is not known. Hori (1927) in experimental work used _Chlorella pacifica_ for larvae of _O. gigas_ and pulverized _Ulva_ for young _O. lurida_. Amemiya (1926) raised

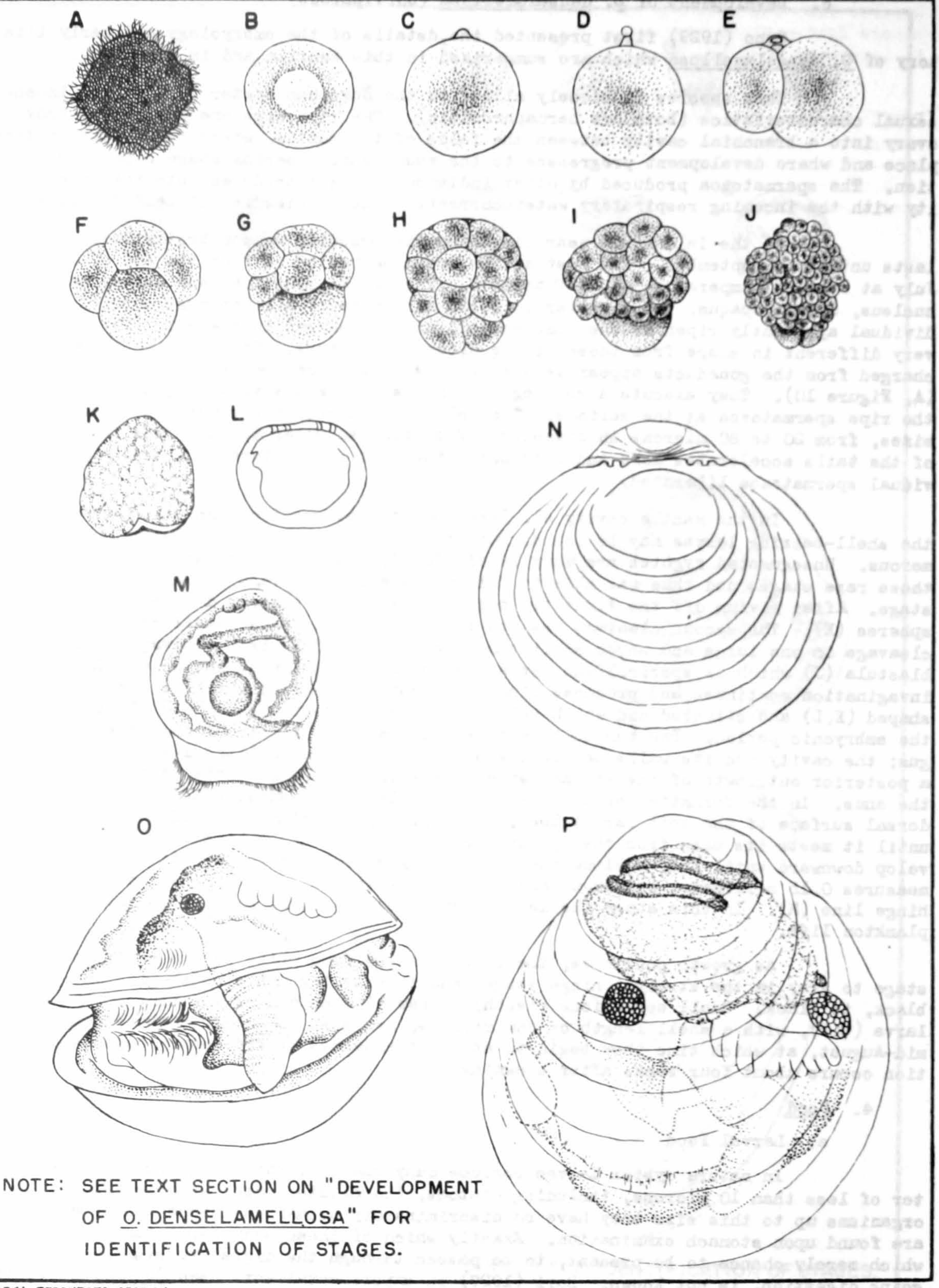

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Figure 10. - Development of **Ostrea denselamellosa**

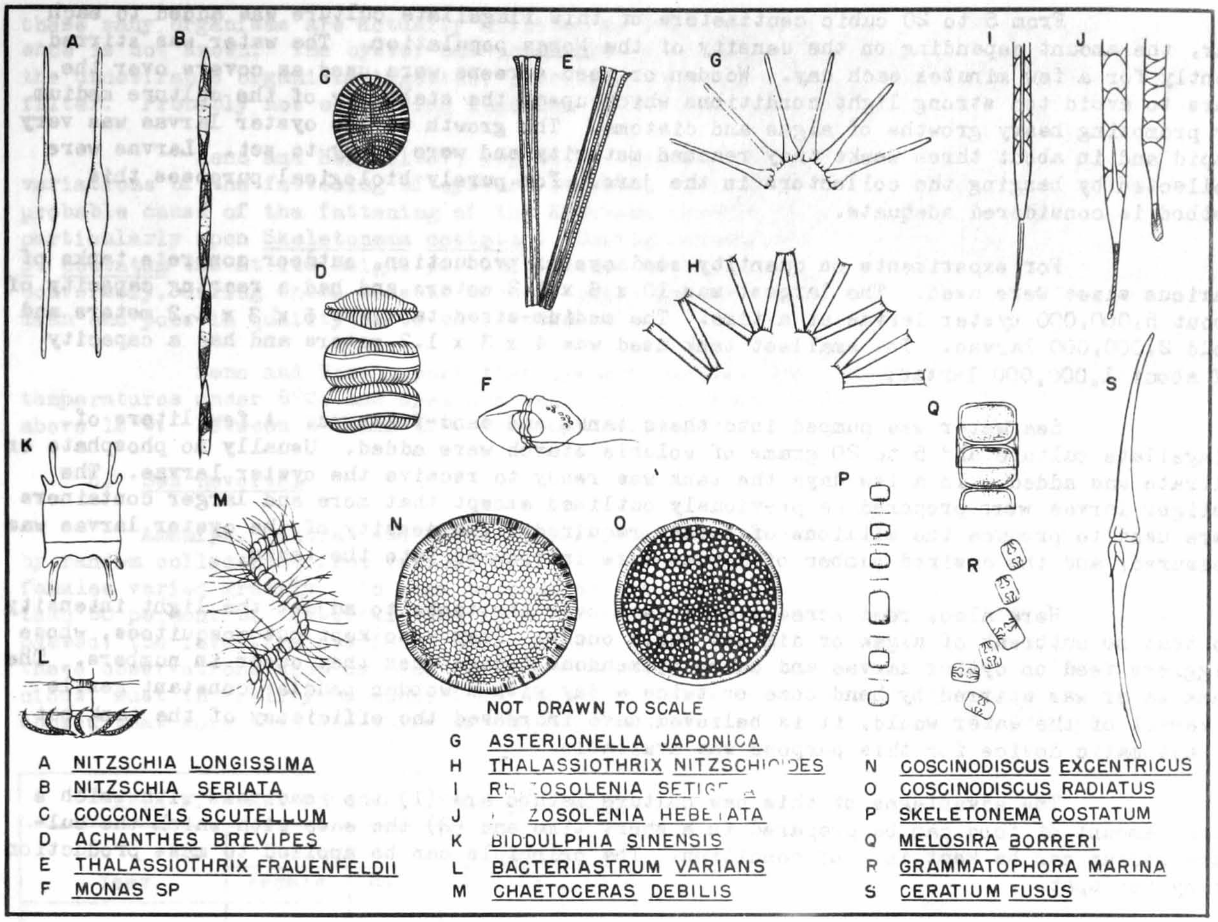

Figure 11. - Food of oysters

larvae of O. virginica on Pontosphaera huxleyi. Cole (1936) found that the non-motile monocellular algae were not suitable as food for larval oysters but that the motile flagellates (Chlamidomonadinae, Cryptomonadinae, Chrysomonadinae) are suitable. Bruce, Knight, and Parke (1940) obtained good results feeding Chrysophycea and Chlorophyceae in pure culture. These organisms are pigmented.

Imai and Hatanaka (1949) discovered the colorless, naked flagellates Monas sp. are excellent larval food and used them in their recent extensive work on oyster culture, the best thus far done in Japan. Larvae of O. gigas obtained by artificial fertilization were reared by feeding nothing but these flagellates. The oyster eggs were fertilized in small dishes and thoroughly washed thereafter. The seawater used was sand-filtered and had a density of about 16 or 17 0/00 chlorine. When the larvae reached the veliger stage and began to feed, they were put into glazed earthen culture jars having a capacity of about 50 liters, between 1,000, and 2,000 larvae per jar. A few cubic centimeters of cultured Monas were then introduced as food.

For the culture of Monas a sterilized solution of 30 percent sea water was used, to which was added 0.1 to 0.2 percent sugar or starch, and a small amount of phosphate and nitrate. When the stock culture was introduced into the solution a rapid growth of bacteria occurred, followed immediately by the rapid development of Monas. Monas density as high as 200,000 to 800,000 per cubic centimeter of water can be obtained quite easily in about five days. The bacteria get their energy from the carbohydrates by decomposition and nutrient elements such as phosphate and nitrate for multiplcation. Monas fed on the bacteria and reproduced very rapidly. Only mature culture forms more than five days old were used as food material.

From 5 to 20 cubic centimeters of this flagellate culture was added to each jar, the amount depending on the density of the *Monas* population. The water was stirred gently for a few minutes each day. Wooden or reed screens were used as covers over the jars to avoid too strong light conditions which upset the stability of the culture medium by promoting heavy growths of algae and diatoms. The growth of the oyster larvae was very rapid and in about three weeks they reached maturity and were ready to set. Larvae were collected by hanging the collectors in the jars. For purely biological purposes this method is considered adequate.

For experiments on quantity seed oyster production, outdoor concrete tanks of various sizes were used. The largest was 10 x 6 x 1.2 meters and had a rearing capacity of about 5,000,000 oyster larvae at a time. The medium-sized tank was 6 x 3 x 1.2 meters and held 2,000,000 larvae. The smallest tank used was 4 x 3 x 1.2 meters and had a capacity of about 1,000,000 larvae.

Sea water was pumped into these tanks and sand-filtered. A few liters of flagellate culture and 5 to 20 grams of soluble starch were added. Usually no phosphate or nitrate was added. In a few days the tank was ready to receive the oyster larvae. The veliger larvae were prepared as previously outlined except that more and larger containers were used to produce the millions of larvae required. The density of the oyster larvae was measured, and the desired number of larvae were introduced into the tanks.

Here also, reed screens were used over the tanks to adjust the light intensity so that no outbreak of algae or diatoms would occur. They also kept out mosquitoes, whose wigglers feed on oyster larvae and cause tremendous damage when they occur in numbers. The tank water was stirred by hand once or twice a day with a wooden paddle; constant gentle movement of the water would, it is believed, have increased the efficiency of the tank but no automatic device for this purpose was available.

The advantages of this new culture method are (1) the readiness with which a large amount of food can be prepared in a short time and (2) the ease with which the culture medium can be kept in good condition. The principle can be applied to mass production of oyster spat.

b. Food of Adult Oysters

Adult oysters feed on detritus and microorganisms. The most important are species of phytoplankton such as diatoms, and species of zooplankton such as flagellates (Figure 11). The species taken vary according to the season and locality, but they provide rich carbohydrates and proteins for the oysters. In order to produce a rich plankton supply the culture ground should be abundant in inorganic salts (such as $NaHSO_4$, $NaNO_3$, $NaNO_2$, and $KHPO_4$) in order to provide nourishment for the microscopic organisms.

The oysters filter their food from the water by means of the gills. The quantity of food ingested is directly proportional to the abundance of the plankton in the water and also to the velocity of the current which transports it. In their investigations of the feeding habits of oysters, Seno and Hori (1927) found that oysters grow very rapidly in autumn after the spawning season and slowly in winter and spring. The quantity of available plankton is most abundant in autumn and decreases in winter when the water temperature drops. In spring the quantity of plankton increases gradually with the rise in water temperature. A list of plankton organisms found commonly in the stomachs of *O. gigas* in Kanazawa, Kanagawa Prefecture, is given in Table 5. Ikari (1929) states that the diatoms *Thalassiothrix nitzschioides* and *Coscinodiscus symmetricus* are predominant in the stomach contents of *O. gigas* at Misaki, Kanagawa Prefecture. He also reports the following species as important diatoms from the stomachs of *O. gigas* at Nagasaki, Nagasaki Prefecture: *Skeletonema costatum*, *Coscinodiscus marginatus*, *Coscinodiscus excentricus*, *Coscinodiscus symmetricus*, *Cyclotella striata*, and *Nitzschia tribryonella*. As important food items for *O. nippona* at Asamushi, Aomori Prefecture, he found *Trachyneis aspera*, *Cocconeis scutellum*, *Coscinodiscus lineatus*, *C. radiatus*, *C. marginatus*, and *C. excentricus*. Which of these many organisms are actually utilized as food and which are of merely fortuitous presence is not known. The oyster has no selective mechanism for separating the desirable from the undesirable organisms ingested, providing they are small enough to pass through the filter. Probably not everything ingested is utilized as food.

Seno and Hori (1927) report an intimate relationship between the seasonal variations of the fattening of oysters and both the species and quantity of plankton. The probable cause of the fattening of the Kanazawa oysters is the vigorous feeding on diatoms, particularly upon Skeletonema costatum. During October and November, when the quantity of S. costatum was at its height per unit volume of water, the oysters fattened most rapidly. Conversely, during those seasons when S. costatum was scarce or absent, the oysters were so lean and poor in quality as to be unmarketable.

Seno and Hori report that oysters neither open their valves nor take food at temperatures under 8°C, and open and begin to take food normally when the temperature rises above 12°C. Between 8°C and 12°C they open sluggishly.

5. Sex Reversal

Amemiya, Tamura, and Senuma (1929) studied sex ratio and sex stability in O. gigas by random collections from various oyster beds and found that the proportion of males and females varied greatly. In some beds males predominated, in some instances comprising more than 80 percent of the total, and in other beds females predominated. Moreover, as time passed, the investigators found that the sex ratio for any one bed was not constant. From these observations they decided that this oyster, which had been considered to be dioecious, must in reality be monoecious and experiments were accordingly planned. The results showed that more than one-third of the individuals observed underwent sex change (Table F).

TABLE F. - SEX REVERSAL IN OSTREA GIGAS

Year	Group 1		Group 2	
	Female	Male	Female	Male
1928	119	58	209	145
1929				
Female	82	32	85	48
Male	20	18	34	39
Hermaphroditic	0	0	1	0
Indeterminate	4	0	8	1
Dead	13	8	81	57
TOTAL	119	58	209	145

SOURCE: Amemiya, Tamura, and Senuma, 1929.

6. Growth

a. General

The growth rate of the oysters (Figure 12) has a very definite bearing on the problem of oyster culture from an economic point of view. Various investigators have shown that in general the growth rate of the different species of oysters depends upon environmental factors such as water temperature and the amount of available food filterable from the water. The amount of available food depends on the density of the plankton, the strength of the current which carries the plankton to the sessile oysters, and other environmental conditions. The growth rate varies with these conditions, and the variation may be considerable.

b. Growth of O. gigas

In a study of the growth rate of O. gigas reared by the hanging culture method, Seki (1937) reports differences among three groups of oysters collected from Hiroshima, Sendai, and Ocho respectively (Table G, p 30, Figure 13). The Sendai oysters are fastest growing of the series, the Ocho oysters the slowest.

Seno and Hori (1927) reported practical results from their experiments on fattening O. gigas. Their work was conducted during different seasons and at various depths and involved different culture methods. They found the fattening to be better by the hanging method than by the sowing method (Figure 14), better in the middle layer of the water than in either the upper or lower aquatic zone, and better in autumn than in winter.

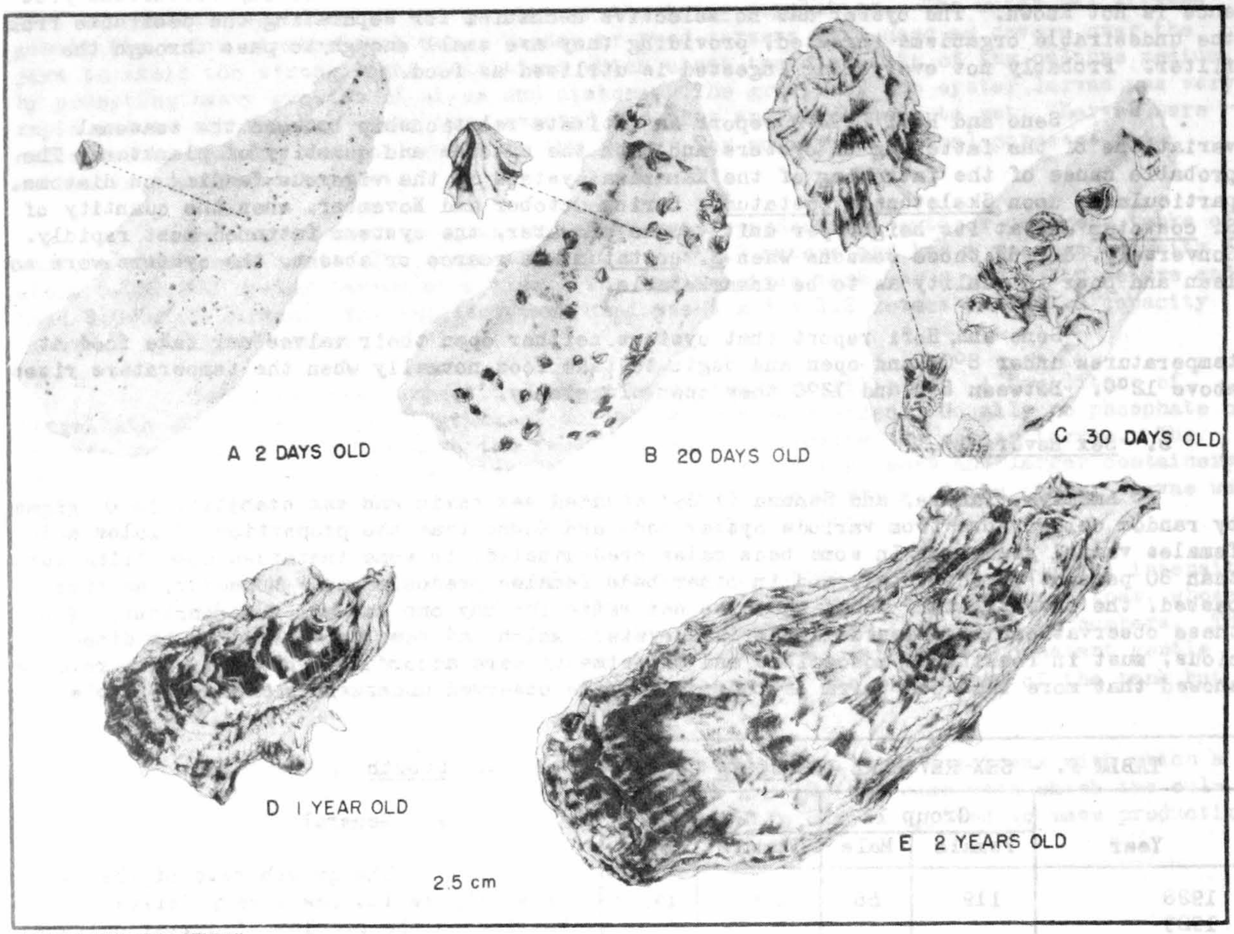

Figure 12. - Growth of young Ostrea gigas in Miyagi Prefecture

TABLE G. - GROWTH RATES OF OSTREA GIGAS IN THREE CULTURE AREAS											
	Average Shell Height (millimeters) a/										Total Increase
Area	25 Apr	20 Jun	18 Jul	21 Aug	19 Sep	20 Oct	20 Nov	29 Dec	25 Jan	20 Feb	(percent)
Hiroshima	16	23	33	41	42	44	44	45	46	47	193.0
Sendai	13	22	34	42	46	48	53	54	57	59	354.0
Ocho	32	39	46	49	49	50	51	52	52	52	62.5

a/ Distance from umbone to ventral margin of the shell
SOURCE: Seki, 1937.

c. Growth of O. denselamellosa

The work of Seki (1937) on O. denselamellosa provides information on the growth rate for a larviparous species (Figure 15). That the growth rate varies considerably with the habitat is shown by the work of Tanaka (1947). He cultured O. denselamellosa by the hanging method in five different localities (Table H, p 32). The growth at Tokushima, Tokushima Prefecture, was best, and that at Tanabe, Wakayama Prefecture, was poorest. Tanaka's work also shows that the growth varies considerably depending upon the method of culture (Table I, p 32), with the hanging method producing the best results. Tanaka found also that O. denselamellosa reaches a size of 63 by 67 millimeters, the minimum size for sexual maturity, at an age of 16 months. Most of the individuals spawn at the age of two years.

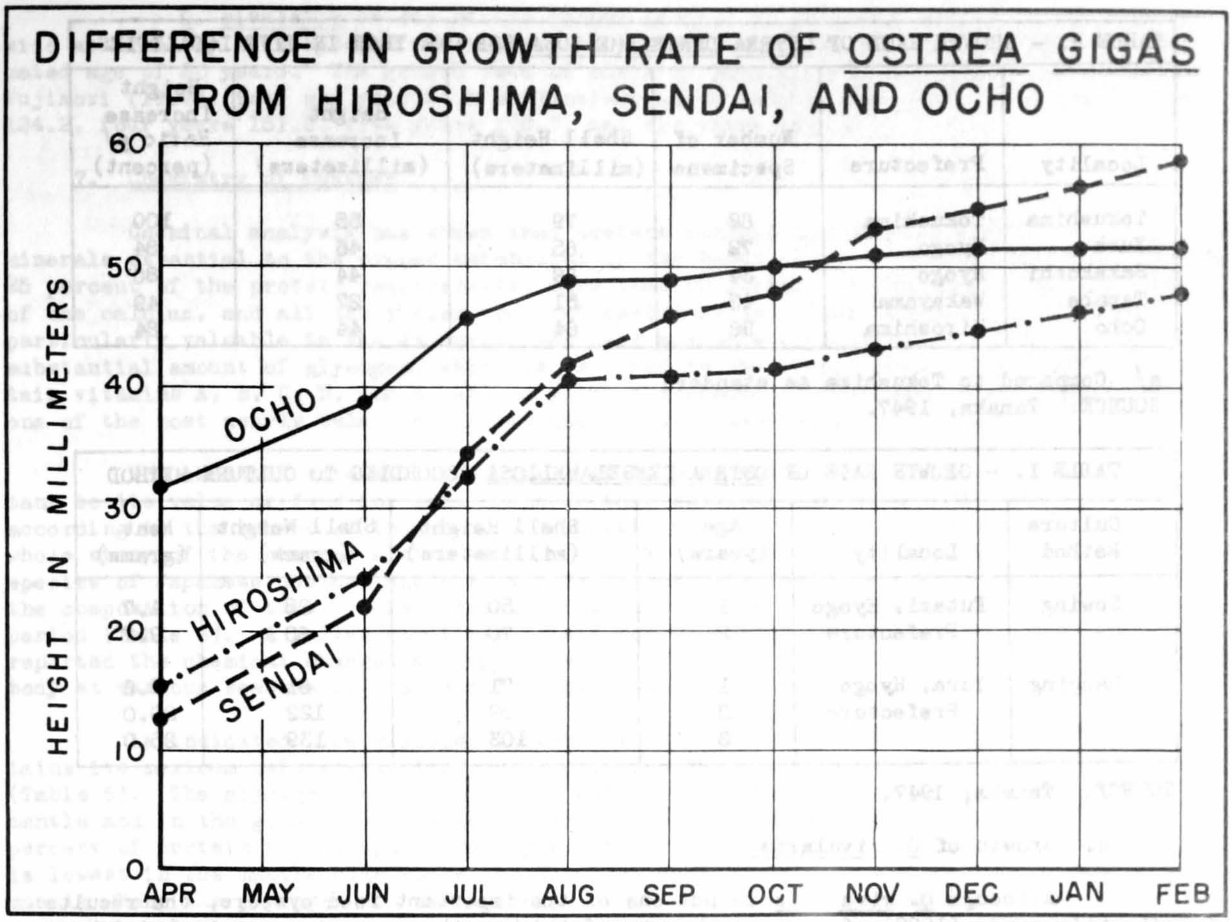

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Figure 13

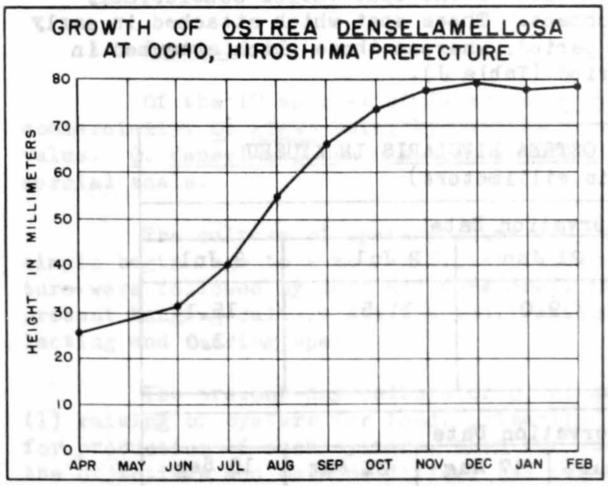

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Figure 14

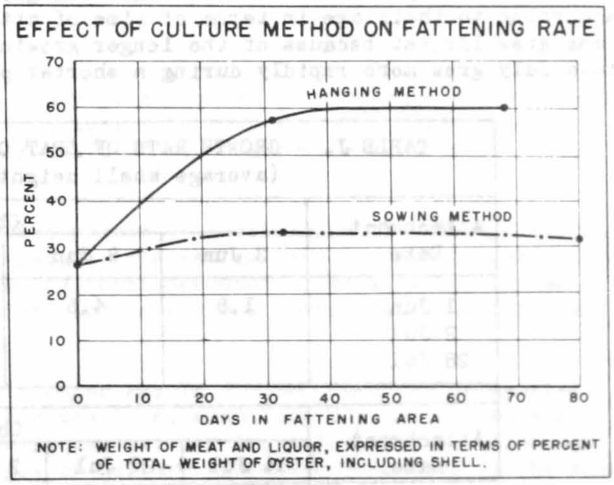

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Figure 15

TABLE H. - GROWTH RATE OF OSTREA DENSELAMELLOSA FOR ONE YEAR IN FIVE LOCALITIES					
Locality	Prefecture	Number of Specimens	Shell Height (millimeters)	Height Increase (millimeters)	Height Increase Ratio a/ (percent)
Tokushima	Tokushima	62	79	55	100
Yura	Hyogo	72	65	46	84
Sakakoshi	Hyogo	34	69	44	80
Tanabe	Wakayama	43	51	27	49
Ocho	Hiroshima	96	64	44	84

a/ Compared to Tokushima as standard
SOURCE: Tanaka, 1947.

TABLE I. - GROWTH RATE OF OSTREA DENSELAMELLOSA ACCORDING TO CULTURE METHOD					
Culture Method	Locality	Age (years)	Shell Height (millimeters)	Shell Weight (grams)	Meat (grams)
Sowing	Futami, Hyogo Prefecture	1	50	28	4.7
		2	70	60	9.7
Hanging	Yura, Hyogo Prefecture	1	71	61	8.6
		2	89	122	20.0
		3	103	139	25.0

SOURCE: Tanaka, 1947.

d. Growth of O. rivularis

Although O. rivularis is not one of the important food oysters, the results of Fujimori's study (1929) of the growth rate of this southern species are included here for comparison.

Fujimori divided his study into two parts: (1) spat and young oysters and (2) the sexually adult. He found that the growth rate of the spat varies considerably according to their age in terms of time of attachment. Those spat which attached in early June grew largest because of the longer growing period, whereas those which attached in late July grew more rapidly during a shorter period (Table J).

TABLE J. - GROWTH RATE OF SPAT OF OSTREA RIVULARIS IN KYUSHU
(average shell height in millimeters)

Attachment Date	Observation Date				
	3 Jun	8 Jun	21 Jun	2 Jul	8 Jul
1 Jun	1.8	4.5	9.0	11.5	15.1
2 Jul					3.0
28 Jul					

Attachment Date	Observation Date					
	14 Jul	27 Jul	2 Aug	17 Aug	31 Aug	15 Sep
1 Jun	ND	18.0	21.2	40.0	45.4	48.5
2 Jul	6.0	10.3	12.0	24.0	30.0	40.0
28 Jul			1.5	9.9	12.0	18.0

ND: No data available
SOURCE: Fujimori, 1929.

O. rivularis is one of the larger species of Japanese oysters. The maximum size attained by this species as recorded in literature is 257 millimeters, with an estimated age of 20 years. The growth rate of adult O. rivularis in Kyushu, as determined by Fujimori (1929), is: one year 54.5 millimeters shell height, two years 96.9, three years 124.2, four years 151.5, five years 178.7, and six years 196.9.

7. Chemistry of Oysters

Chemical analysis has shown that oysters contain appreciable quantities of all the minerals essential to the proper metabolism of the human body. A pint of oysters furnishes 25 percent of the protein requirements, more than 50 percent of the phosphorus, 33 percent of the calcium, and all the iodine and iron needed daily. Their high protein content is particularly valuable to the Japanese, who lack adequate protein foods. Oysters contain a substantial amount of glycogen, which is required in the normal human diet, and also contain vitamins A, B, C, D, and G, all of which are needed by the human body. The oyster is one of the most nearly balanced, nutritionally, of human foods (Sekine et al, 1929).

The chemical composition of the oyster, especially the glycogen content, is important to its value as food for man. Because this chemical composition is highly variable according to the season of the year, a 12-month cycle of analyses is necessary to tell the whole story of the changes within the oyster. These studies have been made for some of the species of Japanese oysters and are especially complete for O. gigas. Seasonal changes in the composition of this species clearly show the changes associated with the breeding period (Table 6). A smilar condition exists for O. circumpicta (Table 7). Hatanaka (1940) reported the chemical changes during the spawning season and in the different organs of the body at various seasons of the year (Tables 8 and 9).

As indicated, the glycogen content is considerable. The storage of glycogen attains its maximum before spawning and reaches its minimum just after spawning is complete (Table 6). The glycogen is stored mainly during the fattening season in the edges of the mantle and in the gonad, but the amount in the gonad decreases as the oyster matures. The percent of protein varies approximately inversely with the glycogen content of the body; it is lowest in the mantle edge where the glycogen content is high and highest in the adductor muscle where the glycogen content is very low (Table 9). The percent of fat is high in the hepato-pancreas and in the egg (gonad), and low in the adductor muscle. The fat content of hepato-pancreas decreases as the maturation of the gonad proceeds.

CULTURE OF OSTREA GIGAS

1. General

Of the 17 species of Japanese Ostrea, only O. gigas and O. rivularis are cultured commercially, O. gigas being by far the more important both in scale of production and in value. O. denselamellosa has been successfully cultured experimentally but not on a commercial scale.

The culture of oysters shows progressive phases of development, advancing from simple beginnings to a more efficient modern system. The sowing methods used in early culture were followed by more and more complicated cultural procedures, culminating in the present hanging culture and its modifications and in the various devices evolved for collecting and rearing spat.

The present-day culture of O. gigas in Japan may be divided into two categories: (1) raising of oysters for food, primarily for domestic consumption; (2) culture solely for production of seed oysters, both for domestic use and for the export trade. Although the objectives and methods differ, the two types of culture often are conducted in the same village.

The location where an oyster culture farm can be successfully established must be selected with care and must be determined by intelligent examination of local ecological conditions. The following conditions must be fulfilled:

(a) The farming area must be protected by nature against violent wind and wave action.
(b) The adult oysters which produce the spawn must be present in nearby waters in sufficient numbers to insure adequate reproduction.
(c) Tidal and/or current flow must be sufficient to change the water of the area completely and frequently.
(d) The salinity should be very close to 27 parts per thousand and the water should have a specific gravity of approximately 1.020 within a total range of from 1.014 to 1.025.
(e) The water must contain adequate nourishment for plankton production and should be abundant in phytoplankton suitable as food for the oysters and their larvae.
(f) Except where hanging methods are to be used, the bottom must be relatively flat and sandy-mud in quality, free of excessive growth of aquatic vegetation.
(g) Because the optimum temperature for oyster culture is about 24°C or 25°C, the water temperature must be within the tolerance range of the species, which is 15°C and 30°C.

2. Spat Collection

a. Season

The oyster larva begins to swim five or six hours after fertilization and continues a planktonic life for 10 to 14 days, when it attaches to a solid base and is thereafter sessile. When this time for attachment arrives, the collectors (or "cultch" as they are called in the industry) must already be in the water to catch the larvae.

Of primary importance is the problem of selecting the best period of the spawning season in which to place the cultch in the water. If these spat collectors are set out too early, their surface will be covered with barnacles (Balanus), mussels (Mytilus sp.), and other animal and plant growths to such an extent that the spat will be unable to attach easily, thus greatly reducing the possible set. Therefore the time of placing the collectors must be closely correlated with the beginning of the major setting period. This can be done by making daily records of changes of water temperatures and by counting samples of swimming oyster larvae collected by a plankton net. In Hiroshima and Miyagi prefectures, trained technicians at the fisheries experimental stations gather this information and transmit it directly to the individual oyster farmers so that they may place their collectors in the water at exactly the right time for greatest efficiency. In general, when the water temperature rises over 25°C a good spawning is assured. The spawning is sporadic, and the advantages of the longer growing period make it advisable to catch the first peak of the spawning season for maximum production results.

b. Placing the Cultch

The oyster larvae are free-swimming plankton organisms that tend to congregate near the surface of the water. They are not evenly distributed throughout the water either horizontally or vertically so location of the collector in the best possible position to catch these swimming larvae is extremely important. The collector must be placed where the tidal current carries the larvae back and forth, and water temperature, salinity, and available food supply must be favorable.

The level at which the collectors are hung should match as closely as possible the level of the swimming larvae. The height should be within the intertidal range and at least 10 to 20 centimeters above the sea bottom so that the spat will not be killed by the mud or debris or attacked by drills or starfish. In Hiroshima Prefecture the range within which the collectors are placed is at depths of 50 to 120 centimeters, between high low water level (HLWL) and low low water level (LLWL). In Kumamoto Prefecture, Ota (1948) found depths of 40 to 100 centimeters above the bottom and below LLWL to be the best for shallow water (Figure 16) and 0 to 100 centimeters above LLWL to be best in deeper ranges (Figure 17). Moreover, the collectors should be set not over 100 centimeters above LLWL in order to avoid dense attachment of barnacles (Figure 17).

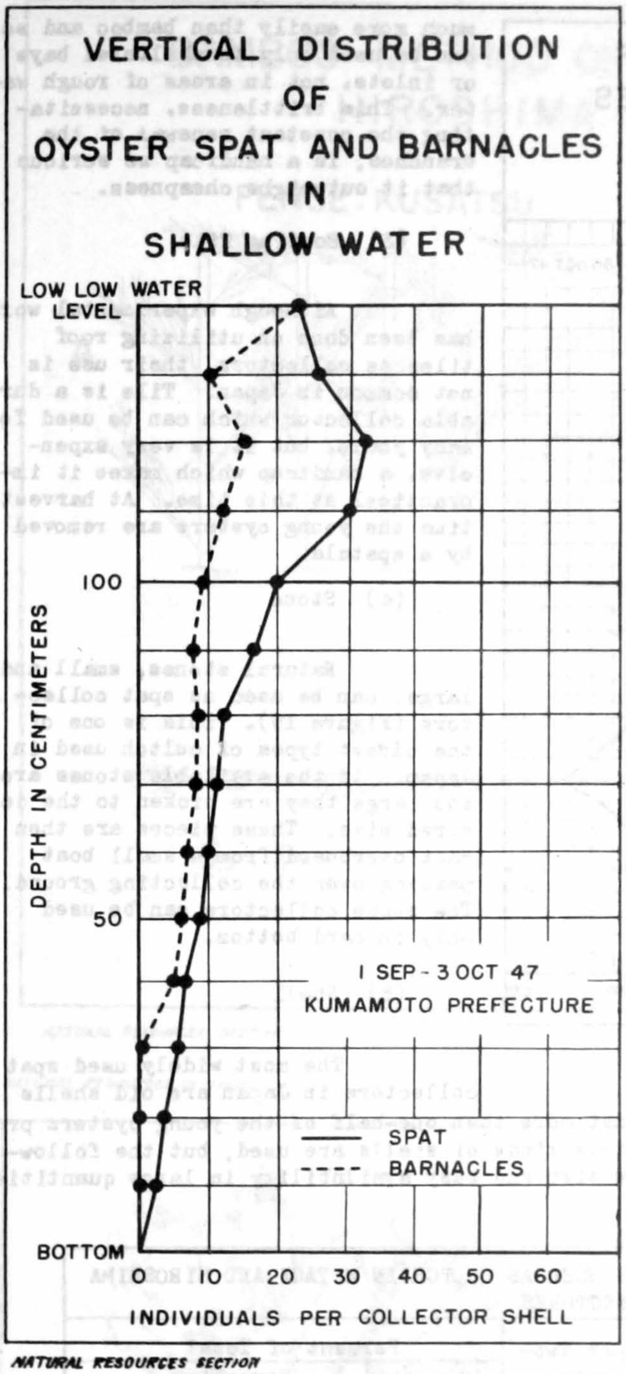


Figure 16

c. Types of Collectors

The type of collector used is determined by local preferences and conditions, availability of material, and cost. Many kinds are in use in Japan, but the following are most common:

(1) Bamboo

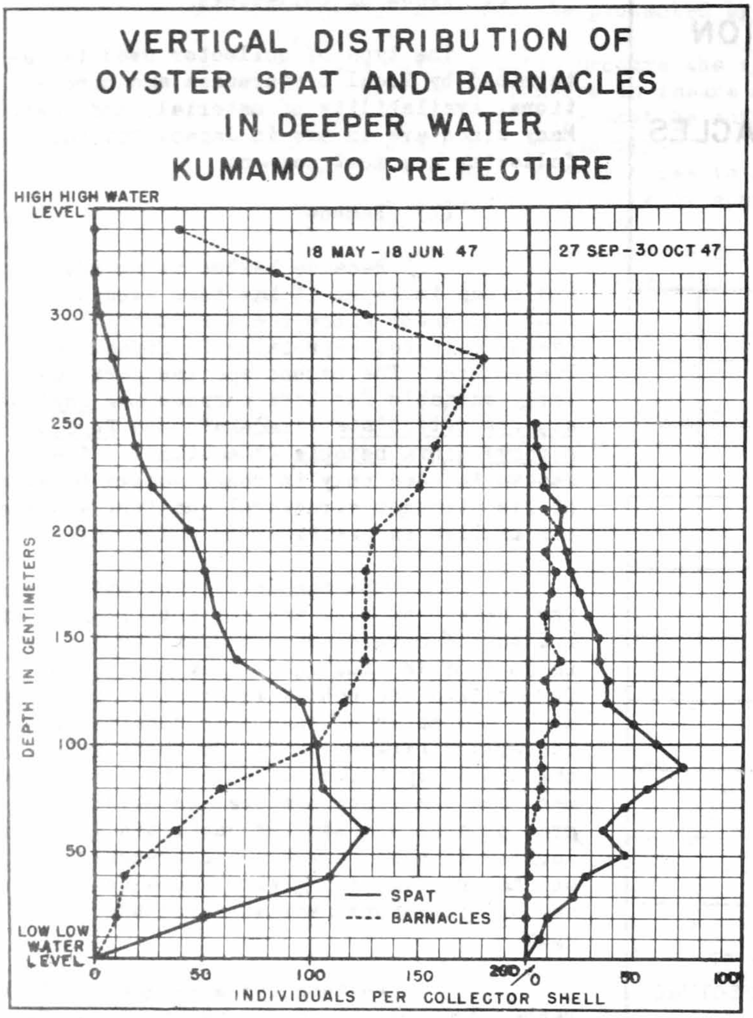
Because bamboo is abundant and cheap in Japan it has been used as a spat collector since the earliest days of oyster culture, especially in Hiroshima Prefecture. The bamboo species particularly suitable for this purpose are Phyllostachys reticulata ("madake") and Phyllostachys nigra henonis ("hachiku"). The madake is used only in rough waters because of its stronger structural quality, whereas the hachiku is practical in quiet water.

The bamboo sticks, still bearing their branches, are cut into lengths of 1.2 to 1.5 meters and are arranged either in rows or in clusters. They are thrust firmly into the bottom material so that about one meter of each pole remains above the ground (Figure 18). On these sticks the oyster spat are collected in early summer, and the young oysters are allowed to grow on them undisturbed until the following April. At that time the oyster-bearing sticks are removed, giving place to another set of collectors available for the new spat.

Whether the arrangement of the bamboo branches is in clumps ("toya") or fence-like rows depends on the individual preferences of the farmer and on the extent and configuration of the area he is cultivating, but different regions show definite and rather uniform tendencies. The bamboo branch can be used for about three years. During the first year the spat do not attach well on the smooth surface, and some are killed, apparently by an oil exuded from the bamboo tissue. The second and third years of the bamboo's use are best for spat attachment. The young oysters are removed from the bamboo by scraping with a kind of spatula.

(2) Tree Branch

The branches of almost any tree can be used as spat collectors in the same manner as bamboo, but the principal trees so utilized are the chestnut and various species of oaks and pines. Although tree branches are even cheaper than bamboo, and the attachment of spat on them is better, the wood is much less resistant to decay than bamboo and therefore does not last as long. Furthermore these woods are relatively weak and break



NATURAL RESOURCES SECTION

Figure 17

much more easily than bamboo and so can be used only in sheltered bays or inlets, not in areas of rough water. This brittleness, necessitating the constant renewal of the branches, is a handicap so serious that it outweighs cheapness.

(3) Roofing Tile

Although experimental work has been done on utilizing roof tiles as collectors, their use is not common in Japan. Tile is a durable collector which can be used for many years, but it is very expensive, a handicap which makes it impractical at this time. At harvest time the young oysters are removed by a spatula.

(4) Stone

Natural stones, small and large, can be used as spat collectors (Figure 19). This is one of the oldest types of cultch used in Japan. If the available stones are too large they are broken to the desired size. These pieces are then cast overboard from a small boat passing over the collecting ground. The stone collectors can be used only on hard bottom.

(5) Shell

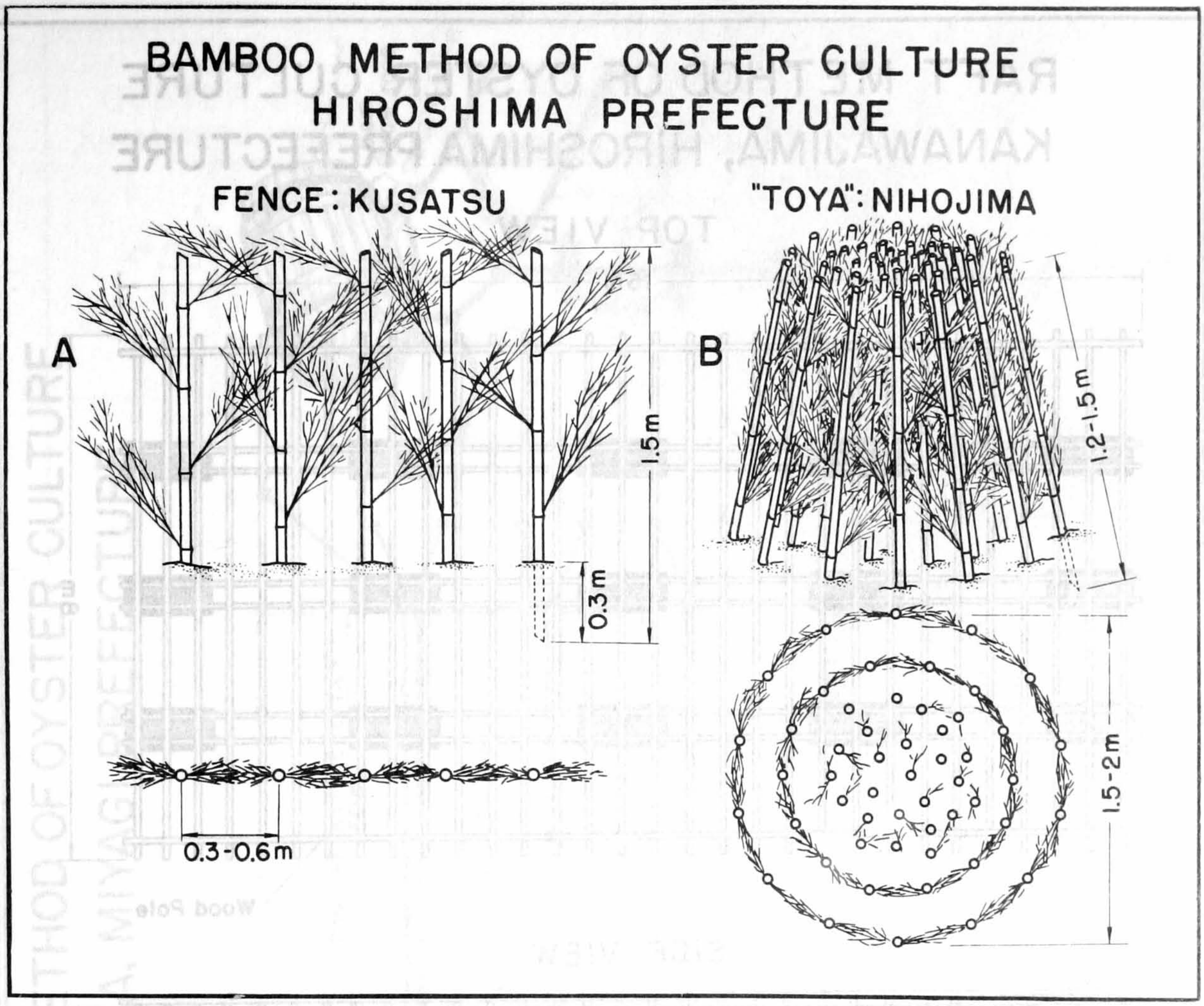
The most widely used spat collectors in Japan are old shells of various marine mollusks. Estimates are that more than one-half of the young oysters produced are gathered on shell collectors. Various kinds of shells are used, but the following species, because of their relatively large size and easy availability in large quantities at low cost, are most commonly used:

TABLE K. - SPECIES OF MOLLUSK SHELLS USED AS CULTCH IN MIYAGI AND HIROSHIMA PREFECTURES

Genus and Species	Cultch per Two-Meter String	Percent of Total	
		Miyagi	Hiroshima
Pecten laqueatus	110	0	60-70
Pecten yessoensis	80	10-20	0
Mytilus crassitesta	80	0	20-30
Cardium muticum	ND	0	a/
Ostrea gigas	75	80-90	a/
Chlamys farreri nipponensis	ND	a/	0
Haliotis kamtschatkana b/	ND	a/	0

a/ Experimental
b/ An abalone (gastropod)
ND: No data available

SOURCE: Hiroshima Fisheries Experimental Station and Mr Miura in Miyagi

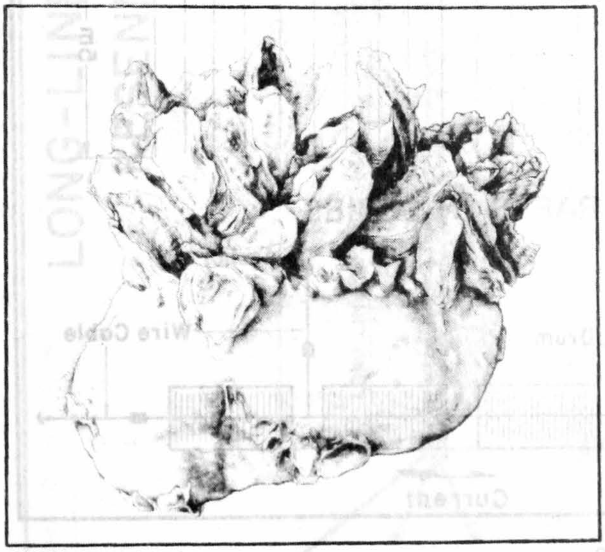


NATURAL RESOURCES SECTION

Figure 22

NATURAL RESOURCES SECTION

Figure 18

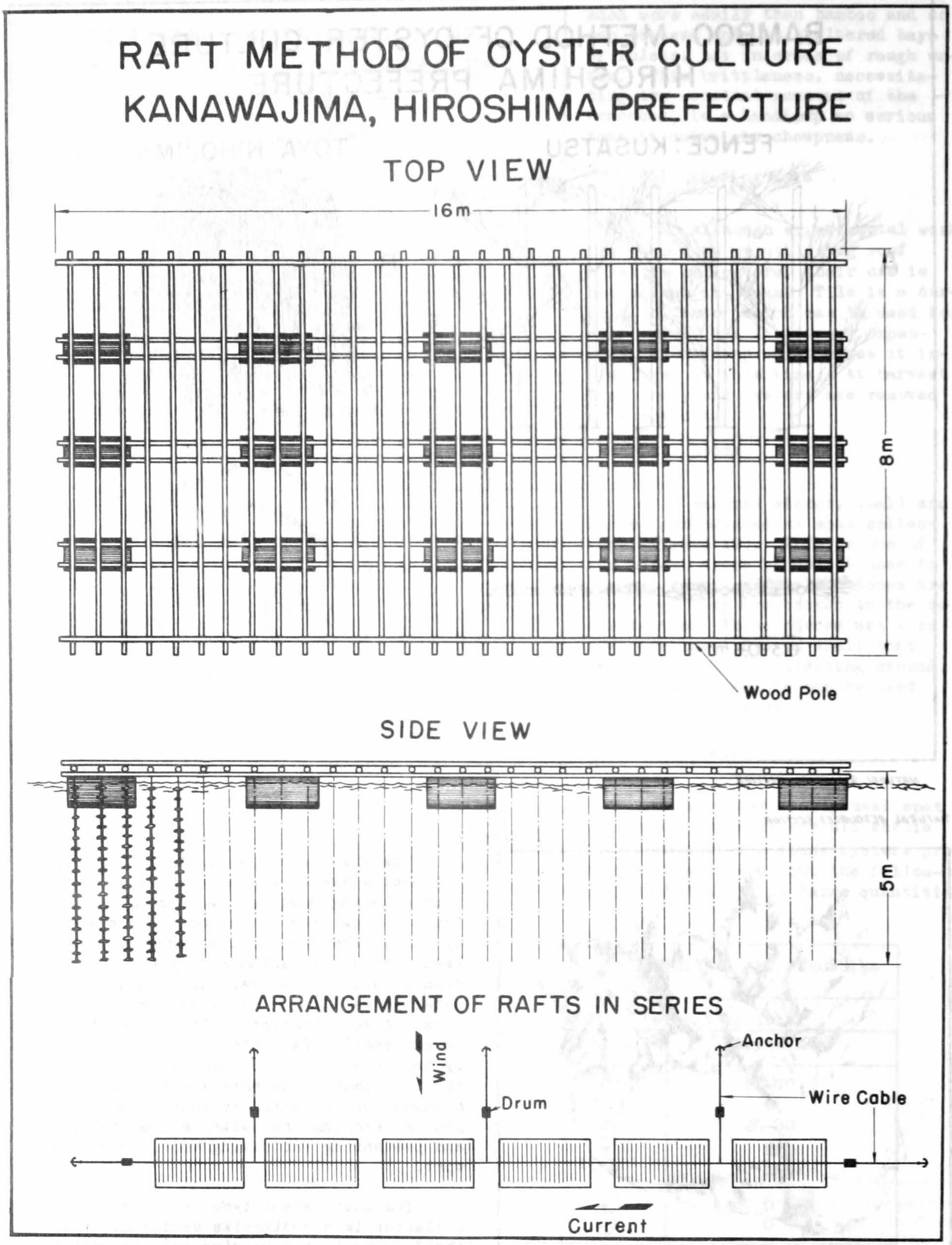


NATURAL RESOURCES SECTION

Figure 19. - Stone method of oyster culture

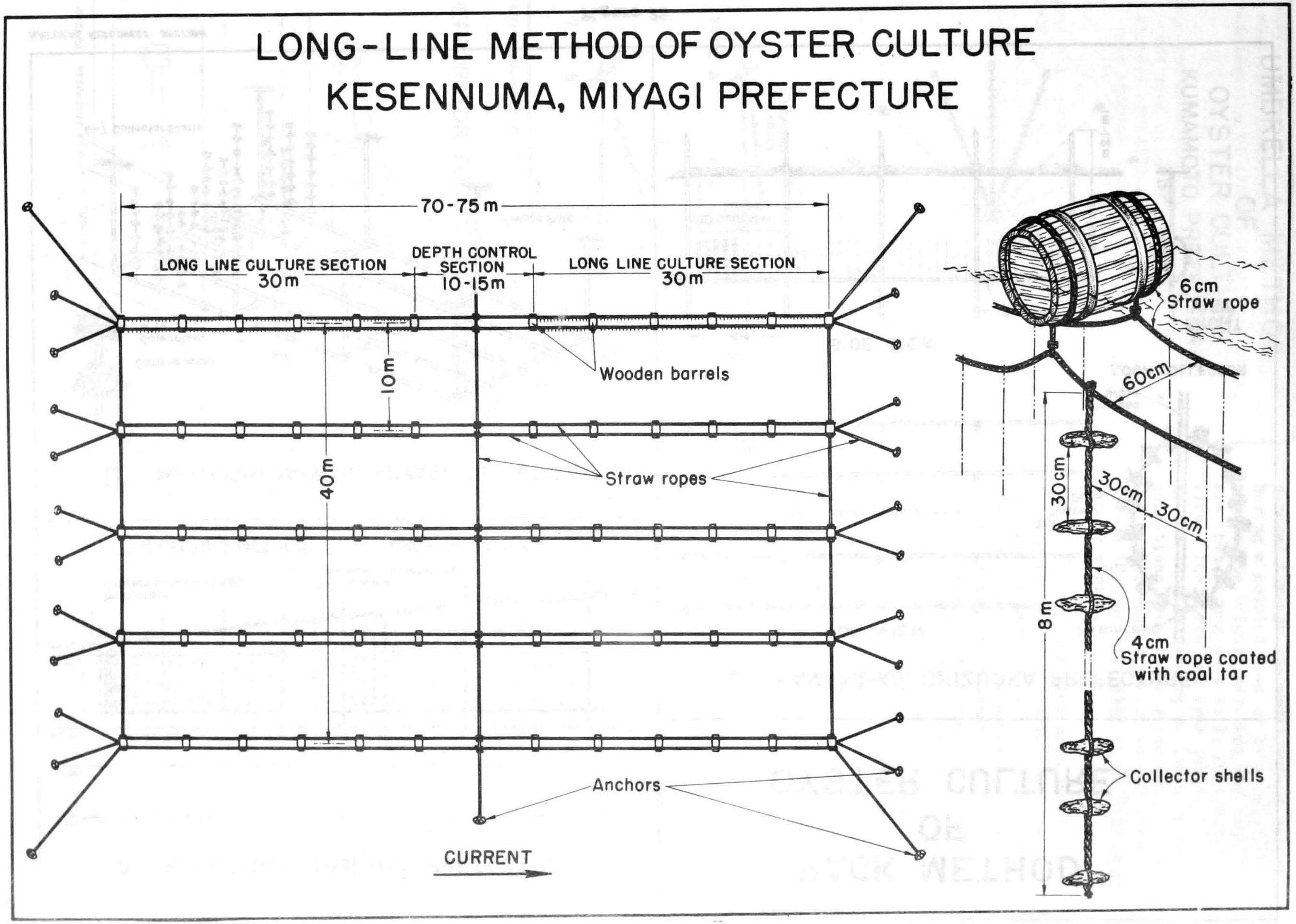
The simplest techniques for placing the shells are by sawing them broadcast from a moving boat, or by walking on the flats at low tide and spreading the shells by hand. The shell collectors, which have been used in Hiroshima and Kyushu since the dawn of oyster culture, can be used in deep water as well as on areas exposed at low tide. A modification of the method for use on extremely soft bottom has been developed by the Japanese in Formosa, where such bottom is common. Two shells are fastened to a bamboo holder which is pushed into the ground, keeping the cultch above the bottom and preventing smothering and loss of the spat.

The most recent type of commercial collector is a chain-like series of empty shells used in the hanging culture method (Figures 20,21,22, and 23). To prepare the collector shells for this method holes are



NATURAL RESOURCES SECTION

Figure 20



LONG-LINE METHOD OF OYSTER CULTURE
KESENNUMA, MIYAGI PREFECTURE
70-75 m
LONG LINE CULTURE SECTION
30m
DEPTH CONTROL SECTION
10-15m
LONG LINE CULTURE SECTION
30m
Wooden barrels
10m
40m
Straw ropes
Anchors
CURRENT
6cm
Straw rope
60cm
30cm
30cm
30cm
8m
4cm
Straw rope coated with coal tar
Collector shells

Figure 21

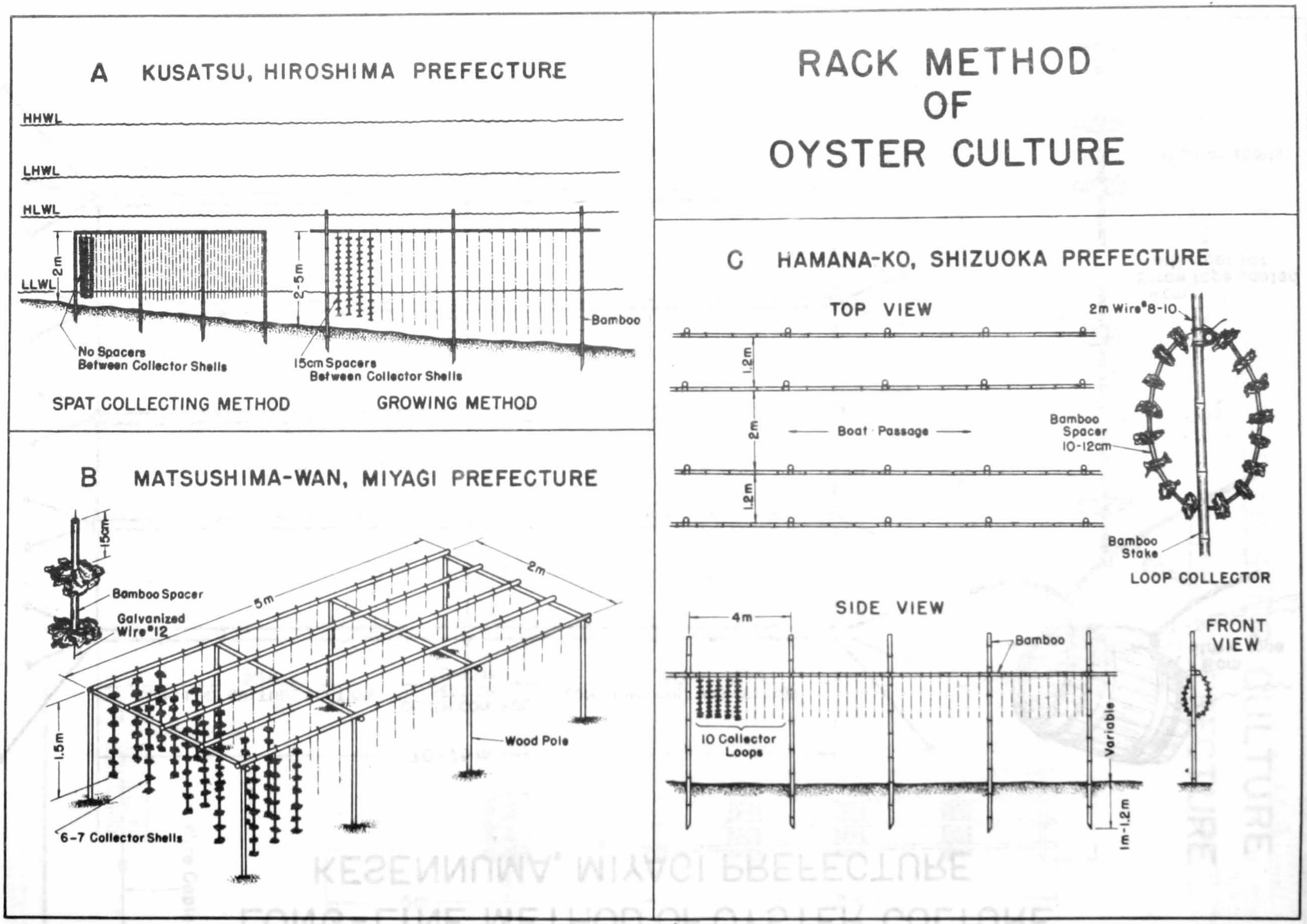
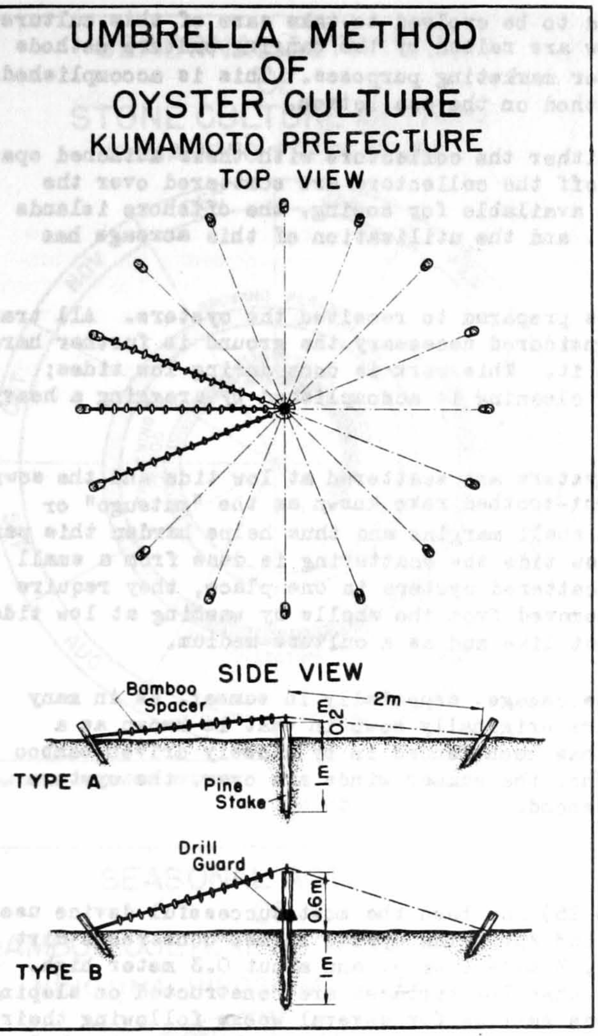
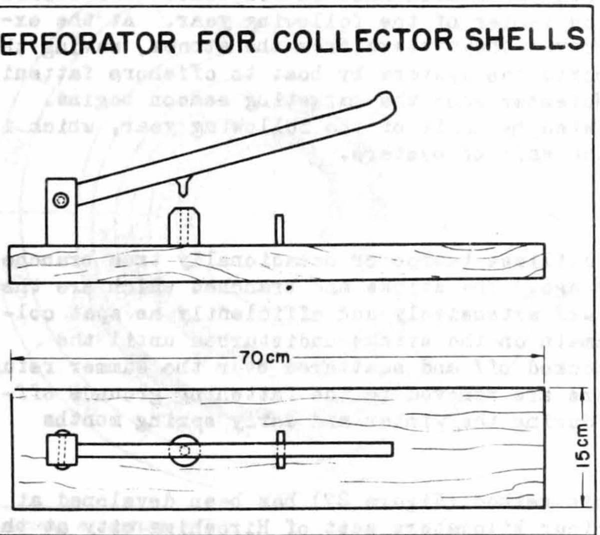

RACK METHOD
OF
OYSTER CULTURE
A KUSATSU, HIROSHIMA PREFECTURE
HHWL
LHWL
HLWL
LLWL
2m
2-5m
Bamboo
No Spacers
Between Collector Shells
15cm Spacers
Between Collector Shells
SPAT COLLECTING METHOD
GROWING METHOD
B MATSUSHIMA-WAN, MIYAGI PREFECTURE
15cm
Bamboo Spacer
Galvanized
Wire #12
5m
2m
1.5m
Wood Pole
6-7 Collector Shells
C HAMANA-KO, SHIZUOKA PREFECTURE
TOP VIEW
1.2m
2m
Boat Passage
1.2m
2m Wire #8-10
Bamboo
Spacer
10-12cm
Bamboo
Stake
LOOP COLLECTOR
SIDE VIEW
4m
Bamboo
10 Collector
Loops
Variable
1m-1.2m
FRONT
VIEW

Figure 22



NATURAL RESOURCES SECTION

Figure 23



NATURAL RESOURCES SECTION

Figure 24

punched through the shell with a hammer having a pointed nose or by a special perforator (Figure 24), and the shells are then strung on a No 12 galvanized wire. The wires are from one to six meters long, depending on local water conditions. On these wires about 70 to 100 oyster shells or 120 to 140 pecten shells (<u>Pecten laqueatus</u> or <u>P. yessoensis</u>) can be strung.

The most common method for setting this type of cultch is to place wooden or bamboo poles in the ground of the oyster seed area, spaced so that they can be connected by wooden or bamboo poles on which the strings of collector shells are fastened. This is the main method employed in Miyagi Prefecture, where large quantities of seed oysters are produced, and will be described in the section dealing with seed oyster culture. Another common method makes use of a raft similar to that used in the culture of adult food oysters, which supports the strings hung in loops from the raft.

The spat collected on shells are used in both the hanging and the sowing methods of growing adult oysters. The shell collectors have proved most convenient and practical for transport of spat in the export trade.

3. <u>Growing Methods</u>

Collecting of the spat completes the first phase of oyster culture. The second phase is the growing period, during which the young oysters are fattened for market. The various methods used in growing <u>O. gigas</u> are described as follows:

a. Sowing Culture

Sowing is the most ancient and the simplest of oyster culture methods and has been used in the Hiroshima and Kyushu districts since oyster culture began. The basic environmental qualification is that the sea bottom in the farm area be hard, because in muddy areas the shells are easily buried and lost. While sowing is a very old method, it still has its practical application even in connection with the most modern culture procedure. For example, the bamboo stick on which spat is collected is not strong enough to support the growing oysters during the entire period until they reach marketing size. Hence a rearing procedure had to be evolved to take care of this culture deficiency. Furthermore the oysters which now are raised by the hanging culture methods have a fragile shell which must be hardened for marketing purposes. This is accomplished by sowing the oysters grown by the hanging method on the sea bottom.

In the spring or early summer, either the collectors with their attached spat or the young oysters which have been knocked off the collectors are scattered over the sowing bed at low tide. To increase the area available for sowing, the offshore islands are now recommended in the Hiroshima district, and the utilization of this acreage has considerably increased the local output.

Prior to the sowing the bottom is prepared to received the oysters. All trash and accumulated debris are removed, and if considered necessary the ground is further hardened by scattering sand, pebbles, or shell on it. This work is done during low tides; where the area is not exposed at low tide the cleaning is accomplished by dragging a heavy net over the bottom.

After the bed is prepared, the oysters are scattered at low tide and the sown oysters leveled off by means of a six- or eight-toothed rake known as the "mutsugo" or "yatsugo". The raking breaks off the brittle shell margins and thus helps harden this part of the shell. If the bed is not exposed at low tide the scattering is done from a small boat. As strong wind or waves may pile the scattered oysters in one place, they require watching. At times the drifted mud must be removed from the shells by washing at low tide. Obviously the Japanese oyster culturists do not like mud as a culture medium.

In areas where strong winds cause damage, especially in summer, as in many places in Hiroshima Prefecture, the oysters are originally sown in what is known as a summer refuge. This is a prepared bed which has been fenced in by closely driven bamboo sticks which act as a wind and wave break. When the summer winds are over, the oysters are removed to a winter refuge which is not fenced.

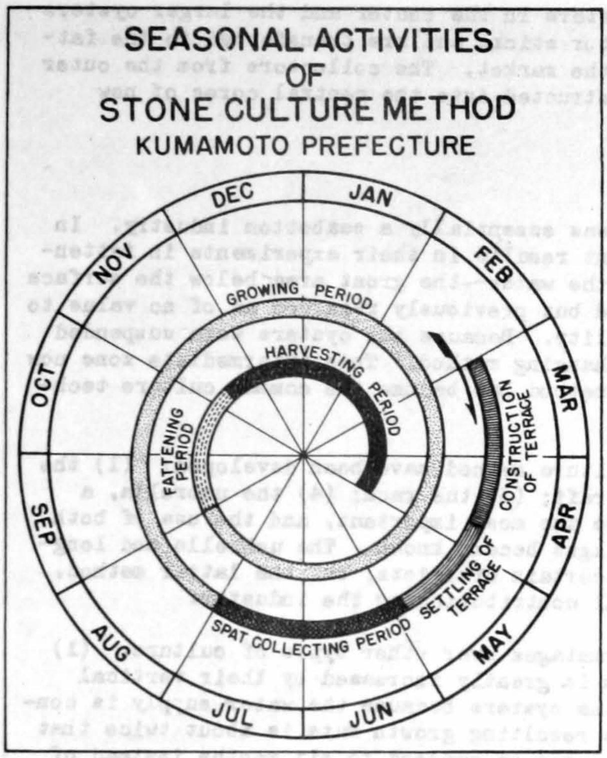
b. Stone Culture

The stone culture method (Figure 25) has been the most successful device used in Kumamoto Prefecture since 1909. In March and April the oyster farmer constructs dirt terraces, measuring from 40 to 80 meters long, 3 meters wide, and about 0.3 meter high. This is done at low tide in much the same way that low terraces are constructed on sloping agricultural land. The surface of the terraces settles for several weeks following their construction. From early June through July the farmer scatters stones bearing attached spat over these submerged terraces as he follows their main axes in his boat. The stones are left on the terraces as they fall, until September of the following year. At the expiration of this growing period the farmer removes the oysters from the stones, saving them for future use in spat collecting. He transports the oysters by boat to offshore fattening grounds, where the oysters remain until mid-November when the marketing season begins. Final harvest and marketing usually are completed by April of the following year, which is the beginning of the legal closed season on the sale of oysters.

c. Bâmboo Culture

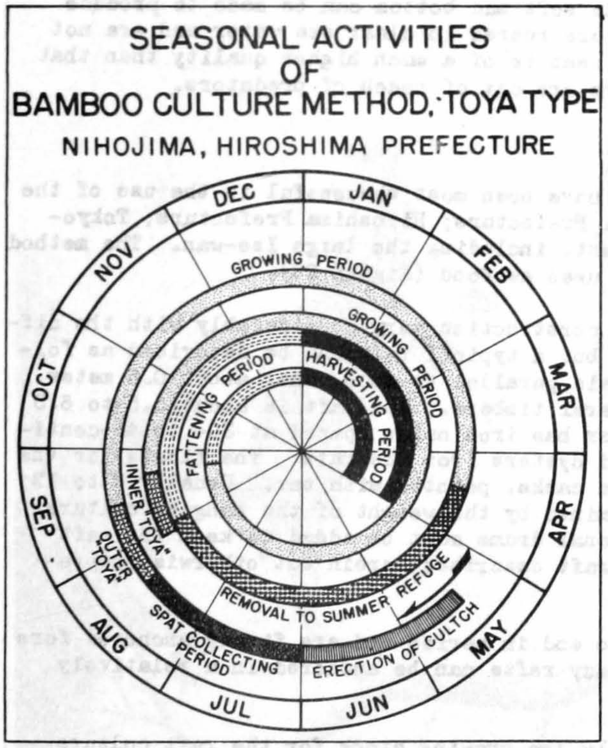
The bamboo culture method which utilizes bamboo or occasionally tree branches, began in Hiroshima Prefecture about 300 years ago. The sticks and branches which are the basis of this method (Figure 18A) are those used extensively and efficiently as spat collectors. The young oysters are allowed to remain on the sticks undisturbed until the spring following collection, when they are knocked off and scattered over the summer refuge area at low tide. In mid-September the oysters are removed to the fattening grounds offshore, and they are marketed as food oysters during the winter and early spring months (Figure 26).

A more complicated version of this method (Figure 27) has been developed at Nihojima, Hiroshima Prefecture. Nihojima is four kilometers east of Hiroshima city at the mouth of the Enkoh-gawa. Here the oyster culture grounds are composed of spat collecting, growing, and fattening areas. Only the spat collecting grounds are outside the mouth of the river, the other two areas being within the river mouth. From May to July the bamboo branches are stuck in the ground in clusters of four or five over the spat collecting areas. These sticks are about 1.5 meters long and 2.5 centimeters in diameter. By the end of August these collectors are well covered with spat, and they are then removed and used in the construction of the toya (literally "chicken house"). One type of toya is round and the other is rectangular, but the method of construction is the same. The round toya is a group of spat-covered bamboo collectors measuring about 1 1/2 meters high and 2 meters in diameter at the base (Figure 18B). In the center is a group of old bamboo collectors bearing oysters collected the previous year. Outside this core and arranged in two circles around it with branches interlacing, are placed the new bamboo collectors which have just received their spat on the collecting ground. About 360 circular toya are placed on an acre of oyster ground.



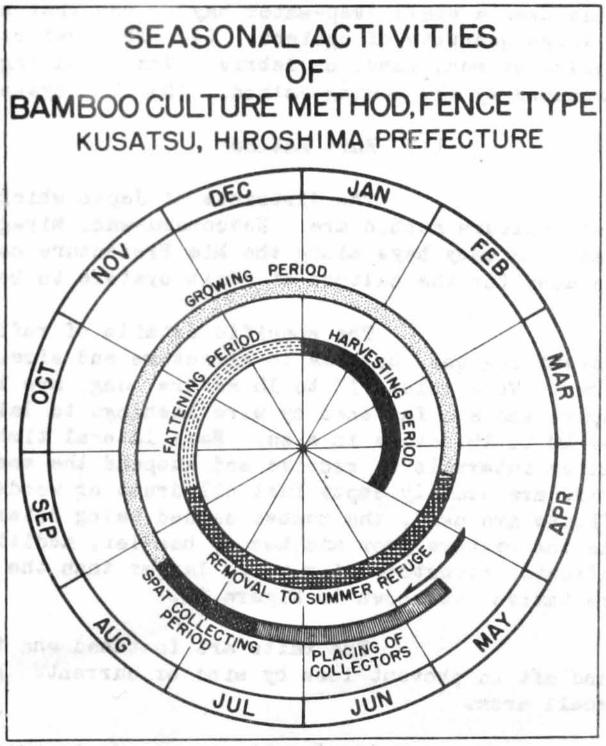
NATURAL RESOURCES SECTION

Figure 25



NATURAL RESOURCES SECTION

Figure 26



NATURAL RESOURCES SECTION

Figure 27

Approximately a year later, the oysters in the center and the larger oysters in the outer circles are knocked off the collector sticks and are transferred to the fattening ground to be sold at the proper time on the market. The collectors from the outer circles, bearing the smaller oysters, are reconstructed into the central cores of new toyas and remain thus for another year.

d. Hanging Culture

Until 1923 the culture of oysters was essentially a seabottom industry. In that year Seno and Hori (1927) obtained excellent results in their experiments in fattening oysters by utilizing the middle stratum of the water--the great area below the surface and above the bottom--abundant in available food but previously regarded as of no value to the oyster culturist because of its inaccessibility. Because the oysters were suspended vertically, the new method became known as the hanging method. This intermediate zone now has been utilized extensively, and the hanging method has become the common culture technique in Miyagi Prefecture.

Four adaptations of the hanging culture method have been developed: (1) the raft; (2) the long-line, a modification of the raft; (3) the rack; (4) the umbrella, a modification of the rack. The raft and rack are the most important, and the use of both spread rapidly throughout Japan as their advantages became known. The umbrella and long-line are confined to small-scale operations in certain districts, but the latter method, the newest of all, gives promise of being a real contribution to the industry.

The hanging method has certain advantages over other types of culture. (1) The crop of oysters per unit area of sea bottom is greatly increased by their vertical suspension. (2) More food can be ingested by the oysters because the water supply is continuous (there are no low tide exposures). The resulting growth rate is about twice that obtained by other methods, so the culture period can be reduced to six months instead of the year necessary for equal growth by the "ground" methods. (3) The farmer can culture his oysters without regard to the physical condition of the seabottom or water depth. Thus even a small deep-water bay or one that has soft mud bottom can be made to produce a large quantity of oysters. (4) The oysters are reared in clear sea water and are not fouled by mud, sand, or debris. The resulting meat is of a much higher quality than that produced by the sowing method. (5) The oysters are out of reach of predators.

(1) Raft Method

The districts of Japan which have been most successful in the use of the raft culture method are: Kesennuma-wan, Miyagi Prefecture; Hiroshima Prefecture; Tokyo-wan; and many bays along the Mie Prefecture coast, including the large Ise-wan. The method is used for the culture of adult oysters to be used as food (Figure 28).

The specific details of raft construction vary considerably with the different regions, both as to structure and size, but a typical raft can be described as follows: Wood poles, 10 to 15 meters long, are laid parallel to each other about 0.5 meter apart and are fastened by wire lashings to lateral timbers. The raft is about 5.5 to 6.5 by 10 to 16 meters in size. Each lateral timber has iron nails spaced at 30- to 45-centimeter intervals to receive and suspend the seed oysters from the raft. The floats for the raft are usually empty fuel oil drums or wooden casks, painted with tar. Usually 8 to 12 floats are used, the number needed being determined by the weight of the hanging culture. As the oysters grow and become heavier, additional drums must be added to keep the raft afloat. Structure of a raft, larger than the raft described herein but otherwise representative, is shown in Figure 20.

The rafts are fastened end to end in series and are firmly anchored fore and aft to prevent loss by wind or current. Many rafts can be anchored in a relatively small area.

Spat collectors used to supply the growing stock for the raft culture method consist of strings of collector shells. Each collector shell is separated from the next in series by a bamboo tube 10 to 15 centimeters long, known as a "spacer". The shells

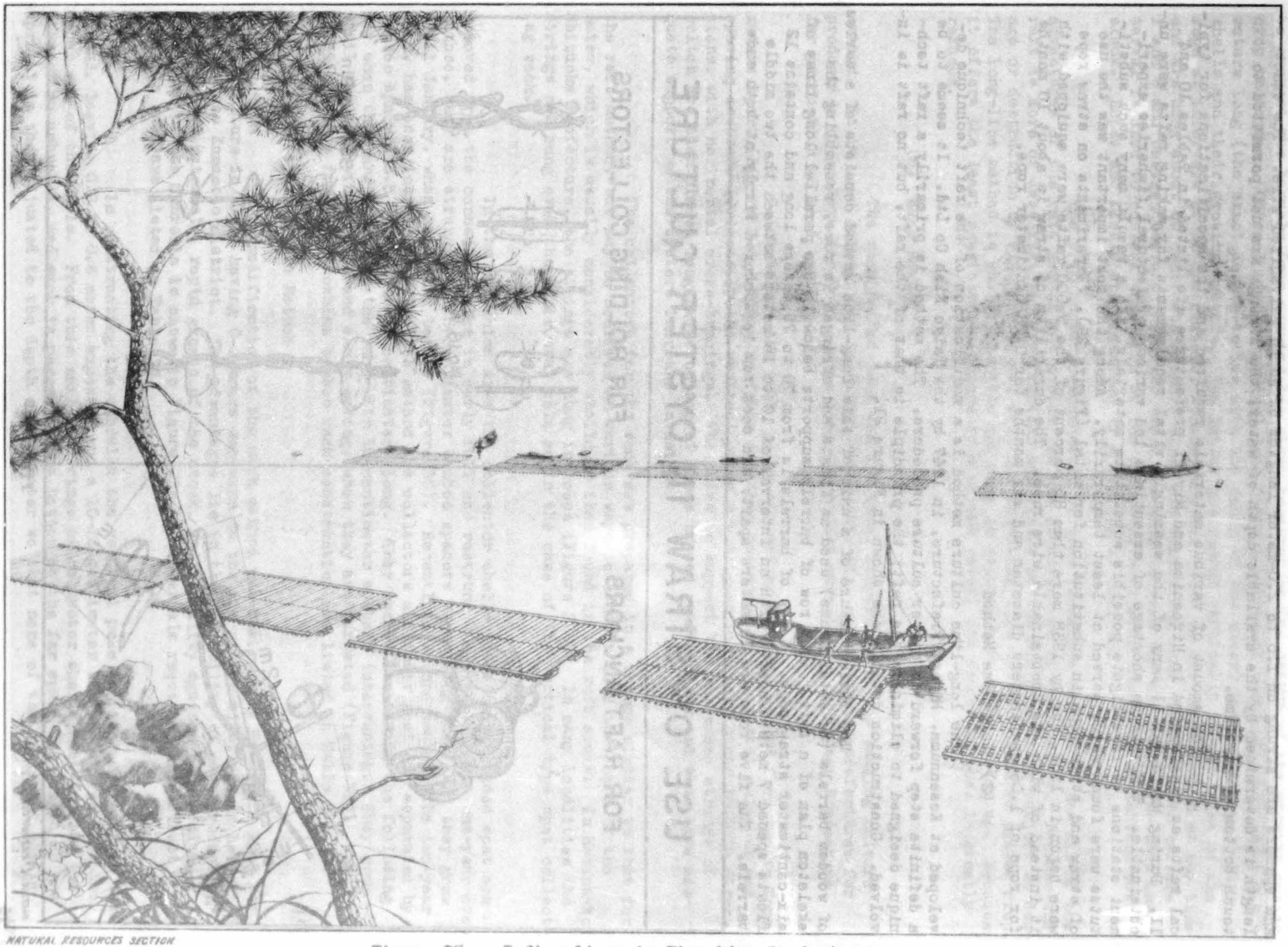


Figure 28. - Raft culture in Hiroshima Prefecture

and spacers are strung on 1.5 to 2.0-meter lengths of No 12 galvanized wire. The exact length is determined by the available depth of water; the strings are not permitted to touch bottom at any time.

The amount of various materials required and the specifications for typical rafts as constructed in Hiroshima and Miyagi prefectures are listed in Tables 10 and 11. During World War II many of the seemingly vital requirements for making rafts were unobtainable. The extreme shortage of essentials led various prefectural fisheries experiment stations to investigate possible substitute materials. As a result many such substitutes were found which served at least temporarily. Among the most important was the use of straw and straw rope in substitution for metal (Figure 29). Experiments on straw rope were begun in 1932, and by 1938 more than 80 percent of the 5,000 rafts were equipped with it instead of with the unobtainable wire rope. The durability of straw is about 10 months for rope of 1.06 centimeters diameter and six months for 0.76-centimeter rope.

(2) Long-Line Method

The long-line culture method is a modification of the raft technique developed at Kesennuma, Miyagi Prefecture, in 1947 by the Taiyo Fish Co Ltd. It seems to be a definite step forward in oyster culture procedure. The method is primarily a raft technique designed to eliminate the raft; the principle is that of the raft, but no raft is involved. Construction details are shown in Figure 21.

The basic feature of a unit of this long-line method consists of a series of wooden barrels (or metal drums) used as floats and arranged in rows, resembling the skeleton plan of a raft. Each row of barrels supports below it two parallel long lines of six-centimeter straw rope. A row of barrels is from 70 to 75 meters long and contains 12 floats spaced 7 meters apart, with an interval of 10 to 15 meters between the two middle barrels. The five rows are 10 meters apart; and each row is anchored firmly at both ends

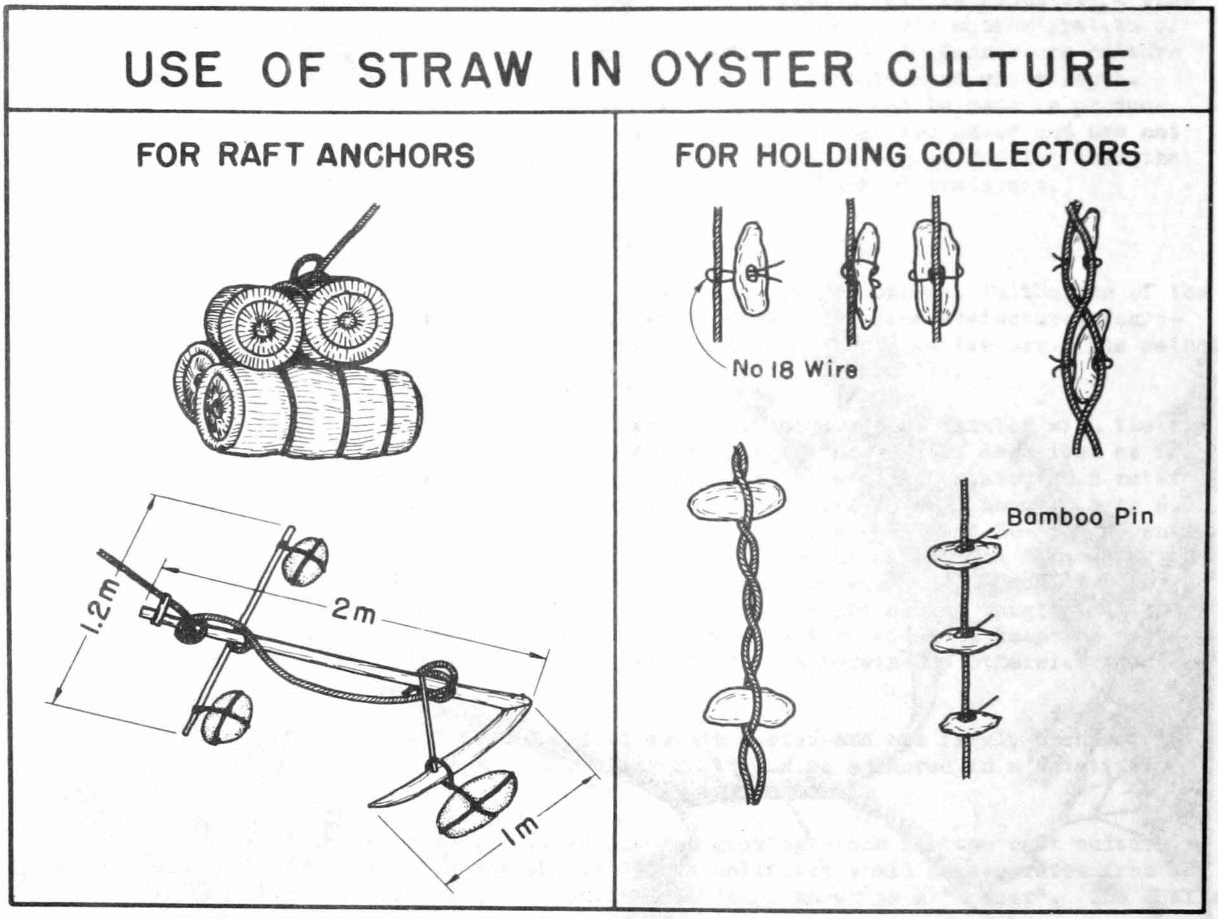


Figure 29

to prevent the barrels from drawing too close together as the weight of the growing oyster crop increases. On each of the parallel long lines a series of vertical ropes about 7.5 meters long (the exact length varies with the depth of the water) suspend the collector shells and their growing oysters. The latter are spaced vertically in the twist of the rope at intervals of 30 centimeters. These vertical lines do not touch bottom at any time and are hung about 30 centimeters apart along the supporting long lines between barrels 1 and 6 and between barrels 7 and 12. None are hung between barrels 6 and 7 as this interval is used to control the depth of the collector shells by taking in or letting out slack. Ropes and floats are preserved by a coating of coal tar.

The principal recommendation of this technique is that it has all of the advantages of the raft method and avoids the one disadvantage of that method. Because the raft is more or less rigid in construction and floats on the surface, it is subject to damage or destruction by wind and waves, with the resulting loss of the suspended oyster crop. The long-line method is wholly flexible and uses no exposed raft to be broken up. Because it offers the least possible resistance to wind and waves, the danger of loss is greatly reduced.

(3) Rack Method

The rack method is a shallow-water adaptation of the hanging culture method. It is used extensively in Miyagi, Shizuoka, Mie, and Hiroshima prefectures for production of oysters for food and is also the common method used in Miyagi Prefecture for production of seed oysters.

To construct the rack, poles are driven into the ground from two to four meters apart (Figure 22). These uprights are then connected by horizontal poles at any spacing desired. Ordinarily the vertical poles are aligned with each other in both directions, with horizontal cross-bracings. The poles to support the suspended strings of cultch are then placed lengthwise on top of these braced scaffoldings and thus have adequate support as the oysters increase in weight.

The collectors for the rack are prepared in a manner similar to that for the raft method, but may be modified in various ways to conform with the depth of the water, which is usually considerably shallower than found in the raft areas. In Hamana-ko, Shizuoka Prefecture, the strings are hung in loops (Figure 22C). In many localities the strings are hung over the horizontal pole as in the case of the vertical type spat collecting rack.

In the Hiroshima area the collector shells with their crowded spat are removed from the connecting wire in early fall and restrung on wires. In the one-year crop method, they are strung with 15-centimeter bamboo spacers separating them, and they grow until January, when marketing begins (Figure 30). Recently a second method, the two-year crop, has been introduced. By this method the collectors and their spat are separated by bamboo spacers 2.5 instead of 15 centimeters long. They remain thus until the following May when they are rehung on the rack with 15-centimeter spacers intervening. They grow until the following winter and early spring, when they are marketed (Figure 31). The specifications for the Hiroshima bamboo rack construction are listed in Table 12.

(4) Umbrella Method

This modification of the rack method was designed by Mr Ota in 1946 for oyster culture in areas having 0-3 hours exposure to the air at low tide. It is being used in the Kumamoto district. The advantages lie in the possibility of mass production with limited materials, rapid growth of the stock, and stability against wave action. Structure of the umbrella is shown in Figure 23; the materials required to construct one umbrella rack are listed in Table 13.

In constructing the umbrella the vertical pole is first driven into the ground, leaving 0.2 to 0.6 meter exposed, and a 10-12 centimeter nail is driven into the upper end of this pole. From this nail 16 strings of collector shells radiate like the ribs of an umbrella, and each is pegged to the bottom at the far end. The length of the upright is then adjusted to the depth of the water so that none of the collector shells

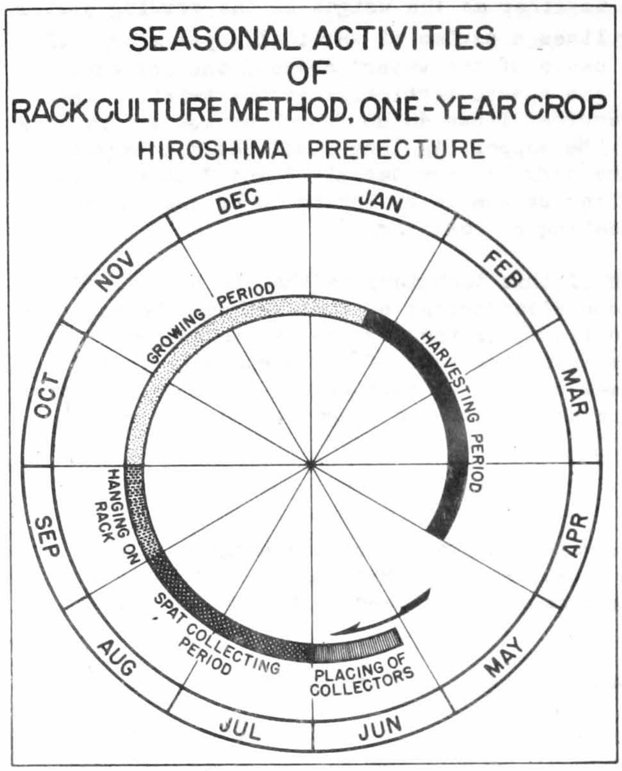


Figure 30

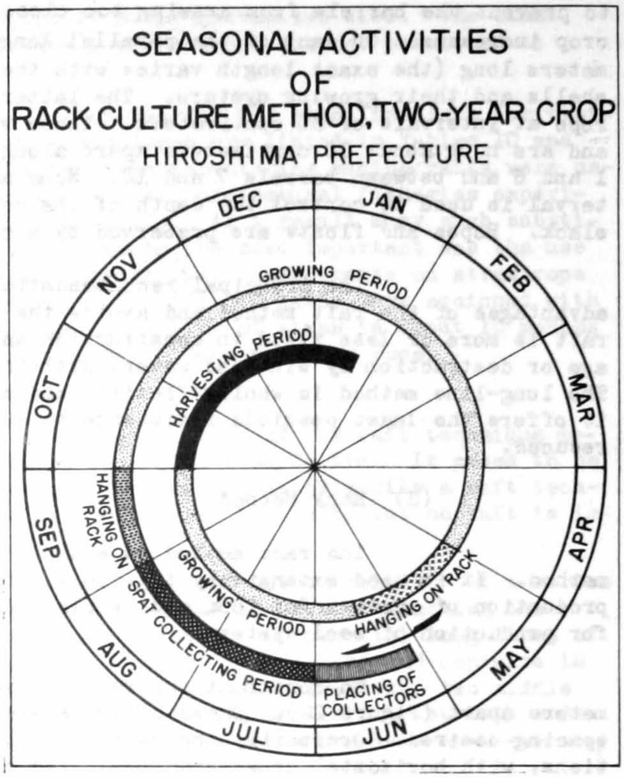


Figure 31

touch bottom. To prevent damage by oyster drills, a metal drill guard is attached to the upright near its base (Figure 23B), and chestnut burrs can be used near the far end of the radii, thus preventing access by the injurious gastropods.

4. Seed Oyster Culture

The methods used for production of seed oysters are in general similar to those used for production of oysters for food, but they have been adapted to put the young oysters through a hardening period which will enable them to stand shipment.

a. Miyagi Method

The production of seed oysters in Japan centers in Miyagi Prefecture and specifically in Matushima and Mangoku-ura area of Ishinomaki-wan.

In early April, preparations are begun for collecting the spat (Figure 32). The empty shells of oysters (O. gigas) and various other marine mollusks (Chlamys laqueatus, C. yessoensis, Haliotis kamtschatkana, Chlamys farreri) are strung on wires 1.5 meters long, 70 to 100 collector shells per wire (Figure 33). Such a sequence thereafter is known as a "string" or a "string of cultch", called "ren" by the Japanese. Unlike strings prepared for food oyster culture, the collector shells are not separated by bamboo spacers.

While the strings of cultch are being prepared, racks and rafts of horizontal poles are constructed in areas where spatting or setting of oysters is known to occur. About mid-July, when the spat are known to be ready to set, the collector strings are dropped over the horizontal poles of the racks or suspended from the rafts. Care is taken to see that the tips of the strings of cultch are clear of the bottom by at least 0.25 meter at all times. This precaution excludes oyster drills from the collectors because the drills are not free-swimming at any stage of their life cycle.

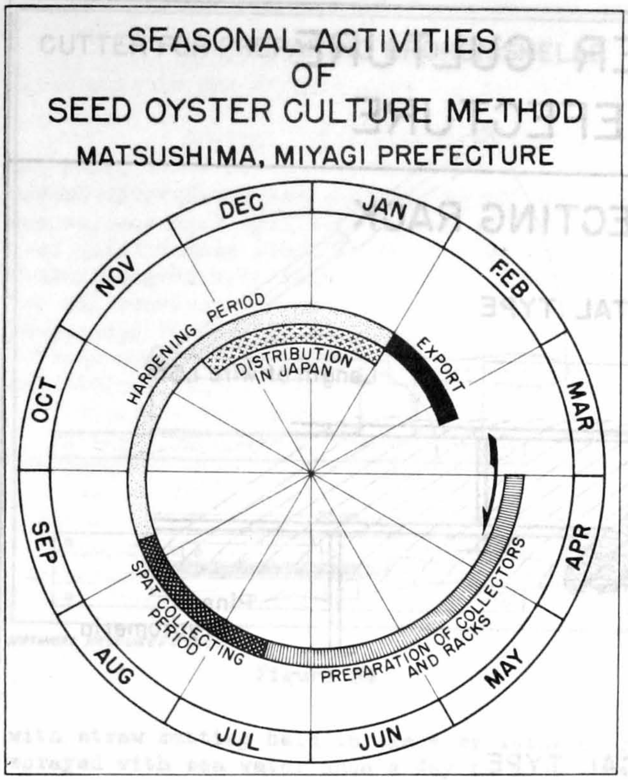


Figure 32

In early September the strings of cultch are removed from the supports and are distributed horizontally on specially constructed grids high in the intertidal zone where they are exposed to the air for many hours a day during ebb tides. Here the spat are "hardened" by exposure to conditions quite unfavorable to them. By this process the young oysters are under water (and hence active) for only a few hours a day. The result is the survival of only the strongest individuals; the weak oysters die. The strong survivors are stunted in their growth because of the unfavorable conditions and the shortage of food, but those that survive develop a strong, thick shell having an almost gasket-like seal which enables them to retain the sea water between the closed valves during a long period of exposure. Oysters not so hardened grow rapidly and develop thin, fragile shell edges which will not withstand shipment and which do not have the required watertight seal. Both the stunted size and the heavy watertight shell are essential to ensure survival during slow transpacific shipment. The hardening process continues from early September to February when export to America occurs.

For local use within Japan the hardening process is shorter and simpler because the time and distance elements are less extreme. Furthermore drills are generally distributed over all the oyster grounds in Japan, so the precautions required for export to prevent the access of drills to the cultch are not necessary for local culture. Therefore the methods used to avoid contact by the strings with the bottom are not attempted. Often the strings of cultch are simply laid on the sea bottom in the upper tidal zone. The distribution of spat for domestic use begins in the middle of November and continues through January.

A few days before the arrival of the vessel on which the seed for export is to be shipped, the strings of cultch are removed from the grills and taken to the seed-packing center. Here the wires are cut, and the collector shells bearing the spat are placed in baskets, washed in sea water, and dumped on sorting tables. Women examine both sides of each shell to make sure that more than 10 spat of the desired size are present. The export requirements set up by the Pacific Coast Oyster Growers Assn specify a minimum of 10 spat having a diameter between 6 and 15 millimeters per collector shell. At the same time they are examined for the possible presence of drills or other oyster pests. In the meantime wooden packing cases 36 x 18 x 12 inches, with a center cross partition, are prepared as shipping containers.

Collector shells are shipped in two forms: unbroken and broken. Unbroken shells, after being inspected and approved, are placed in the packing cases whole. If broken shells are desired the collector shells are cut transversely into two or three pieces, depending on the size of the shell, by an apparatus resembling a paper cutter (Figure 34). Each piece of cut shell having a minimum of five spat is then packed. The broken shell method of shipment is preferred by oyster growers having oyster beds which are neither muddy not affected by swift tides or storms. These cut shells provide small clumps of oysters which require no further separation after planting, thus reducing labor costs, and give more seed per case. A case of broken shell contains about 1,900 pieces of shell bearing 18,000 to 20,000 spat and weighing about 165 pounds. The unbroken collectors are desired by farmers having oyster beds with soft bottoms into which the larger unbroken

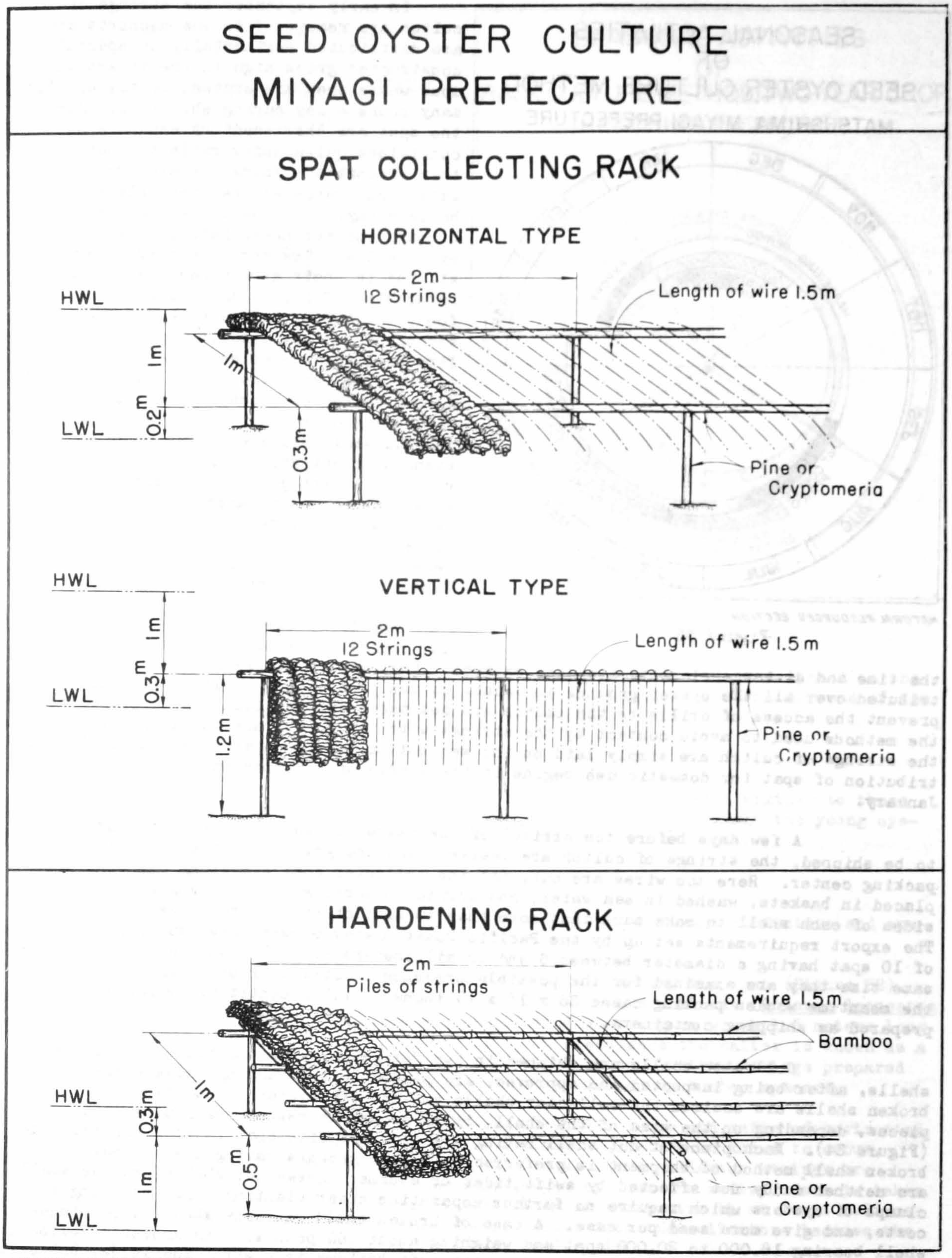


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Figure 33

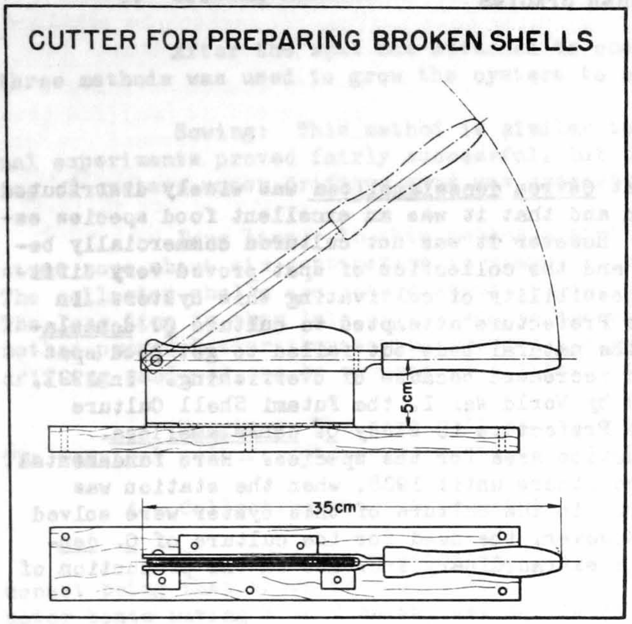

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Figure 34

shells do not sink so readily; they are preferred also in areas of swift current and storms where the smaller fragments would be carried away more easily. A case of unbroken seed collectors contains about 12,000 spat and weighs about 110 pounds.

If the period of storage prior to loading the ship is longer than three days, the packed seed and containers are returned to the intertidal zone and placed on the grids which keep the cases at least six inches above the bottom and safe from enemy attack. The seed can be held safely in this manner for at least two weeks; even four weeks' holding has proved not injurious to the spat.

Aboard the ship broken and unbroken seed are stored separately. Dunnage at least one inch thick is placed on the deck and the cases stacked in layers on this, the layers being separated by 1/2-inch laths to provide ventilation. The top layer is covered with straw matting held in place by laths to reduce evaporation. The seed oysters are sprayed with sea water once a day to keep them moist. The mats must be kept moist but not wet.

b. Kumamoto Method

The export of seed oysters from Kumamoto Prefecture began in 1946 through the Kumamoto Fisheries Assn which exported seed on a small scale to America and Australia. The important culture grounds are located in the mouths of the many rivers that flow to the sea in this area, especially along the coast of Ariake-kai.

The season for collecting spat extends from April to October, but mid-May is the best for the purpose. The spat are collected by two methods: (1) the horizontal (Figure 33) and (2) the umbrella (Figure 23). The principal difference between the Kumamoto and Miyagi methods is that in Kumamoto straw mats are used successfully to cover the racks to reduce the otherwise severe attack of barnacles. This practice will be discussed in the section dealing with oyster enemies. The hardening process is similar to that used at Miyagi, but for the purpose of export to Australia the height of the hardening racks above the sea bottom is raised twice, once in mid-June and again in mid-July. This is done in order to harden the oysters sufficiently so that they can withstand the higher air temperatures of the Australian region when exposed at low tide.

c. Hiroshima Method

In Hiroshima Prefecture, the western half of the coast around the city of Kure is suitable for collecting spat and for the growth of oysters but the eastern half is suitable only for growth purposes. The seed oysters collected in the western part by the rack method (Figure 22) are transplanted to the farms in the eastern part. This is done by the Hiroshima Fisheries Experimental Station. No seed oysters have yet been exported to the United States from Hiroshima.

1. Ostrea denselamellosa

a. History

The Japanese long have known that Ostrea denselamellosa was widely distributed along the warm current coastal areas of Japan and that it was an excellent food species especially desirable as a "half-shell" oyster. However it was not cultured commercially because it inhabited comparatively deep water and the collection of spat proved very difficult. T. Fujita (1886) first suggested the possibility of cultivating this oyster. In 1914 and 1915 a few fishing villages in Hyogo Prefecture attempted to culture O. denselamellosa by scattering collector shells over the natural beds but failed to get good spat survival. The natural oyster production then decreased because of overfishing. In 1921, under the influence of food shortages created by World War I, the Futami Shell Culture Experimental Station was established in Hyogo Prefecture to study O. denselamellosa. Futami was known to be the best natural production area for the species. Here fundamental studies were made by Seno, Seki, Kusakabe, and others until 1938, when the station was abandoned. Many of the basic problems involved in the culture of this oyster were solved at this station and the results published. However, the need for the culture of O. denselamellosa steadily diminished because of the extraordinary increase in the production of O. gigas by the new hanging culture methods.

b. Spat Collecting

The spawning season of this species extends from June to September when the water temperature ranges from 19° to 23°C, and the young, incubated within the mantle cavity of the parent, are liberated into the sea as free-swimming larvae. Three weeks after hatching these larvae sink to the sea bottom; they are then about 0.37 millimeter in length. When they attain a length of 0.40 millimeter they attach themselves to solid objects on the bottom such as shells (Ostrea, Anomia, Solen, Mactra are the commonest utilized), wood, stones, concrete blocks, tile, glass, and other solid materials. Both shell and tile are excellent for attachment of spat, but bamboo, which is well-suited for the attachment of O. gigas spat, has been found to be unsuitable for the spat of O. denselamellosa.

Experiments carried on in Hyogo Prefecture by Seki and Tanaka (1931) showed that the number of spat is greater near the bottom than at higher levels. The following collectors for spat of O. denselamellosa have been tried, but none has been used extensively.

Stone and Shell: Collecting spat on stones and shells was suggested by Fujita as early as 1886 and actually practiced with some success in Hyogo Prefecture (Seki and Tanaka, 1931). The collector stones or shells were scattered on the natural oyster beds, the spat which attached to them were cultured either by leaving them on the bed or by artificial methods similar to those employed with similar cultch in rearing O. gigas. The amount of spat gathered was, however, never satisfactory.

Tile: Seki and Tanaka (1931) collected 115,000 spat on 48 tile collectors which measured 30 by 30 centimeters. The assembled collector consisted of 48 tiles each measuring 6 x 5 x 1.8 centimeters, attached by wire to a concrete disc 64 centimeters in diameter and 12 centimeters thick. The tile plates were separated by four knobs, two centimeters high, moulded on one face of the tile. This separation gave the dark-seeking spat access between the plates. The entire assemblage weighed 245 kilograms.

Wire Netting: Seki and Tanaka also designed a collector consisting of a box made of wire netting measuring 60 x 60 x 60 centimeters, containing 5,700 shell collectors. The wire box was attached to a concrete disc as described for the tile collector method, the entire assemblage weighing 210 kilograms. Tanaka (1934) substituted wood chips coated with coal tar for the shell collectors, and this was found to be more practical because the chips were merely waste material from match-box manufacture and wooden ship construction.

c. Growing Methods

After the spat has attached to one of the various forms of cultch, any one of three methods was used to grow the oysters to marketable size.

Sowing: This method is similar to that used for O. gigas. Some of the original experiments proved fairly successful, but the loss owing to predators and the smothering of oysters under drifting sand was excessive.

Long Line: In this method a string of collector shells is fastened to a long straw rope about six centimeters in diameter, as used in the long line fishing methods. The collector shells are spaced about 10 centimeters apart by the use of bamboo spacers. The long line is then laid on the sea bottom and weighted so as to prevent drift. This method proved better than sowing because the collector strings are not lost by burial in drifting sand and can be removed or shifted when desired.

Hanging: The same raft and rack methods used in culturing O. gigas were used. The vertical culture methods produced better growth than culturing on the sea bottom.

d. Collecting Methods and Gear

The oysters are gathered by means of dredge nets of several types, the commonest being that shown in Figure 35. In the Ube district of Yamaguchi Prefecture small motor boats having 3 to 8 horsepower motors are used to drag the nets. Each boat is equipped with one dredge which is handled by a crew of two fishermen. From 12 to 25 pounds of oysters are caught in about half an hour of dredging, and a day's operation

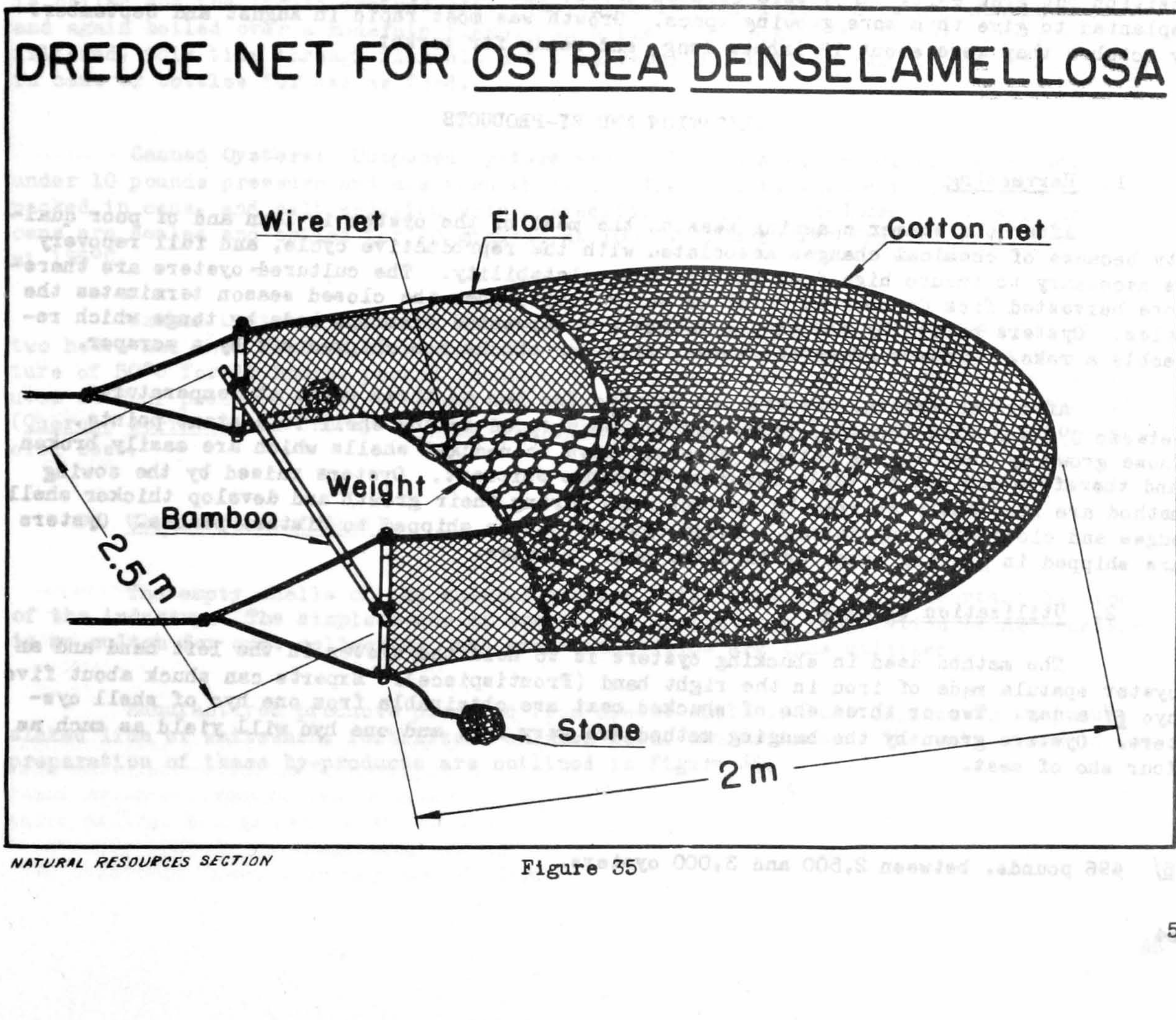

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Figure 35

yields anywhere from 230 to 460 pounds of oysters per boat. The fishing season extends from December to March. Of the total production during this period, 40 percent is obtained during December, 30 percent during January, 25 percent during February, and 5 percent during early March.

2. Ostrea rivularis

Ostrea rivularis is found in Ariake-kai and Yatsuchiro-wan, Kyushu, and along the western coast of Korea. Locally it is distributed in places of comparatively low salinity and at a depth sufficient to insure that it is not exposed at low tide. It is most abundant in the inner parts of Ariake-kai, Fukuoka and Saga prefectures.

A primitive system of culture has been developed for this species at the mouth of the Suminoe-gawa, Ariake-kai. The natives had followed the custom of gathering all the natural oysters possible and storing the larger individuals for a short time on the bottom of the Suminoe-gawa, to be shipped at the proper season for sale in Nagasaki. For some reason during the winter of 1884 these oysters were not gathered according to schedule. The following year it was found that they had added a very considerable amount both in size and weight. From this beginning a new type of culture was evolved to meet local conditions, and the industry developed a production of 357,435 sho of oysters in 1897.

The method employed was simple. Young oysters about 3.5 centimeters in length were gathered from every possible growing place from July until March and were placed on oyster beds in the mouth of the river. To prevent their being lost they were heaped close together in masses. They were washed and cleaned two or three times each month at low tide. In April the individual oysters were stuck in the mud almost vertically, hinge down and ventral margins uppermost. As the mud was very firm, the oysters not only kept this position but grew well. They were cleaned often, and as they grew they were thinned and replanted to give them more growing space. Growth was most rapid in August and September. By October they were about 12 inches long, and ready for market.

UTILIZATION AND BY-PRODUCTS

1. Harvesting

After the summer spawning season, the meat of the oyster is lean and of poor quality because of chemical changes associated with the reproductive cycle, and full recovery is necessary to insure high food quality and palatability. The cultured oysters are therefore harvested from October to March or early April, when the closed season terminates the sales. Oysters raised by the sowing method are harvested from the beds by tongs which resemble a rake. Oysters grown on stones, tile, or sticks are chipped off by a scraper.

After harvesting, oysters can survive for two to three weeks at temperatures between 0°C and 13°C (Tamura, 1931) and can be shipped in the shell to distant points. Those grown by the hanging method, however, have thin-edged shells which are easily broken and therefore are not suitable for long-distance shipment. Oysters raised by the sowing method are frequently stirred by an iron rake during their growth and develop thicker shell edges and closer-fitting valves. These oysters can be shipped to distant places. Oysters are shipped in packing boxes or in straw bags or bales.

2. Utilization of Meat

The method used in shucking oysters is to hold the oyster in the left hand and an oyster spatula made of iron in the right hand (Frontispiece). Experts can shuck about five hyo 6/ a day. Two or three sho of shucked meat are obtainable from one hyo of shell oysters. Oysters grown by the hanging method are very fat, and one hyo will yield as much as four sho of meat.

6/ 496 pounds, between 2,500 and 3,000 oysters.

Formerly shucked oysters usually were shipped in wooden barrels, but now they are packed in zinc cans having a capacity of from one to four gallons. When shipped by train, express freight is used and oysters can travel from market where they are shipped to distant consumers overnight. Flat boxes having closely laced lattice bamboo bottoms were utilized in the past for marketing shucked oysters, each having a capacity of 1.05 pints. However, in order to avoid bacterial contamination, oysters are now sold in cans. The quality of the contents also is greatly improved, for the juices which were lost in the latticed boxes are retained in the new method. Oysters in these cans, if kept cool, remain in good condition for four or five days.

In Japan most of the oysters are eaten raw, but processed products also are prepared. These include dried oysters, oyster extract, oysters soaked in sweet rice wine and then dried, canned oysters, and smoked oysters.

Dried Oysters: For 60 kan of shucked oysters, two sho of salt are used, the oysters being soaked overnight in this salty liquid to shrink the meat. The juice is then removed and the oysters are washed in fresh water, drained in a basket, boiled for about 20 minutes, and again drained on a latticed bamboo sheet. They are then dried slowly for two to three days. The juice which was removed is utilized to make oyster sauce ("shoyu"). Its bulk is reduced one-half by heating; eight percent salt is added, and the juice is again condensed to one-half its volume. After filtration through flannel it is put up in sealed containers.

Oyster Extract: The raw oysters are thoroughly washed, sliced into small pieces, and placed in a double boiler. An equal amount of water is added, the mixture is boiled and the liquid drained off. The juice is then filtered twice through a cloth and again boiled over a moderate flame. When the juice begins to thicken it is again filtered, this time through flannel, and then reboiled until thick. It is packed either in cans or bottles for use as food.

Canned Oysters: Unopened oysters are boiled in a steam boiler for 10 minutes under 10 pounds pressure and are then shucked. The meat is washed in cold water and packed in cans, and salt solution with a specific gravity of 3°Baume is added. The cans are sealed and boiled for 10 minutes at 100°C, then cooked from 12 to 17 minutes at 135°C.

Smoked Oysters: Shucked oysters are put into 15 percent salt water for one to two hours and then drained on a wire net. They are then placed in smoke at a temperature of 50°C for 18 hours, packed in cans with vegetable oil and pasteurized for 90 minutes at four pounds pressure. Among the woods used for smoking oysters, the white oak (*Quercus serrata*) and cherry (*Prunus macrophylla* and *P. serrulata spontanea*) are considered best.

3. Utilization of Shell

The empty shells of the shucked oysters constitute the only important by-product of the industry. The simplest use of the shell, without any preparation being necessary, is as cultch for spat collecting, and great quantities are thus utilized.

Manufactured products produced from oyster shell include Chinese White paint, slaked lime or whitewash, fertilizer, chicken feed, and medicine. The main steps in the preparation of these by-products are outlined in Figure 36.

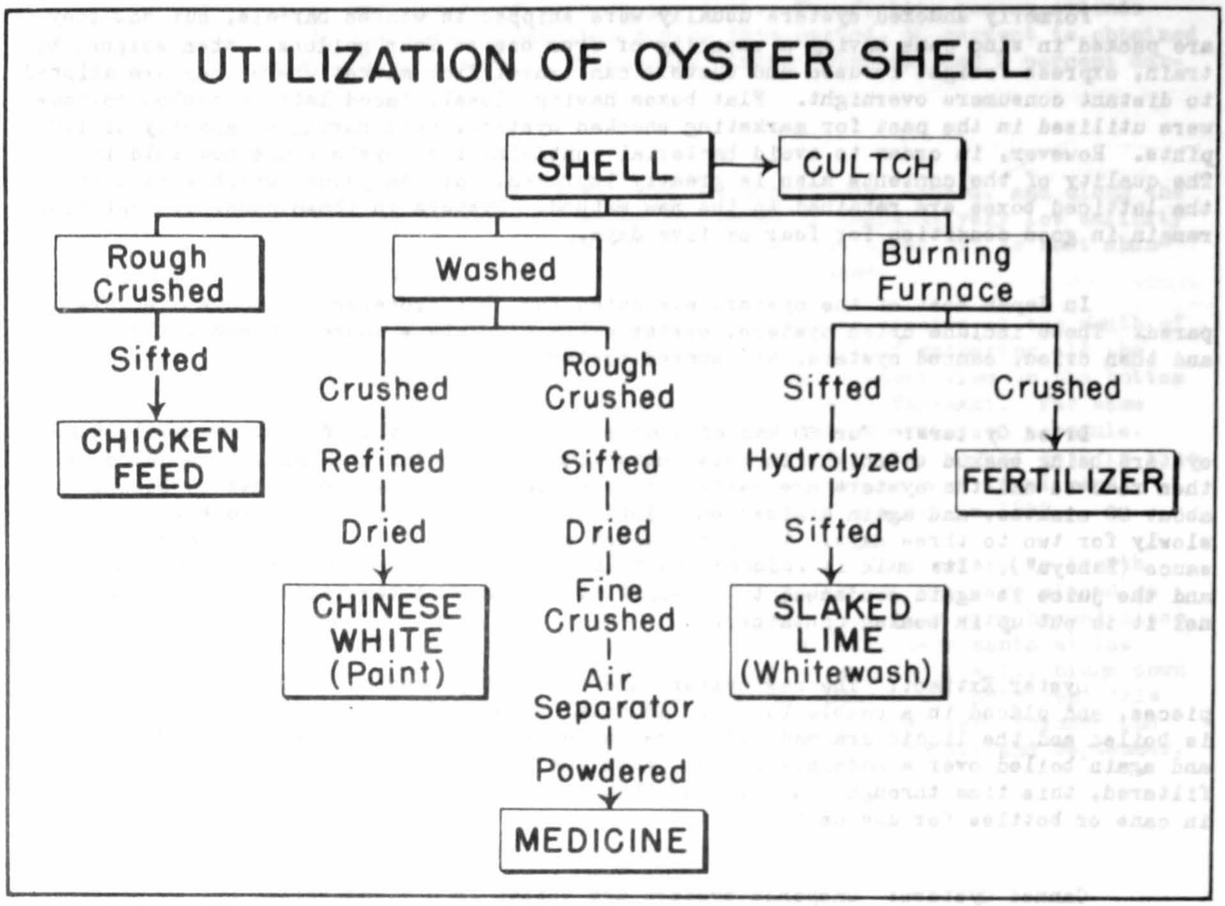

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Figure 36

PRODUCTION AND EXPORT

1. Production of Edible Oysters

Japanese production of food oysters during 1908-45 totaled 2,063,311 metric tons (Table 14, Figure 37). In 1946 and again in 1947 the system of collecting and the basis for tabulating statistical data were changed, so that the data for the last three years are not comparable with those of the previous years. Production statistics for 1946-48 are therefore given separately in Table L. No data were collected on natural production during these years.

TABLE L. - PRODUCTION OF CULTURED OYSTERS, 1946-48

Year	Production (metric tons)	Ceiling Price (yen) a/	
		Lowest	Highest
1946	22,746	3.50	5.00
1947	12,201	44.00	50.00
1948	13,903	141.20	180.00

a/ Shucked oysters, per kan.
SOURCE: Fisheries Agency

Recorded oyster production decreased sharply after 1945, but whether the crop was actually as sharp as the tabulated figures indicate is doubtful. The Fisheries Agency attributed the drop to shortage of vital materials such as wire and floats, and to restrictions on waters available for culture purposes. The writer believes that the decline was more probably due, at least in part, to the extremely low ceiling price set by the government on shucked oysters (Table L) and the consequent diversion of

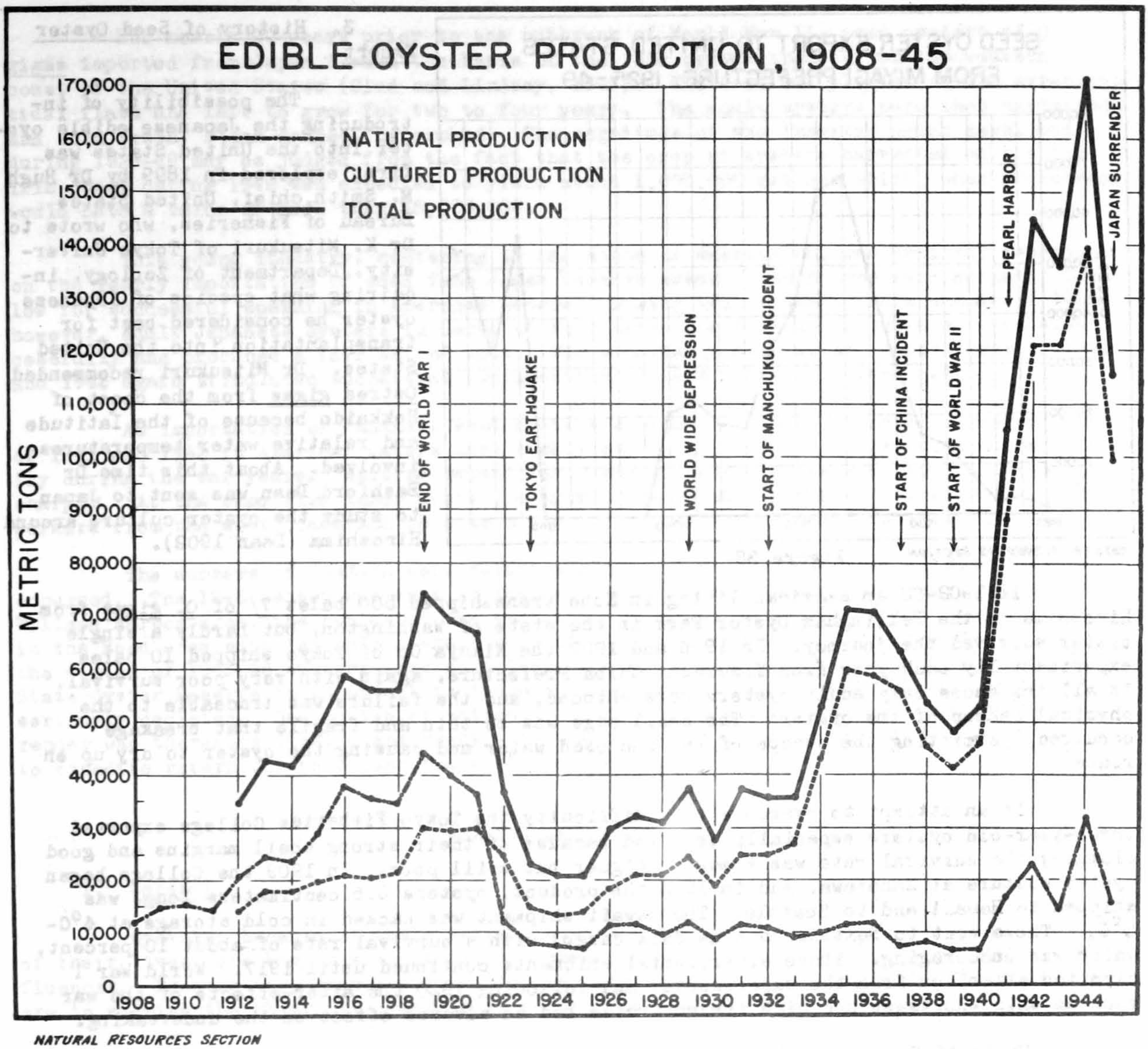

Figure 37

this shellfish into black market channels where it was not reported. For comparison, during these same years the fish known as "tai" (sea bream) sold at a ceiling price, per kan, of ¥42.25 in 1946, ¥53 to ¥88.54 in 1947, and ¥133.95 in 1948.

2. Seed Oyster Production and Export

The amount of seed oysters exported to the United States (and Canada via the United States) totaled 581,907 cases during 1925-49 (Table 15, Figure 38). A few other countries have imported small amounts of seed oysters from Japan. Before World War II, China had received 1,457 cases. Since the Surrender, Okinawa has begun to import seed oysters and has received 1,397 cases, while Australia has received 100 cases. Seed oyster exports to countries other than the United States and Canada are itemized in Table 16. The domestic consumption of seed oysters produced in Miyagi Prefecture, virtually the entire Japanese supply, is shown in Table 17.

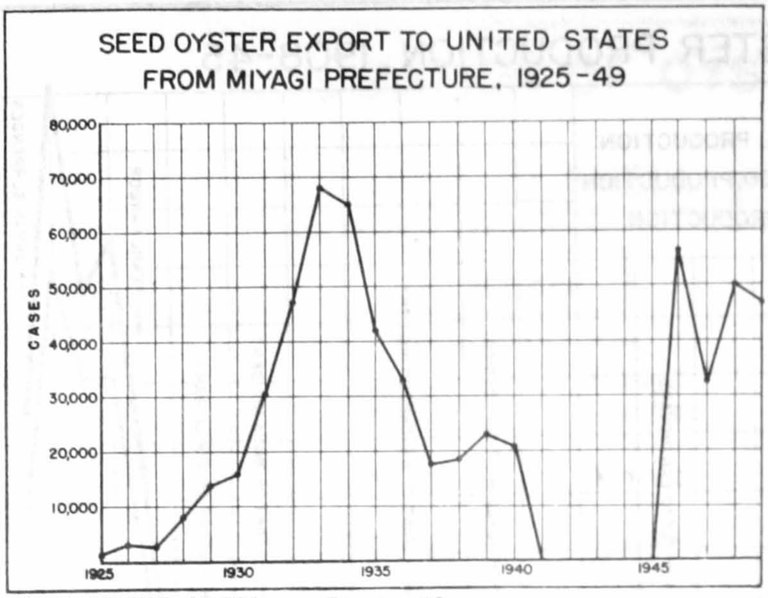

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Figure 38

3. History of Seed Oyster Export

The possibility of introducing the Japanese edible oyster into the United States was first explored in 1899 by Dr Hugh M. Smith, chief, United States Bureau of Fisheries, who wrote to Dr K. Mitsukuri of Tokyo University, Department of Zoology, inquiring what species of Japanese oyster he considered best for transplantation into the United States. Dr Mitsukuri recommended Ostrea gigas from the coast of Hokkaido because of the latitude and relative water temperatures involved. About this time Dr Bashford Dean was sent to Japan to study the oyster culture around Hiroshima (Dean 1902).

In 1902-03 an American living in Kobe transshipped 500 bales 7/ of O. gigas from Hiroshima to the Bellingham Oyster Farm in the state of Washington, but hardly a single oyster survived the journey. In 1906 and 1907 the Kikuya Co of Tokyo shipped 10 bales experimentally each year from Kisarazu, Chiba Prefecture, again with very poor survival. In all instances only adult oysters were shipped, and the failure was traceable to the physical makeup of the oyster: The shell edge was so thin and fragile that breakage occurred, permitting the escape of the enclosed water and causing the oyster to dry up en route.

In an attempt to overcome this difficulty the Tokyo Fisheries College exported three-year-old oysters especially selected because of their strong shell margins and good closure; the survival rate was somewhat higher but still poor. In 1909 the College began oyster culture at Kanazawa, and in 1912 the product, oysters 2.5 centimeters long, was shipped to Hawaii and to Seattle. The Hawaii shipment was packed in cold storage at 4°C-5°C. Those sent to Seattle went as deck cargo, with a survival rate of about 10 percent, which was encouraging. These experimental shipments continued until 1917. World War I diverted attention from the experiments, and following 1920 the after-effects of the war such as ship shortages and high freight rates had an adverse effect on the undertaking.

Up to 1920 the exported oysters were large adult individuals, about 700 to 800 to a case. In 1919, 400 cases of these large food oysters were exported from Miyagi. All of these large oysters were dead on arrival in Washington, having been shipped below decks because of shortage of deck space. They were dumped overboard on a shallow water bed. A few years after this failure this bed was checked and was found to be alive with a splendid growth of O. gigas (Hori, 1935). While the large oysters in the original shipment had died, the spat which had accidentally been attached to the shells when shipped had survived the journey and had flourished on being returned to the sea. This evidence proved to be the turning point in the development of the transplant industry for oyster culturists then recognized that the key to the transportation problem lay in shipping spat, not adult or semi-adult individuals.

In 1925, with the return to more normal shipping conditions, the export trade in oysters revived, this time as a private business. Spat from Matsushima-wan were exported, 1,400 cases in 1924, and 3,200 cases in 1926.

7/ One bale equals 12 kan (100.8 pounds).

For nearly 20 years prior to the outbreak of World War II, seed oysters of O. gigas imported from Japan formed the basis of the food oyster industry on the western coast of the United States (Glud and Lindsay, 1947). The seed was planted on the extensive tidal flats and left to grow for two to four years. The adult oysters were then harvested and sold fresh, steam-canned, or smoked. The magnitude of the industry which developed during 1929-49 may be judged from the fact that the crop of oysters harvested on the Pacific coast during 1949 was expected to yield about 1,000,000 gallons which, when processed, would have a value of more than $5,000,000.

This young industry, centering in the state of Washington, was entirely dependent on the yearly importation of seed from Japan because water temperatures were normally too low for successful spawning in American waters. During the unusually warm summer of 1936, however, adult Japanese oysters in parts of Washington and British Columbia spawned successfully and produced a fair set of spat. The abnormally high water temperatures in 1941 and 1942 again stimulated successful reproduction of this species in Washington.

As importation of Japanese seed oysters stopped in 1941, the natural reproductions of 1941 and 1942 in American waters were timely and in a large measure supported the industry during the war years. Wartime demand for oysters caused prices and production to rise sharply. At the same time labor costs increased because of the removal of Japanese oyster workers from the west coast and because of labor competition of war industries.

The summers of 1943-45 were relatively cool, and little commercial reproduction occurred. The 1946 season was warm in the Hood Canal area of Puget Sound but cold in the Willapa Harbor area, the center of the industry. The limited production of seed oysters in the Hood area supplied only a small part of the requirements of the industry. During the winter of 1945-46 oysters were sold from all available sources including the Washington State Oyster Reserve in an effort to increase the supply. Oyster beds in many areas were seriously depleted. Resumption of shipment of seed oysters from Japan following the Surrender was therefore timely, and every effort was made by both the United States and Japan to expedite return to the prewar scale of operations.

ENEMIES AND DAMAGE

1. General

Oysters, because of their sessile habits after the first brief ambulatory period of their lives, are highly susceptible to damage either by predators or by elemental influences. Because they cannot retreat before adverse conditions, their only alternatives are to survive the hazard if possible or perish where they are.

The enemies of the oyster can be conveniently divided into two categories: (a) the elemental factors, which include all climatic, oceanographic, and ecological influences, and (b) the biological factors, which include the organic (animal and plant) enemies. Every individual has its own personal survival boundary within the survival limits of the species as a whole, so local conditions can easily become a life and death matter and may greatly influence production. Sometimes the damage by adverse factors can be controlled or minimized by the oyster farmer; at other times little can be done.

2. Elemental Enemies

Severe Temperature Changes: Severe changes which carry the water temperature considerably above or below either the optimum or the tolerance range cause great damage to oysters, particularly when these occur during periods of low tide. Oysters cultured by the hanging methods are less susceptible to these thermal changes because they are suspended in a relatively stable environment. The only way this damage can be avoided is to transplant the stock to culture grounds where these unfavorable conditions are minimized.

Wind: In areas where winds are severe the oyster farmer who uses the sowing culture method must fence his area to avoid the scattering of his stock. Where hanging methods are used, especially the raft modification, much damage and severe losses result from the destruction by wave action of the supporting structures. Ordinarily areas exposed to heavy winds are not used as culture grounds.

Flood: In culture areas within the influence of discharging rivers, oysters may be suffocated by the deposition of mud and silt carried into the sea by flood conditions. Such damage is most severe to young oysters which require less deposition of sediment to destroy them. If the adult oysters are not actually smothered beneath the deposit, they become lean and the meat inferior in quality. A flood in Hiroshima Prefecture covered oysters with mud to a depth of from eight centimeters to one meter; the resulting death rate was 100 percent.

3. Biological Enemies

a. Red Tide

The first reference in Japanese literature to the so-called "red tide" appears in the writings of the priest Koken in 1312: "On April 12th the sea water of Sagami Bay, Kanagawa Prefecture, turned to red. This was found to range from Shizuoka Prefecture to Chiba Prefecture, a distance of about 1,200 kilometers. All the waters of the sea turned red and this could be dipped out by hand and it was found that the water contained reddish fish-egglike granules."

The "akashio" or red tide is an aquatic phenomenon that occurs at irregular intervals and with variable intensities and results. It may be highly destructive not only to edible oysters but also to the pearl oysters (Cahn, 1949) and to other forms of marine life. In recent years the microorganisms which cause the red tide in Japan have been shown to be various dinoflagellates such as Gonyaulax, Gymnodium, Peridinium, Ceratium, and other forms of lesser importance.

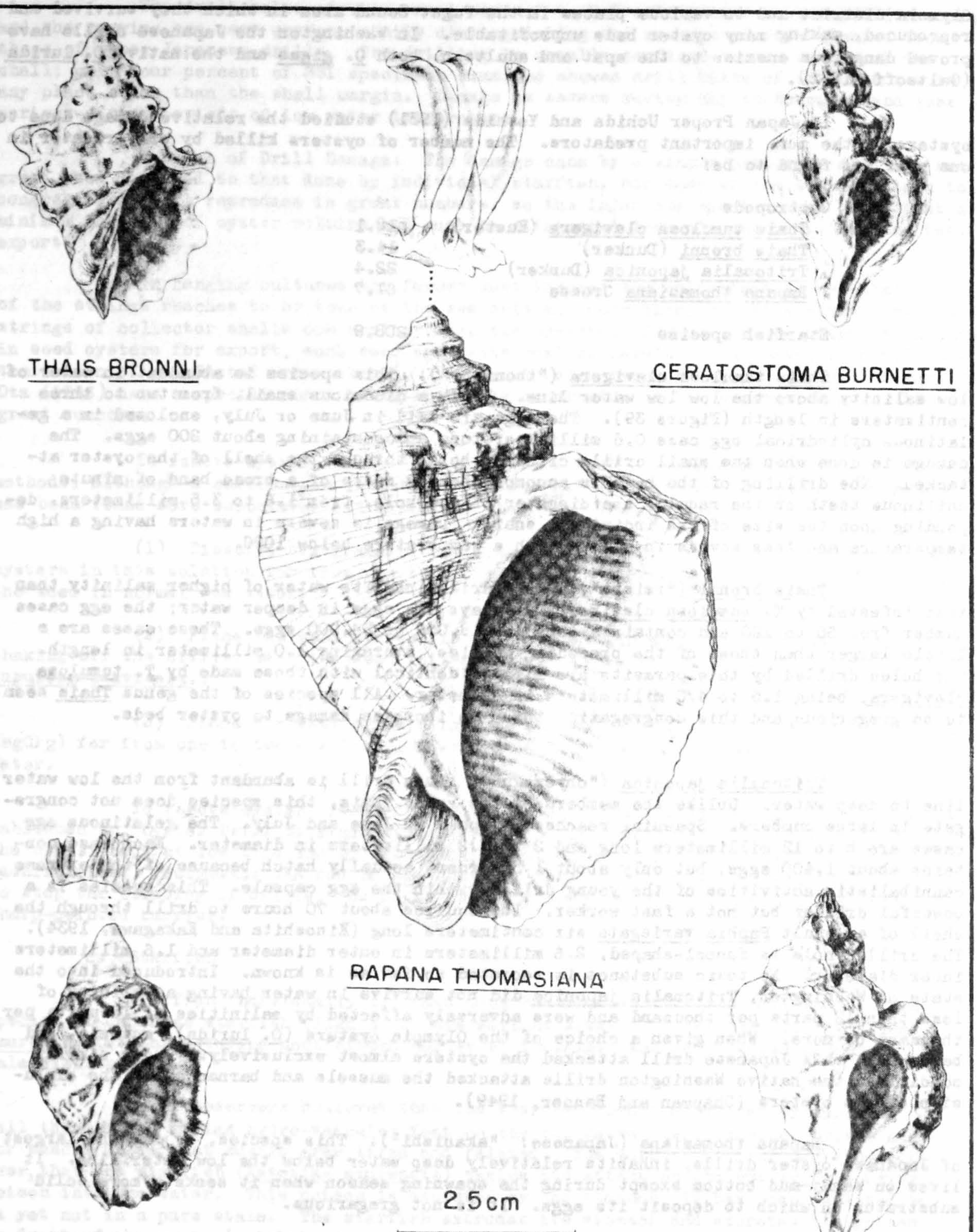
In many instances the red tide has killed tremendous quantities of fish and shell fish. Death is apparently due primarily to suffocation caused either by the abnormally great consumption of available oxygen by the multitudes of microorganisms which by sheer numbers color the water red, or by the clogging of the gills by the organisms accumulating thereon. The Japanese recognize the possibility of a toxin being involved, but they have not demonstrated whether this is a secretion or the product of the decomposition of enormous numbers of dead dinoflagellates.

Red tides occur mostly in the spring and autumn where the ocean current is sluggish, usually during continuously fine, quiet weather. When climatic conditions remaining in a static condition for long periods the dinoflagellates increase incredibly in numbers, and the damage follows. Many red tides do little or no damage to oysters, while others result in a mortality approaching or reaching 100 percent. Only by the raft method of culture can an attempt be made to minimize the effects of the red tide, by towing the rafts into areas free from the deadly organisms before damage results. Experiments using copper sulfate are inconclusive.

b. Oyster Drills

A number of marine gastropods (Figure 39) are highly injurious to the oysters and detrimental to the culture industry, and hence of interest in connection with the export trade (Kinoshita and Kinoshita, 1931).

How many species of the Japanese drills can survive in the waters of the northwestern United States is not known. However, Thais tumulosa clavigera did not survive in those waters while Tritonalia japonica unfortunately did very well there. Both of these pests were introduced accidentally in a brush cultch which was involved in stocking perhaps one-half an acre of original plant in Samish Bay, Washington. The Tritonalia have now spread over that bay where some 1,500 acres are under oyster production. Before the infestation was discovered the drills had been transshipped from Samish Bay to Oyster Bay in the



NATURAL RESOURCES SECTION

Figure 39. - Oyster drills

Olympia district and to various places in the Puget Sound area in which they survived and reproduced, making many oyster beds unprofitable. In Washington the Japanese drills have proved dangerous enemies to the spat and adults of both O. gigas and the native O. lurida (Galtsoff, 1932).

In Japan Proper Uchida and Yoshida (1931) studied the relative damage done to oysters by the more important predators. The number of oysters killed by one predator in one year was found to be:

Gastropods	
Thais tumulosa clavigera (Kuster)	18.1
Thais bronni (Dunker)	14.3
Tritonalia japonica (Dunker)	22.4
Rapana thomasiana Crosse	61.7
Starfish species	208.9

Thais tumulosa clavigera ("iboniehi"): This species is abundant in water of low salinity above the low low water line. It is a dioecious snail, from two to three centimeters in length (Figure 39). The eggs are laid in June or July, enclosed in a gelatinous cylindrical egg case 0.6 millimeter long and containing about 200 eggs. The damage is done when the snail drills circular holes through the shell of the oyster attacked. The drilling of the hole is accomplished by means of a broad band of minute chitinous teeth on the radula, the diameter of the hole, from 1.6 to 3.5 millimeters, depending upon the size of the individual snail. Damage is severe in waters having a high temperature and less severe in waters with a temperature below 10°C.

Thais bronni ("reishi"): This drill inhabits water of higher salinity than that infested by T. tumulosa clavigera. It lays its eggs in deeper water; the egg cases number from 65 to 120 and contain a total of 19,000 to 34,000 eggs. These cases are a little larger than those of the preceding species, averaging 1.0 millimeter in length. The holes drilled by this parasite are almost identical with those made by T. tumulosa clavigera, being 1.5 to 4.0 millimeters in diameter. All species of the genus Thais seem to be gregarious, and this congregating tends to increase damage to oyster beds.

Tritonalia japonica ("ohyoraku"): This drill is abundant from the low water line to deep water. Unlike the members of the genus Thais, this species does not congregate in large numbers. Spawning reaches its peak in June and July. The gelatinous egg cases are 8 to 12 millimeters long and 2 to 4.2 millimeters in diameter. Each case contains about 1,400 eggs, but only about 1.5 percent actually hatch because of the extreme cannibalistic activities of the young drills within the egg capsule. This species is a powerful driller but not a fast worker. It requires about 70 hours to drill through the shell of an adult Paphia variegata six centimeters long (Kinoshita and Kakagawa, 1934). The drilled hole is funnel-shaped, 2.6 millimeters in outer diameter and 1.6 millimeters inner diameter. No toxic substance is secreted so far as is known. Introduced into the state of Washington, Tritonalia japonica did not survive in water having a salinity of less than 12 parts per thousand and were adversely affected by salinities of 18 parts per thousand or more. When given a choice of the Olympia oysters (O. lurida), mussels, and barnacles, this Japanese drill attacked the oysters almost exclusively. Under similar conditions the native Washington drills attacked the mussels and barnacles to the exclusion of the oysters (Chapman and Banner, 1949).

Rapana thomasiana (Japanese: "akanishi"): This species, by far the largest of Japanese oyster drills, inhabits relatively deep water below the low water line. It lives on sandy-mud bottom except during the spawning season when it seeks a more solid substratum on which to deposit its eggs. It is not gregarious.

R. thomasiana is dioecious and spawns in June and July. The egg cases are shaped like a scabbard (Figure 39), about 2.5 centimeters by 2.5 millimeters in size. They are pale yellow and are attached to solid objects in dense clusters. Each case contains approximately 1,100 eggs.

The drill holes of this snail are 4.5 to 5.8 millimeters in outside diameter, and the margins are very uneven, easily distinguishing the ravages of this species from those of other Japanese drills. The drilling is usually confined to the margin of the shell; only four percent of 381 specimens examined showed drill holes of this species in any place other than the shell margin. Damage is severe during May to November and less serious during periods of low water temperature.

Control of Drill Damage: The damage done by a single predatory drill is not great when compared to that done by individual starfish, but many of the mollusks tend to congregate and all reproduce in great numbers, so the injurious species must be kept at a minimum in areas of oyster culture and must be eliminated from all material intended for export.

In hanging cultures the farmer must inspect the collectors to see that none of the strings reaches to or touches the sea bottom. Only through bottom contact by the strings of collector shells can drills reach the oysters. Because drills might be included in seed oysters for export, such seed shipments must be carefully inspected to avoid contamination of uninfected areas abroad. In the umbrella type of hanging culture (Figure 23) Ota (1946) uses a special guard of metal on the under side of the supporting pole with great success.

To remove oyster drills from spat, Hori (1935) recommends any of the following methods, although a combination of methods (1) and (2) will remove all oyster drills and has been found more successful and efficient that the third method:

(1) Dissolve six grams of table salt in one liter sea water. Place the seed oysters in this solution for from one to two minutes. After shaking off the drills, wash the seed in normal sea water.

(2) Place the seed oysters in fresh water for about two minutes. After shaking off the drills, wash the seed in sea water. (This method will not remove *Thais tumulosa clavigera*.)

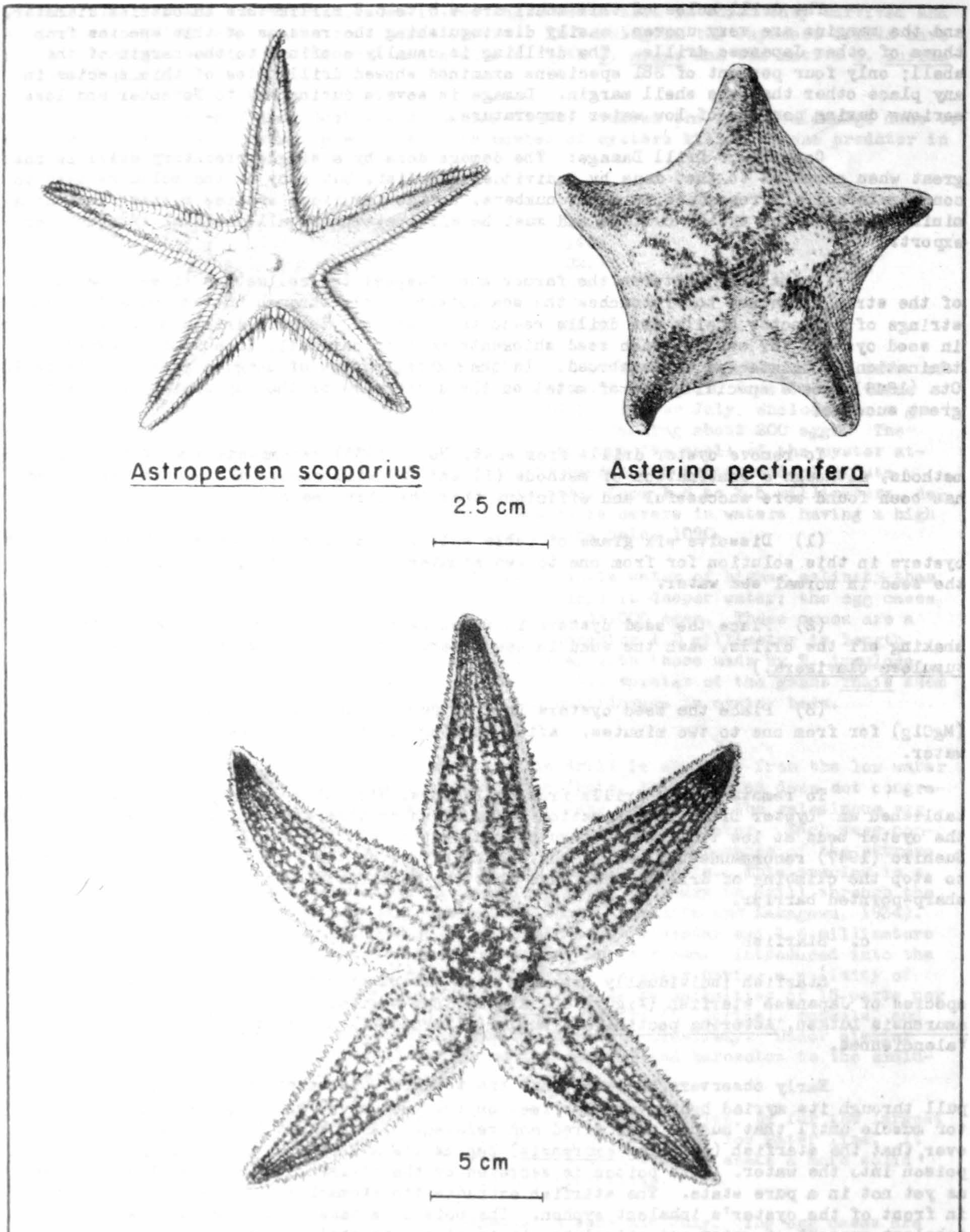
(3) Place the seed oysters in a 30 percent solution of magnesium chloride ($MgCl_2$) for from one to two minutes. After shaking out the drills wash the seed in sea water.

To remove oyster drills from collectors, Hiroshima and Miyagi prefectures established an "Oyster Drill Extermination Day", at which time the school children swarm over the oyster beds at low tide and by hand-picking gather all the drills they can find. Suehiro (1947) recommends the use of the chestnut burr on the rope of the collector string to stop the climbing of drills. He found that the soft-footed drills would not cross the sharp-pointed barrier.

c. Starfish

Starfish individually are much more destructive than the mollusks. Three species of Japanese starfish (Figure 40) are serious enemies of the oyster: *Asterias amurensis* Lutken, *Asterina pectinifera* Muller et Troschel, and *Astropecten scoparius* Valenciennes.

Early observers believed that the starfish opened an oyster by applying pull through its myriad hydro-vascular feet on the two valves held together by the adductor muscle until that muscle grew tired and relaxed. The work of Mr Imai has shown, however, that the starfish (*Asterias amurensis*) begins its attack on the oyster by pouring a poison into the water. This poison is secreted by the stomach; it has been isolated but as yet not in a pure state. The starfish extrudes its stomach and excretes its poison in front of the oyster's inhalent syphon. The poison is taken into the mollusk with the inhalent current of water and stimulates it to close its shell at once. However, as the poison is already inside this closure merely hastens the end, which is indicated by the relaxation of the adductor muscle. The adductor nerves are affected and the muscle loses tonus and finally can no longer hold the shell closed. As the muscle relaxes the shell



NATURAL RESOURCES SECTION

Figure 40. - Starfish injurious to oysters

is pulled open by the action of the hydro-vascular feet of the starfish pulling on the outside of the two valves. Experimentally, this paralysis remains effective for many hours, if it does not result in death. A very small dose of the poison acts as a heart stimulant, while a heavy dose stops heart action. The same reactions to this poison have been demonstrated in the laboratory on the frog heart.

Once the adductor relaxes and the valves are opened, the starfish protrudes its stomach between the valves and digests the oyster. The time required to destroy an oyster is about two hours from the first injection of the poison into the water to the complete digestion of the body.

Great quantities of starfish are collected annually from all oyster culture areas as a protective measure against their ravages. Those gathered are dried, ground up, and used as fertilizer.

d. Internal Parasites

The presence of Turbellaria as parasites of oysters was demonstrated by Kato (1939) who found them in oysters at Tanabe, Wakayama Prefecture, in 1931 and 1932. He reported that Stylochus ijimai and Planocera reticulatus did considerable damage to oyster crops. The period of damage was one of exceptionally warm weather with little rainfall. To avoid Turbellaria damage Kato recommends: (1) that no seed oysters from infested areas be used or transported, (2) that the food oysters be removed to a region of low salinity which is not favorable to the parasites, (3) that the parasites be destroyed by the use of copper sulfate ($CuSO_4$).

Two species of larval distomes have been reported as parasites in O. gigas, one in the mantle, the other in the gonad. The mantle parasite is Gymnophalloides tokiensis, an organism 0.4 millimeter long and leaflike in shape. It is abundant and is found in oysters from the lower salinity areas of Tokyo and Ise bays. The adult is parasitic in sea birds.

The parasite in gonads (Fujita, 1943) is Proctaeces ostreae, a form common in 10 percent of the oysters from Hiroshima Prefecture. O. gigas is the intermediate host, the adult being found in two species of fish: Pagrosomus major and Epinephetus akaara. The parasites are visible as long, elliptical white areas on the soft parts of the oyster. It is said to be harmless to man.

e. Fouling Animals

Although numerous animals and plant forms attach to oyster shells at various times, few are reported as going any considerable damage to the crop. Various barnacles and the mussel Mytilus edulis cause the most damage to the oysters, mostly through competition for food.

The barnacles are typical fouling organisms, attaching abundantly to the growing oysters during the period May to October. The damage is said to be considerable. It can be minimized by careful regulation of the time and height of setting out the spat collectors (Figures 16,17). Numerous methods to avoid contamination by barnacles have been investigated by the Hiroshima and Kumamoto fisheries experimental stations working on larval forms. At Kumamoto, Ota (1948) suggested that the damage could be minimized by collecting at lower salinity levels such as river mouths. He also showed that straw matting used as a cover over the collector was a simple and efficient method of reducing barnacle infestation. In experiments 25 Aug-3 Oct 47, the collector strings were fixed horizontally on the racks 20 centimeters above the bottom; on one-half of each rack the mats were placed over the racks 30 centimeters above the collectors. The presence of the mats greatly reduced the setting of barnacles and increased the setting of spat. On the straw mat-covered section the number per collector (average for 50 collector strings) was 11.9 oyster spat and 9.7 barnacles. Without a mat the raft collected 4.1 oyster spat and 89.1 barnacles.

The common mussel, Mytilus edulis, causes considerable damage in certain areas by sheer force of numbers. These animals began to cause damage in the Kobe and Unagawa harbor areas about 1929 and by 1932 had spread into the Hiroshima district. *Mytilus* has a very long spawning season. The mollusks attach in great abundance from January to April in water as deep as two meters and the growth thereafter is very rapid. Oysters to which they attach may eventually die of undernourishment as a result of this overwhelming competition. As a protective measure in Hiroshima Prefecture the farmers begin their oyster culture in July, thus avoiding the peak of mussel spawning. The menace of *Mytilus* constitutes one of the few defects of the hanging culture method, for by this method the young mussels are picked up from all depths. Sometimes an entire area may be ruined for culture purposes because of the abundance of these mussels.

f. Hypertrophy of Ovary

In Hiroshima Prefecture Seki (1934a) noted the frequent occurrence of abnormal protuberances on the surface of the ovary of *O. gigas*. These abnormalities were found to be especially abundant following the breeding season, when 20 percent of the individuals were thus affected. They have been found to be most commonly associated with hanging and sowing cultures. Seki reports that (a) 14.1 percent were infected in three-year-old oysters, 12.9 percent in two-year-olds, and 7.4 percent in one-year-old individuals; (b) the frequency is greater in hanging than in sowing methods; (c) the infestation is greater in Hiroshima oysters than in Matushima oysters; and (d) hypertrophy is confined to *O. gigas* and is not found in *O. nippona*, *O. denselamellosa*, *O. echinata*, or *O. futamiensis* in the same region. The cause of the hypertrophy is not mentioned, but Seki believes it to be pathological rather than parasitological in origin.

REGULATIONS

In an industry as extensive as oyster culture in Japan it might be expected that rather stringent laws and regulations would govern the operations. However, this is not the case. The oyster industry in unencumbered by limiting restrictions, except for some local prefectural regulations dealing with sanitation or fishing season. In many areas both are lacking, and in most areas the sanitation regulations are reduced to a dangerous minimum.

One of the best and most modern of the sanitary codes now in force was issued by Miyagi Prefecture in 1948:

REGULATIONS FOR OYSTER CULTURE OPERATIONS, MIYAGI PREFECTURE GOVERNMENT REGULATION NO 23 1 April 1948

1. By oyster culture operations as referred to in this regulation is meant an enterprise which collects oysters or shucks oysters for food purposes.

2. A person who intends to engage in this operation must obtain a permit from the prefectural governor by submitting an application containing the following information:

   a. Permanent address, present address, name, date of birth of operator. In the case of an organization: persons involved, name and location of main office, name and address of representative, and a copy of the articles of incorporation.

   b. Location of oyster collecting grounds shown on a map.

   c. Culture methods to be used.

   d. Location and structure of shucking plant, oyster landing yard and toilet, with plans.

e. In the case of an oyster storage area being built: location area, structure and facilities, and all structures surrounding it within a radius of 400 meters.

f. Kind of drinking water and water supply facilities. A person planning to change conditions mentioned following (b) will follow the same procedure. However, a person who will be engaged exclusively in collecting oysters may omit sections (d) and (f); one who will deal exclusively in shucking may omit (b) and (c) from application.

3. A fisherman's association which intends to build the establishment mentioned in (d) of the foregoing article for the purpose of using it for association purposes must obtain a permit from the prefectural governor by presenting an application stating location, structure and facilities of the establishment, together with a plan.

4. Structure and facilities of the shucking plant, storage area and toilet will be subjected to the following specific conditions:

a. A clean shoreline must be selected for shucking structure, the ground to be covered with a waterproof material. The building will have walls that can be washed clean and will have suitable lighting and ventilation. The shucking stand will be built of waterproof material such as galvanized iron.

b. The oyster landing yard will be built of waterproof material.

c. The oyster storage will be an area of clean sea water.

d. The toilet will be of modern construction of semi-septic tank and equipped with wash-stand and running water.

e. Clean sea water supplied through a conduit will be used for shucking work, but water from a pump well which is protected from pollution may be used to wash the inside of the building.

5. When the construction of the above structure is completed it is not to be used until the prefectural governor has been informed and has inspected it.

6. Oysters which have not been bred by the hanging method or which have become stained with mud can not be shucked until they have been soaked and cleaned in the oyster storage area.

7. The operator of this enterprise and his employees must observe the following:

a. Collected oysters will be soaked nowhere but in the oyster storage area mentioned in (e) of Article 2.

b. Oysters with broken shells will not be shucked or used as food.

c. When shucked meat is stored it must be kept in a clean place and protected from flies.

d. No water other than that herein specified in (e) of Article 4 or water permitted by the prefectural governor may be used for washing or soaking shucked meat.

e. Workers shucking oysters must wear clean clothing.

f. The shucking stand, instruments and vessels will always be kept clean.

g. The shucking area will always be kept clean.

8. The name, address and age of all employees who are engaged in this operation will be reported by their employer to the prefectural governor before 15 September each year.

9. When the operator appoints a manager he must notify the prefectural governor within five days after the appointment, giving the name, permanent address, present address and date of birth of the manager.

10. When an operator takes over or rents an oyster shucking plant or an oyster storage area from another operator, making joint signature for the transfer of the property, he must notify the prefectural governor, together with an abstract of their census register.

11. Every document submitted to the prefectural governor in accordance with this regulation must be through the chief of a health center within the jurisdiction.

12. A person who violates (a) section of Article 2, and/or the regulations from Article 3 to 10, will be subjected to a fine of not over 10,000 yen or detention.

13. When a person who represents an operator or the legal representative of the operator and those who are in the employ of them have committed the violation, not only they, but also the legal representative and the person who represents the operator will be subjected to the foregoing fine.

14. The foregoing penalties of this regulation will apply also to a retailer of shucked oyster meat who has violated Section (d) of Article 7 of this regulation.

Regulations on activities governing the taking or marketing of oysters are meager. Some prefectures enforce a closed season, but dates are not uniform and many evasions are possible. Only a few prefectures have a minimum legal size limit on oysters to be taken for market purposes. The haphazard nature of these regulations is shown in Table M.

TABLE M. - CLOSED SEASON AND SIZE REGULATIONS RELATING TO JAPANESE OYSTERS

Prefecture	Minimum Legal Size (centimeters)	Closed Season From	Closed Season To	Species
Hokkaido	7.5	16 Jun	30 Sep	O. gigas
Yamagata	7.5	a/	a/	O. gigas
Hyogo	6.0	1 Apr	31 Oct	O. denselamellosa
Kagawa	5.0	a/	a/	O. denselamellosa
Miyagi	b/	11 Jul	31 Aug	O. gigas
Fukushima	b/	1 Jun	31 Jul	O. gigas
Tokyo	b/	1 Jun	31 Aug	O. gigas
Ishikawa	b/	1 Apr	31 May	O. gigas
Osaka	b/	1 May	30 Sep	O. gigas
Wakayama	b/	1 May	30 Sep	O. gigas
Okayama	b/	1 Apr	31 May	O. gigas
Kochi	b/	1 Jul	30 Sep	O. gigas

a/ No closed season
b/ No size limit
SOURCE: Japanese Bureau of Fisheries report, 1938.

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GLOSSARY

1. Technical Terms

The following definitions of technical and semi-technical terms are offered as an aid to the reader. Each term is defined in the sense in which it is used in this report, not in the all-inclusive sense found in a dictionary or in a biological vocabulary.

adductor muscle — The powerful muscle extending between and attached to the two halves of a bivalved mollusk shell, the contraction of which closes the shell.

archenteron — The primitive body cavity in the blastula stage of individual development.

artificial fertilization	Union of egg and sperm induced under conditions which are not natural.
bivalve	A shellfish (mollusk) having two valves or half-shells, which are hinged together; oysters and clams.
blastula	A developmental stage in the early life history of an individual in which a single layer of cells surrounds the primitive body cavity.
branchial cavity	The cavity lying between the folds of the mantle of a bivalved mollusk. In some species of oysters this is a brood chamber.
cleavage	The process by which the number of cells is increased through cell reproduction, resulting in growth of the individual.
collector	Any material, such as shells, laid down on oyster grounds to provide attachment for the spat; cultch.
cultch	Collectors for oyster spat.
cypris	A developmental stage of barnacles in which a bivalved shell is present.
diatoms	Unicellular plant organisms.
dinoflagellates	A group of microscopic aquatic plants (flagellates) having two flagella for locomotion, located about the middle of the body.
dioecious	Opposite sexes located in different individuals; an individual which is dioecious is either male or female.
flagellate	A group of minute plant forms bearing one to four whiplike locomotor appendages (flagella) at the anterior end of the body.
gastropod	A mollusk in which the shell is a single coiled unit; a snail.
gastrula	The developmental stage following the blastula, in which, by invagination, two layers of cells surround the body cavity.
gonad	An essential sex gland, such as the ovary or testis.
gonaduct	A tube leading from the sex gland through which the egg or sperm is discharged.
height of shell	Distance from the umbo to the ventral margin of the valve.
hepato-pancreas	A digestive gland of certain mollusks which secretes fluids acting on both fats and proteins.
hermaphrodite	Having both male and female reproductive organs present in an individual.
hydrovascular	In starfish, a water vascular system used in locomotion to move the many small feet.
infusoria	A group of unicellular animals (Protozoa) microscopic in size.
larva	Early embryonic free-moving stages of the oyster prior to fixation.
larviparous	The condition in which young individuals are extruded from the parent as pre-formed, free-swimming larvae.

length	When applied to a bivalve shell, the distance between the ligamentous hinge and the opposite free margin of the shell.
littoral	The coastal region.
mantle	The curtain-like fold of tissue lying between the body of the oyster and the shell.
mollusk	A soft-bodied salt or fresh-water animal living within a calcareous shell which is the product of specialized cells of the mantle. In this report, oysters, clams, and snails.
Monas	A flagellate used successfully as food for larval oysters in laboratory culture experiments.
monoecious	Two sexes within a single individual; hermaphroditic.
morphological	Concerning the form and structure of a body.
nauplius	A free-swimming stage of barnacles; the first stage after leaving the egg.
oviparous	Producing eggs which hatch after extrusion from the body of the parent.
ovum	The egg or female sex product.
photosynthesis	The formation of carbohydrates from water and carbon dioxide within the chlorophyl-containing tissues of plants in the presence of sunlight.
phytoplankton	Plankton consisting of microscopic plants.
plankton	Floating animal and plant life in water, of microscopic size.
polar body	A minute cell which separates from the egg in the early stages of its maturation.
radula	A chitinous band in the mouth of gastropods which bears numerous minute teeth used to break up food.
sessile	Permanently fixed; nonmobile.
spat	Veliger larvae of the oyster which have attached permanently to an object.
spermatozoan	The active male sex cell; sperm.
trochophore	The free-swimming larval stage of mollusks having a preoral ciliated ring and in which the shell has not yet begun to form.
umbo	The lateral prominence just above the hinge of a bivalve shell; the beak, or shoulder. It is the first part of the calcareous valve to be formed. (Plural is umbones.)
valve	One of the two halves of the shell of a bivalved mollusk.
veliger	A larval mollusk in the velum-bearing stage.
velum	A larval swimming organ developed from the ciliated ring of the trochophore.
zooplankton	Plankton consisting of microscopic animals.
zygote	The fertilized egg.

2. Conversion Factors

a. Japanese Units of Measurement

Japanese		English
1 kan	=	8.267 pounds
1 kin	=	1.322 pounds
1 hyo	=	99.2 pounds
1 ren	=	A series of 70-100 collectors for spat, strung on wires 1.75 meters long; 140 ren equal one case
1 sho	=	3.812 pints 0.051 bushel

b. Metric Units of Measurement

Metric		English
1 micron	=	0.000039 inch
1 millimeter	=	0.039 inch
1 centimeter	=	0.394 inch
1 meter	=	3.281 feet
1 kilometer	=	0.621 mile
1 square meter	=	10.764 square feet

Metric		English
1 cubic centimeter	=	0.061 cubic inch
1 liter	=	2.113 pints
1 kilogram	=	2.205 pounds
1 metric ton	=	2,204.6 pounds 1.102 short tons
1° centigrade x 9/5 + 32	=	1° Fahrenheit

3. Japanese Terms

akashio	"red tide"
-gaki (-kaki)	oyster
-gawa (-kawa)	river
-gunto	archipelago
hachiku	Japanese bamboo
-jima (-shima)	island
-kai	sea
kakibune	floating seafood restaurant
ko	lake
madake	Japanese bamboo
-mura	village
mutsago (yatsugo)	oyster rake having six or eight teeth
ren	see Japanese units of measurement
toya	form of bamboo structure used for oyster culture
-ura	inlet
waka	one-year crop of oysters
-wan	bay

TABLE I. - DISTRIBUTION OF GENUS OSTREA IN JAPANESE WATERS

Species	Japanese Name	Area			
		Pacific Ocean	East China Sea	Japan Sea	Inland Sea
Ostrea (Lopha) folium Linne	Wani-gai Wani-gaki	Wakayama Kochi			
O. (L.) rosacea-Deshayes	Kanoko-gaki	Sagami-wan Wakayama	Kagoshima	Fukui	
O. (L.) crenuli-fera Sowerby	Nokogiri-ga	Sagami-wan Suruga-wan Wakayama Kochi	Nagasaki		
O. (L.) imbricata Lamarck	Kakitsubata	Suruga-wan Wakayama Kochi Miyazaki	Kagoshima Nagasaki	Fukui	
O. (L.) chemnitzii Hanley	Beni-gaki	Sagami-wan Suruga-wan Wakayama Kochi Miyazaki			
O. (L.) hyotis (Linne)	Shako-gaki	Wakayama			
O. (L.) sinensis Gmelin	Korobi-gaki	Wakayama		Fukui	
O. (Saxostrea) mordax Gould	Ohaguro-gaki	Wakayama Kochi Miyazaki	Kagoshima Tanega-shima		
O. (S.) echinata Quoy and Gaimard	Ke-gaki	Fukushima Ibaraki Chiba Tokyo-wan Sagami-wan Suruga-wan Shizuoka Aichi Mie Wakayama Kochi Miyazaki	Kagoshima Nagasaki Saga	Shimane Hyogo Fukui	Osaka Ehime Yamaguchi Hiroshima Okayama
O. (S.) vitrefacta (Sowerby)	Nisema-gaki		Between Yaku-shima and Tanega-shima		
O. (S.) circumpicta Pilsbry	Kokegoromo	Miyagi Fukushima Wakayama Miyazaki Kagoshima	Nagasaki	Oki-gunto Fukui Yamagata Akita	Ehime Hiroshima
O. (S.) nippona Seki	Iwa-gaki	Hokkaido Aomori Miyagi Suruga-wan Mie Wakayama Miyazaki		Fukui Yamagata	Yamaguchi
O. (Crassostrea) rivularis Gould	Suminoe-gaki	Kochi	Yamaguchi Saga a/ Kumamoto a/		
O. (C.) gigas Thunberg b/	Ma-gaki	Hokkaido Aomori Iwate a/ Miyagi a/ Fukushima Tokyo-wan a/ Sagami-wan Suruga-wan Shizuoka a/ Aichi a/ Mie a/ Wakayama Miyazaki Kagoshima	Nagasaki a/ Fukuoka Kumamoto a/	Shimane a/ Tottori a/ Fukui a/ Ishikawa a/ Sado-shima a/ Yamagata Akita	Hyogo Hiroshima a/ Yamaguchi
O. (Ostrea) denselamellosa Lischke	Itabo-gaki	Hokkaido Miyagi Fukushima Tokyo-wan Suruga-wan Aichi Mie Wakayama Kochi Oita	Nagasaki Fukuoka Kumamoto	Fukui Ishikawa	Yamaguchi Hiroshima Okayama Awaji-shima
O. (O.) futamiensis Seki	Kurohime-gaki	Wakayama Tokushima Miyazaki			Yamaguchi Hyogo
O. (Pycnodonta) musashiana Yokoyama	Bekko-gaki Wan-gaki	Aomori Chiba Suruga-wan Wakayama	Kagoshima	Hyogo Fukui Ishikawa Yamagata	

a/ Culture areas
b/ Also Sea of Okhotsk
SOURCE: Nomenclature of species by Kuroda (1930-31); distribution compiled from many published local species lists.

TABLE 2. - COMPARISON OF THREE IMPORTANT JAPANESE SPECIES WITH ATLANTIC COAST OYSTER

Character	Japanese Species			American a/
	Ostrea gigas	*Ostrea rivularis*	*Ostrea denselamellosa*	*Ostrea virginica*
Shape	Oblong	Round	Round	Oblong
Shell				
Color	White, radiating purple bands	Pale pink, radiating burnt lake striae	Gray	White to grayish purple
Surface				
Surface	Plates large, rough	Plates thin, almost smooth; shell thick	Plates thin, many; shell thick	Plates large, rough
Reproduction	Oviparous	Oviparous	Larviparous	Oviparous
Egg, diameter (mm)	0.05	0.05	0.10	0.50
Habitat	High-tide mark to 30 meters	Low-tide mark on muddy bed	15 to 40 meters on pebbly bed	8 to 10 meters
Salinity range b/	7-32	9-30	27-34	5-34
Distribution	Coasts of Japan and Korea	Ariake-kai, Okayama Prefecture, and Korea	Warm water areas of Japan and Korea	Atlantic coast of North America

a/ Atlantic coast
b/ Parts per thousand (o/oo)

TABLE 3. - EFFECT OF WATER TEMPERATURE ON DEVELOPMENT OF YOUNG OSTREA GIGAS

Factor	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Mean temperature (°C)	31.9	29.7	27.7	25.6	23.2 a/	20.8	18.6	16.3	13.6
Hours between fertilization and shelled larvae	NA	ND	25	23	25	34	53	83	NA
Total number of shelled larvae	0	272	3,552	3,971	4,350	3,794	2,295	1,418	0
Number of abnormal shelled larvae	0	264	276	0	209	1,391	1,504	1,418	0
Percent eggs developed to shelled larva	0.0	6.2	81.0	90.0	99.0	86.0	52.0	32.0	0.0
Percent abnormal individuals	NA	97.0	7.8	0.0	4.8	35.6	65.8	100.0	NA

a/ Optimum conditions of water temperature
NA: Not applicable
ND: No data available
SOURCE: Seno, Hori, and Kusakabe (1926).

TABLE 4. - EFFECT OF SALINITY ON DEVELOPMENT OF OSTREA GIGAS AT 23°C WATER TEMPERATURE

Factor	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Specific gravity a/	1.0099	1.0119	1.0139	1.0155	1.0175	1.0184	1.0208	1.0230	1.0246	1.0274
Salinity (0/00)	13.99	16.60	19.22	21.33	23.93	25.10	28.24	31.11	33.19	36.83
Hours between fertilization and shelled larvae	ND	34	28	28	25	22	22	25	22	25
Total number of shelled larvae	349	444	563	505	627	620	617	416	553	477
Number of abnormal shelled larvae	349	444	54	90	58	19	5	76	158	385
Percent eggs developed to shelled larvae	54	68	78	78	96	95	95	64	85	73
Percent abnormal individuals	100.0	100.0	9.6	17.8	9.3	3.7	0.3	18.3	28.5	80.7

a/ Compared at 15°C according to standard procedure
ND: No data available
SOURCE: Seno, Hori, and Kusakabe (1926).

TABLE 5. - STOMACH CONTENTS OF OSTREA GIGAS FROM KANAZAWA, KANAGAWA PREFECTURE

Major Group	Genus and Species
Diatomacea	Achanthes brevipes
	Actinoptychus undulatus a/
	Amphora excisa a/
	Amphora lineata a/
	Arachnoidiscus ornatus
	Asterionella japonica
	Asteromphalus heptactis
	Bacteriastrum varians
	Biddulphia sinensis
	Biddulphia longicrusis
	Chaetoceras affine
	Chaetoceras debilis
	Chaetoceras lorenzianum
	Cocconeis sp a/
	Coscinodiscus centralis
	Coscinodiscus debilis
	Coscinodiscus excentricus a/
	Coscinodiscus janishii
	Coscinodiscus lineatus
	Coscinodiscus radiatus a/
	Cyclotella meneghiana
	Grammatophora marina a/
	Licmophora flabellata
	Licmophora paradoxa a/
	Melosira borreri
	Melosira juergensii
	Navicula sp a/
	Nitzschia closterium a/
	Nitzschia longissima a/
Diatomacea (Cont'd)	Nitzschia seriata a/
	Nitzschia sigma a/
	Pleurosigma angulatum a/
	Pleurosigma hippocampus a/
	Rhizosolenia hebetata a/
	Rhizosolenia setigera a/
	Skeletonema costatum a/
	Surirella cuneata
	Surirella gemma
	Synedra sp
	Thalassiothrix curvata
	Thalassiothrix frauenfeldii
	Thalassiothrix gravida
	Thalassiothrix nitzschioides a/
Flagellata	Ceratium furca a/
	Ceratium fusus a/
	Dinophysis sp a/
	Glenodinium sp a/
	Peridinium sp a/
	Prorocentrum sp a/
	Protoceratium sp
	Pontosphaera sp a/
Infusoria	Dictyocha sp a/
	Tintinopsis sp
Crustacea	Copepoda
Mollusca	Larvae: Pelecypoda, Gastropoda

a/ Important species.
SOURCE: Seno and Hori, 1927.

TABLE 6. - SEASONAL CHANGES IN CHEMICAL COMPOSITION OF OSTREA GIGAS

Month	Weight of Meat (grams)	Water (percent of fresh meat)	Dry Matter (grams) a/	Dry Matter a/ (percent) Ash	Fat	Protein	Glycogen
Jan	13.5	74.0	3.457	7.3	9.4	35.5	4.6
Feb	14.1	74.4	3.566	6.3	10.4	32.5	5.7
Mar	17.2	79.0	3.591	5.9	9.6	30.5	5.5
Apr	15.4	74.6	3.854	5.7	10.1	36.9	4.0
May	12.7	76.3	2.990	7.0	9.6	43.2	2.4
Jun	12.4	79.8	2.533	9.7	9.6	43.5	0.8
Jul b/	6.8	76.4	1.621	8.4	3.5	38.8	0.9
Aug b/	7.2	84.6	1.144	10.8	6.0	51.7	0.4
Sep	9.2	84.7	1.415	9.3	5.8	43.3	0.7
Oct	15.5	80.6	3.017	9.6	6.0	40.4	1.8
Nov	15.1	68.1	5.582	3.7	5.1	23.0	4.2
Dec	20.2	79.6	4.098	5.7	9.3	31.7	3.7

a/ In analysis "dry matter" usually is divided into ash, fat, protein, fiber, and soluble nonnitrogenous substances, and the latter usually calculated as (solid - [ash + fat + protein + fiber]). In this experiment only glycogen in the nonnitrogenous substance has been measured.
b/ Spawning season
SOURCE: Sekine, Tatsuno, and Imamura (1929).

TABLE 7. - SEASONAL CHANGES IN GLYCOGEN CONTENT OF OSTREA CIRCUMPICTA

Date Collected	Glycogen in All Soft Parts	Glycogen in Meat, Except Muscle	Glycogen in Adductor Muscle
9 Mar	4.000	3.815	1.543
9 Apr	2.613	2.708	0.982
8 May	2.962	4.169	1.406
8 Jun	3.505	3.844	1.250
7 Jul	3.200	4.611	1.591
7 Aug a/	0.915	1.719	0.538
9 Sep a/	1.142	1.173	0.846
9 Oct	1.861	1.767	0.912
9 Nov	2.543	2.263	1.189
26 Dec	2.436	2.313	1.032
Jan	ND	ND	ND
10 Feb	3.560	2.763	1.456

a/ Spawning season
ND: No data available
SOURCE: Kobayashi (1929)

TABLE 8. - CHANGES IN COMPOSITION AND WEIGHT OF OSTREA GIGAS IN RELATION TO SPAWNING SEASON

(weight in grams per individual)

Date	Glycogen	Protein	Fat	Ash	Water
22 Jul	1.094	4.034	1.123	0.539	24.826
5 Aug a/	0.875	4.237	1.189	0.505	25.441
19 Aug a/	0.613	3.785	0.865	0.454	22.007
2 Sep a/	0.092	3.996	0.863	0.520	22.926
16 Sep a/	0.109	2.260	0.337	0.242	14.655
30 Sep	0.213	2.005	0.259	0.271	13.705
14 Oct	0.426	2.580	0.435	0.373	17.192
28 Oct	0.523	2.399	0.408	0.272	15.257
11 Nov	0.728	2.516	0.551	0.342	17.645

a/ Spawning season
SOURCE: Hatanaka (1940)

TABLE 9.- CHANGES IN CHEMICAL COMPOSITION IN BODY OF *OSTREA GIGAS* AT DIFFERENT SEASONS

Organ	Date	Dry Matter (percent)				Water
		Glycogen	Protein	Fat	Ash	(percent in fresh meat)
Mantle margin	26 May	29.15	34.69	18.11	5.58	81.19
	1 Aug	37.52	33.35	13.49	6.84	77.78
	23 Aug	35.44	36.07	12.49	6.65	78.83
	27 Sep	32.20	44.10	10.54	7.08	79.49
Gill	26 May	12.79	48.63	14.32	6.92	83.75
	1 Aug	21.94	46.63	11.15	7.74	84.54
	23 Aug	13.96	51.72	17.00	7.50	85.05
	27 Sep	10.21	ND	ND	ND	ND
Adductor muscle	26 May	8.36	65.38	10.51	5.77	76.65
	1 Aug	11.24	69.10	5.66	6.11	78.45
	23 Aug	6.55	70.51	4.81	4.92	78.01
	27 Sep	5.41	76.10	5.46	5.54	80.29
Gonad	26 May	34.01	31.31	18.81	2.48	73.63
	1 Aug	5.00	60.94	16.41	7.63	74.12
	23 Aug	1.94	66.16	17.95	8.33	76.97
	27 Sep	ND	ND	ND	ND	ND
Hepato-pancreas	26 May	23.77	40.44	18.03	5.38	74.38
	1 Aug	15.29	47.16	15.26	5.92	72.30
	23 Aug	16.14	51.63	13.68	6.33	74.64
	27 Sep	21.28	52.54	12.58	6.54	76.33
Entire body	26 May	24.50	40.25	15.95	5.02	77.19
	1 Aug	19.58	49.32	13.09	6.60	76.59
	23 Aug	20.44	52.52	13.18	6.40	77.82
	27 Sep	20.30	49.16	11.02	6.21	77.94

ND: No data available
SOURCE: Hatanaka (1940)

TABLE 10.- SPECIFICATIONS FOR RAFT, a/ HIROSHIMA PREFECTURE

Material	Specifications	Quantity
Poles	Pine or cedar; 7 meters long	40
Poles	Pine or cedar; 5 meters long	20
Wire	No 8	50 kg
Wire	No 10	90 kg
Nails	12 cm long	8 kg
Bamboo spacers	10-12 cm long	6,000
Fuel drums floats	Standard size	18
Collectors	Shells	10,000

a/ Raft 120 square meters in area
SOURCE: Hiroshima Fisheries Experiment Station

TABLE 11.- SPECIFICATIONS FOR RAFT, a/ MIYAGI PREFECTURE

Material	Specifications	Quantity
Poles	Cryptomeria; 7-8 meters long; 35-40 cm diameter at base	30
Nails	12 cm and 15 cm long	7 kg
"A"-type anchor	Pine; 2 meters long; 1 meter nose	4
Straw anchor rope	3-rope twist; tarred	16 kan or 60 kg
Barrel floats	Cryptomeria; 1 meter diameter	10
Cooling	Coal tar	5 drums
Shell collectors	80 shells per string	70 strings
Straw rope	1 cm diameter	75 kg

a/ Raft 50 square meters in area
SOURCE: Miyagi Fisheries Experiment Station

TABLE 12.- SPECIFICATIONS FOR BAMBOO RACK, a/ HIROSHIMA PREFECTURE

Material	Specifications	Quantity
Bamboo *Phyllostachys reticulata*	Diameter, 6-7.5 cm; length, 2 meters	250
P. nigravar henonis	Diameter, 6-7.5 cm; length, 2 meters	96
Wire	No 10; 40-cm lengths	250 (12.5 kg)
Wire	No 10; 2-meters lengths	1,200 (22 kg)
Nails	No 12; 5-cm lengths	1,200 (32 kg)
Bamboo spacers	10 cm long	21,500
Collectors	Shells	20,000

a/ Area of rack, 0.245 acre.
SOURCE: Hiroshima Fisheries Experimental Station

TABLE 13.- SPECIFICATIONS FOR UMBRELLA RACK, KUMAMOTO PREFECTURE

Material	Specifications	Quantity
Upright center pole	Pine or oak; 2 meters long; 10 cm diameter	1
Radiating strings	ND	16
Nail	10-12 cm long	1
Galvanized wire	No 12; 2-meter lengths	16
Bamboo spacers	12 cm long	208
Collectors	Shells	208

SOURCE: Ota (1946)

TABLE 14. - PRODUCTION OF UNSHUCKED EDIBLE OYSTERS, 1908 - 45
(metric tons)

Year a/	Natural Production	Cultured	Total
1908	12,352	ND	12,352
1909	15,198	ND	15,198
1910	15,847	ND	15,847
1911	14,636	ND	14,636
1912	20,553	14,222	34,775
1913	24,787	18,172	42,959
1914	23,733	18,090	41,823
1915	29,092	19,961	49,053
1916	38,021	21,105	59,126
1917	35,775	20,692	56,467
1918	34,788	21,736	56,524
1919	44,355	30,117	74,472
1920	40,035	29,522	69,557
1921	36,551	30,500	67,051
1922	12,288	24,901	37,189
1923	8,261	14,977	23,238
1924	7,620	13,612	21,232
1925	7,023	14,023	21,046
1926	11,512	18,618	30,130
1927	11,752	20,937	32,689
1928	9,761	21,416	31,177
1929	12,086	25,495	37,581
1930	9,045	19,037	28,082
1931	11,801	25,861	37,662
1932	11,043	25,123	36,166
1933	9,397	26,884	36,281
1934	10,042	43,228	53,270
1935	11,692	59,943	71,635
1936	11,966	59,029	70,995
1937	7,586	56,060	63,646
1938	8,347	45,545	53,892
1939	7,083	41,567	48,650
1940	7,162	46,337	53,499
1941	17,025 b/	88,414	105,439
1942	14,396 b/	121,418	135,814
1943	14,745 b/	121,511	136,256
1944	32,300 b/	139,253	171,553
1945	16,800 b/	99,549	116,349
TOTAL	666,456	1,396,855	2,063,311

a/ No complete data available after 1945
b/ Estimates by Japanese Bureau of Fisheries (now Fisheries Agency, Ministry of Agriculture and Forestry).
ND: No data available
SOURCES: Statistic Year Book, Ministry of Agriculture and Forestry; Natural Resources Section Report No 95, Japanese Fisheries Production, 1908-46, 15 Oct 47.

TABLE 15.- SEED OYSTERS EXPORTED FROM JAPAN TO THE UNITED STATES, 1925-49
(cases a/)

Year	Case	Dollar Value	
		Per Case	Total
1925-26	1,400	ND	ND
1926-27	3,200	4.50	14,400
1927-28	2,800	4.50	12,600
1928-29	8,000	4.50	36,000
1929-30	14,000	4.00	56,000
1930-31	16,000	4.00	64,000
1931-32	30,453	3.00	91,359
1932-33	47,392	2.50	118,480
1933-34	68,103	2.00	136,206
1934-35	65,007	2.00	130,014
1935-36	42,097	3.20	134,710
1936-37	32,993	3.50	115,475
1937-38	17,788 b/	3.70	65,816
1938-39	18,529 b/	3.70	68,557
1939-40	14,839	3.80	56,388
1940-41	15,638	3.80	59,424
1946-47	56,619	c/	214,655
1947-48	33,359 d/	e/	120,501
1948-49	46,734 f/	g/	189,672
1949-50	46,956	h/	185,028
TOTAL	581,907		1,869,285

a/ Wood box, 38x18x12 inches; weight 165 pounds for broken shell, 110 pounds for unbroken shell.
b/ Reported figures, exclusive of estimated unreported shipments of 43,000 cases for 1937 and 33,000 cases for 1938.
c/ Unbroken, 35,733 cases at \$3.40; broken, 20,896 cases at \$4.46.
d/ All shipments prior to and including 1947 are from Miyagi Prefecture to United States ports of entry; some being consigned to Canada.
e/ Unbroken, 23,198 cases at \$3.40; broken, 9,461 cases at \$4.40.
f/ Includes 1,000 cases from Kumamoto Prefecture.
g/ Unbroken, 21,391 cases at \$3.50; broken, 25,343 cases at \$4.53.
h/ Unbroken, 21,578 cases at \$3.40; broken, 25,378 cases at \$4.40.
ND: No data available
SOURCE: Data for 1925-38 from Fisheries Agency based on records of Miyagi Seed Oyster Cooperative Assn; data after 1938 from Tokyo Food Product Co records.

TABLE 16.- EXPORT OF SEED OYSTERS TO COUNTRIES OTHER THAN UNITED STATES AND CANADA, 1934-49
(cases a/)

Year	China	Manchukuo	Okinawa	Australia	Hawaii	Total
1934	86	0	0	0	0	86
1935	26	0	0	0	0	26
1936	207	0	0	0	0	207
1937	929	0	0	0	0	929
1938	172	2	0	0	217	392
1939	32	0	0	0	15	47
1940	0	0	0	10	20	30
1941	4	7	0	0	19	30
1942	0	5	0	0	0	5
1947	0	0	550	50	0	600
1948	0	0	675	50	0	725
1949	0	0	172	0	0	172
TOTAL	1,457	14	1,397	110	271	3,249

a/ Case of 110 pounds. Converted from original data, in which unit is 100 kin.
SOURCE: Finance Ministry, Annual Return of Foreign Trade of Japan.

TABLE 17. - DOMESTIC DISTRIBUTION OF SEED OYSTERS PRODUCED IN MIYAGI PREFECTURE, 1942-47
(ren a/)

Prefecture	1942	1943	1944	1945	1946	1947	Total
Hokkaido	32,000	42,000	82,681	0	53,159	10,000	219,840
Aomori	500	300	700	0	700	4,500	6,700
Iwate	148,870	165,000	149,920	60,000	98,372	85,550	707,712
Niigata	79,200	82,320	44,546	0	18,000	23,500	247,566
Tokyo	4,000	8,000	12,749	0	0	0	24,749
Ibaraki	0	300	500	0	0	0	800
Chiba	0	0	100	0	0	1,268	1,368
Aichi	1,500	1,200	0	0	0	130	2,830
Shizuoka	85,000	89,385	62,115	0	16,425	25,700	278,625
Mie	73,200	78,570	50,284	0	41,127	73,200	316,381
Ishikawa	20,820	19,850	17,500	0	17,750	19,010	94,930
Fukui	17,230	21,120	15,363	0	11,716	12,565	77,994
Kyoto	2,000	5,000	7,980	0	19,435	23,810	58,225
Tottori	7,300	12,800	5,106	0	7,300	6,100	38,606
Hyogo	0	0	0	0	60	0	60
Shimane	82,000	86,072	116,521	0	26,751	45,800	357,144
Hiroshima	0	7,529	0	0	0	0	7,529
Okayama	12,000	11,000	8,100	0	10,635	8,990	50,725
Wakayama	2,000	2,500	1,500	0	0	70	6,070
Kochi	3,700	5,300	4,000	0	7,095	0	20,095
Yamaguchi	7,500	8,000	6,484	0	1,200	25	23,209
Ehime	2,000	2,000	2,614	0	700	165	7,479
Oita	1,000	1,000	1,468	0	2,200	2,400	8,068
Miyazaki	0	0	0	0	1,240	4,330	5,570
Miyagi	250,380	281,030	200,604	138,740	182,959	57,070	1,110,783
TOTAL	832,200	930,276	790,835	198,740	516,824	404,183	3,673,058

a/ Series of 70-100 collectors strung on a 1.5-meter wire; 140 ren equals 1 case.
SOURCE: Miyagi Prefecture, Fisheries Section, 1948.

End

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