Bulletin 169

PACIFIC OYSTER CULTURE in British Columbia

by D. B. Quayle

Fisheries Research Board of Canada, Ottawa, 1969

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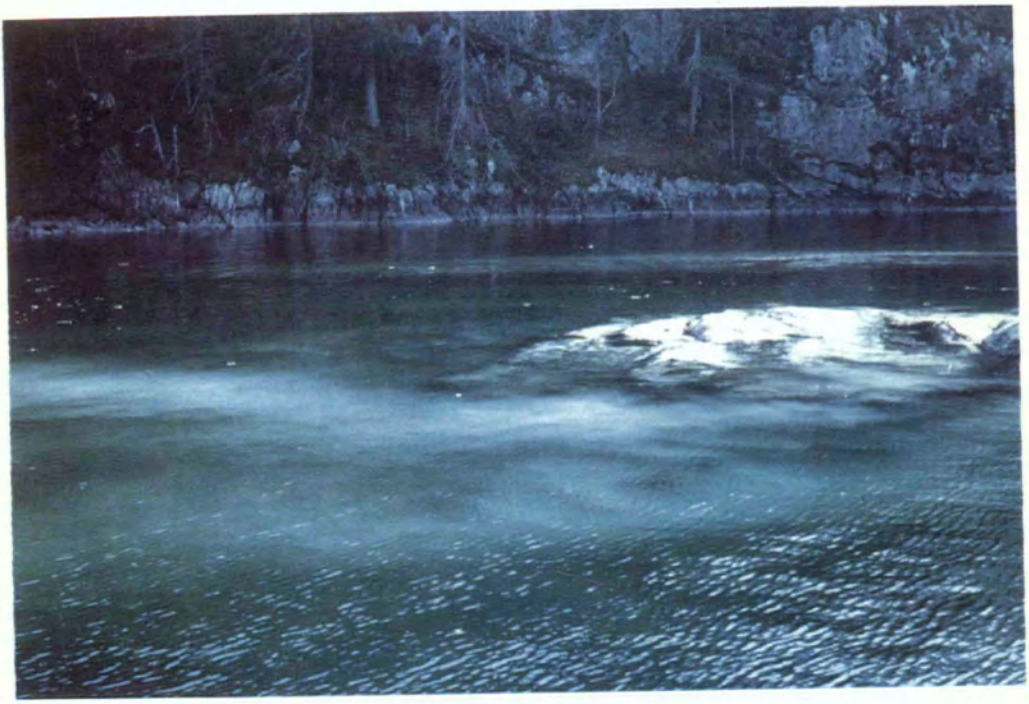

Spawning of Pacific oysters in Pendrell Sound.

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By D. B. Quayle

Fisheries Research Board of Canada
Biological Station, Nanaimo, B.C.

FISHERIES RESEARCH BOARD OF CANADA

Ottawa 1969

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The Queen's Printer
Ottawa, Canada
1969

Bulletins of the Fisheries Research Board of Canada are designed to assess and interpret current knowledge in scientific fields pertinent to Canadian fisheries. Recent numbers in this series are listed at the back of this Bulletin.

Fisheries Research Board of Canada
Office of the Editor
116 Lisgar Street
Ottawa 4, Ontario, Canada

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Contents

Contents — Continued

Contents — Continued

Contents — Continued

ABSTRACT

Of the three species of oysters *(Crassostrea gigas, Crassostrea virginica, Ostrea lurida)* that occur in British Columbia, only the imported Japanese oyster *(C. gigas)* is cultured at the present time.

The anatomy of *C. gigas* is described in some detail. Sexes are separate but may change over winter. Gonads develop in spring and are generally ripe by mid-May with spawning during July and August. The larval period lasts between 15 and 30 days depending on temperature.

Growth of the Pacific oyster *(C. gigas)* is very variable but in the Strait of Georgia few oysters are marketed before 3 years of age. The condition of oysters is also variable but optimum fatness occurs during April.

Successful breeding of the species in British Columbia is irregular except at Pendrell Sound. Spawning occurs frequently but the larvae fail to survive. Widespread breeding in all Strait of Georgia growing areas produced extensive "wild" populations in 1942 and 1958. The standard cultch used for collecting seed is the string of punched oyster shell. These are usually suspended from rafts, for cultch placed on the shore is much less efficacious. Various other cultch materials have been used including cement-dipped wood-veneer circles. Spatfall forecasts are made for Pendrell Sound where unique hydrographic and topographic features make the area a consistent seed producer.

Japanese seed is also collected on shell cultch and is shipped in early spring as deck cargo in wooden cases. Japan, originally the sole source of seed, now exports very little to British Columbia.

Oyster ground, whether used for planting seed, growing, or fattening, should be at the correct tide level. This is usually in the lower third of the tidal zone, with the firmest available bottom consistency and protected from excessive wave action. The seed is spread on ground which is firm in order to reduce silting mortality. The standard planting density is about 25–50 Japanese seed cases or its equivalent per acre and this represents between a quarter and half a million spat. After a year on the seed ground the clusters are separated either by hand or by dragging the bed with a spring-toothed harrow. The broken clusters may be transplanted to a growing area and even subsequently to fattening ground. The number of transplanting operations is variable depending on the type and amount of ground available.

The oysters are harvested either by hand-picking at low tide or by drag or hydraulic dredge at high tide and taken to the shucking house. Shucking is done entirely by hand under strict sanitary regulations which also cover washing, packing, storing, and shipping.

Productivity of an oyster bed is influenced by the oyster growth rate, condition, and mortality. The causes of mortality include predation, disease, competition for space on the shell, silting, and cluster separation.

Oyster production in British Columbia began as early as 1884 with the native oyster *(O. lurida)*. From a value of $100,000 in 1944, almost entirely from Pacific oysters, production rose in 1963 to a value of $635,000 for 170,375 gallons, equivalent to about 1,400,000 pounds of meat. Since then production has dropped slightly. The half-shell trade in Pacific oysters is extremely small and virtually all are marketed either for table use or as soup and stew. There is a small production of canned smoked oysters.

Pollution is an increasingly serious problem. The sources of industrial pollution are pulp mills, log booming, and mining operations; bacteriological pollution emanates from improper sewage disposal in built-up areas. Paralytic shellfish poison may also occur in oysters.

Predator and pest problems are relatively few. Among the serious predators are sea stars, drills, and crabs.

Foreshore is held by the Crown in the right of the Province and is leased for oyster culture by the British Columbia Department of Lands.

Administration of the oyster industry involves a number of departments of both the Federal and Provincial Governments.

The future of the industry depends on how well the problems of pollution and industrial encroachment are solved. Production from the relatively small amount of intertidal ground will be unable to supply the expanding market as the population grows. It will be necessary to utilize marginal ground, subtidal areas, and raft culture techniques.

INTRODUCTION

This is essentially a revision and expansion of a 1933 Bulletin of the Biological Board of Canada (now the Fisheries Research Board of Canada) entitled "Oysters in British Columbia" by C. R. Elsey (No. 34). Since the publication of that bulletin, which has been out of print for many years, there have been many significant changes in the industry. Some of the growers now operating are relatively new to the oyster industry and this new bulletin may assist in providing them with technical information of which they may be unaware. It may also cause experienced growers to take a new look at their operations.

Only the Pacific oyster is considered since the other species that occur in British Columbia have no economic significance at the present time.

HISTORY

Production records show that the native oyster *(Ostrea lurida)* was marketed in British Columbia as early as 1884, although undoubtedly it was used before then. This was the only oyster available until 1903, at which time the eastern or Atlantic species *(Crassostrea virginica)* was introduced into Boundary Bay, and Esquimalt and Ladysmith harbours (Fig. 1). Only limited success was obtained with this oyster at the Vancouver Island sites, but in Boundary Bay results were better and varying numbers were planted until about 1940. At first they were grown to a marketable size from seed procured from the Atlantic coast but high mortality rates soon discouraged this practice, so, instead, 3- or 4-year-olds were relaid for a year or so for a half-shell (raw oyster) market; but even with these older oysters, mortality still amounted to about 25% in one year of relaying.

Breeding of the Atlantic oyster was limited to the estuaries of the Serpentine and Nicomekl rivers which flow into Boundary Bay. By 1930 there were probably 5000 bushels on the bars in these rivers. However, the populations have declined markedly, and now only a few are to be found there.

By 1936 production of both native and eastern oysters had virtually ceased. In British Columbia the native oyster had never been properly cultured as it was in Puget Sound. Being essentially a fishery, its final depletion occurred about the time the Japanese oyster began to flourish. In addition to depletion by fishing, heavy frosts in 1929 destroyed a considerable proportion of the population in Ladysmith Harbour and a later mortality, about 1940, destroyed many of what were left of the native oysters in Boundary Bay.

The Japanese oyster *(Crassostrea gigas)* was first introduced into British Columbia waters about 1912 or 1913 when a few were planted in Ladysmith Harbour and, it is believed, in Fanny Bay. By 1925 there was evidence that some breeding had occurred in Ladysmith Harbour, for a few oysters were found attached to large

rocks. The first significant importation of Japanese oysters took place in 1926 when about 2000 oysters, 2–3 years old, were obtained from Samish Bay in Washington, and 20 cases of seed came directly from Japan. These averaged one year in age and were spatted on brush.

Between 1929 and 1932, approximately 4 million seed oysters were imported. Also small numbers of naturally set oysters were found as a result of spawnings in Ladysmith Harbour in 1926, 1930, and 1931. The first major spawning there occurred in 1932 and this was the beginning of a series of breedings of some magnitude in this harbour.

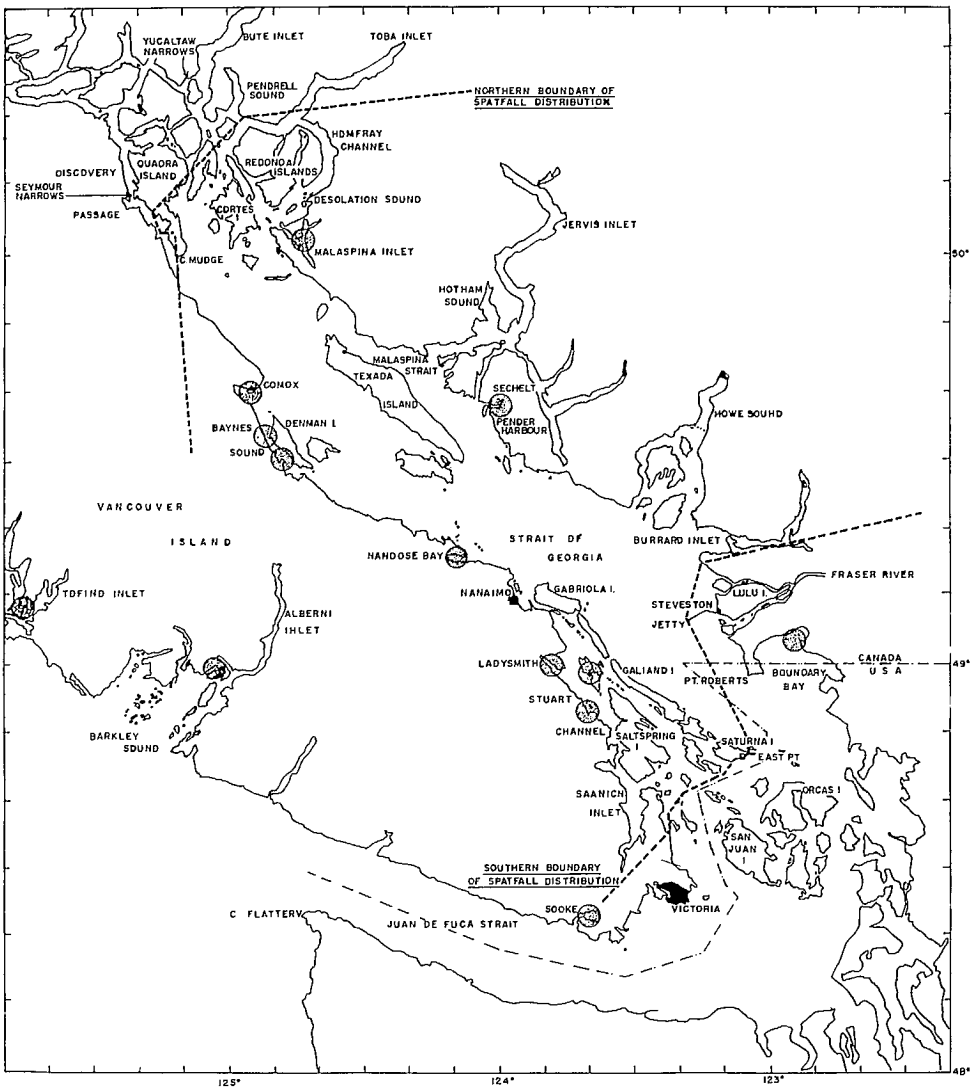


FIG. 1. Map of British Columbia coast with oyster-growing areas marked in circles. The heavy broken line shows the limits of the 1958 spatfall distribution.

Subsequently, Japanese oysters were introduced by planting imported seed into a number of areas in the Strait of Georgia such as Pender Harbour, Boundary Bay, and Baynes Sound. In 1942, there was a general breeding in all of these areas, and many beaches, particularly in the northern part of the Strait of Georgia and in the Gulf Islands, were heavily seeded. These "wild" oysters, as they were called, provided a supply that replaced, in part, the normal requirements for Japanese seed, the importation of which was suspended during World War II.

In 1958 there was prolific and widespread breeding of the Pacific oyster (as the Japanese species came to be called); this has had a significant effect on the industry. It has used these wild stocks to a very considerable extent and as a consequence this replaced Japanese seed, the importation of which virtually ceased about 1961. Also, the increased supply of oysters demonstrated that the market potential was greater than had been previously realized.

Another major event in the history of oyster culture in British Columbia was the development of Pendrell Sound as a seed-producing area and the decision to prohibit leasing there. The Order-in-Council designating the reserve there is shown in Appendix A.

The introduction in 1949 of the first comprehensive set of regulations for the sanitary control of the shellfish industry was a significant milestone and changed oystering from a relatively disorganized business into a stable, responsible industry.

Beginning, in 1963, with closures and restrictions on certain oyster beds, and followed by others in 1964 and 1965, sewage pollution became a serious problem for the oyster industry. The attendant publicity, which had an effect on sales, brought to the industry an awareness of this problem which it previously did not have. As a result, the dormant British Columbia Oyster Growers Association was reorganized and at the present time is an active force in the affairs of the oyster industry. A further important event was the formation of a Shellfish Marketing Board in 1964. Several outbreaks of paralytic shellfish poisoning (see page 151) since 1957 have caused temporary marketing difficulties.

While problems, particularly that of sewage pollution, beset the industry, there is no reason why these cannot be solved with ingenuity and determination. The growing population will inevitably increase the demand for oysters and as there is only a limited amount of growing ground, the industry will have to utilize the available ground more effectively than it has in the past and be prepared to accept changing concepts, and other methods of oyster culture.

TAXONOMY

The species with which this bulletin is concerned is the Pacific oyster. Earlier it was referred to as the Japanese oyster because of its origin. The scientific name, *Crassostrea gigas* (Thunberg), is used to distinguish it from the many species of oysters that occur in Japan and other parts of the world.

The two main groups of commercial oysters are readily separable on the basis of anatomical and of breeding differences. In the *Ostrea* type, to which the British Columbia native oyster belongs, the eggs are discharged into the inhalant chamber where fertilization, and the initial stages of development occur. In the genus

Crassostrea, to which the Pacific and eastern oysters belong, the eggs are discharged into the open water where fertilization and all subsequent development takes place. In this form also, there is an additional exhalant water outlet, the promyal chamber, which does not occur in *Ostrea.* The latter type is considered to be adapted to clear-water environments while *Crassostrea* is better adapted to muddy estuarine waters.

The name of the Pacific oyster *(Crassostrea gigas),* when analysed, means *Crass,* thick + *ostrea,* oyster + *gigas,* huge. The name of the native oyster *(Ostrea lurida)* means the lurid or yellow oyster.

About 100 named species of oysters occur throughout the world but there may, in fact, be fewer, because so many of them have been named mainly on the basis of shell characteristics, which are now known to be extremely variable.

Originally, all North American oysters were called *Ostrea* but, in 1950, it was suggested there should be separation of the two basic types and now both *Crassostrea* and *Ostrea* are generally accepted. The name *Crassostrea* was validated in 1955 in accordance with the rules of the International Commission on Zoological Nomenclature.

Gryphaea, which was the generic name applied to the Portuguese oyster, is now used only for a certain group of fossil oysters and the living oyster has been renamed *Crassostrea angulata.*

TABLE I. Comparative characteristics of the oyster species found in British Columbia.

Scientific name:	*Ostrea lurida*	*Crassostrea virginica*	*Crassostrea gigas*
Common name:	native or Olympia	eastern or Atlantic	Pacific or Japanese
Anatomy:	without promyal chamber	with promyal chamber	with promyal chamber
Adductor muscle scar:	without pigment clearly outlined	dark purple or brown sharply outlined	mauve or white not clearly outlined
Size:	2 inches	3–4 inches	4–6 inches
Concentric growth:	indistinct	flat but clear	projecting with flutings
Colour inside shell:	green iridescent	white	white
Colour outside shell:	gray with dark purple	yellow brown	gray with purple
Radial grooves:	not apparent	barely apparent	generally deep

Descriptions of the three species of oysters found in British Columbia are given below, and Table I and Fig. 2 show comparative characteristics.

NATIVE OYSTER

Ostrea lurida (Carpenter) is the native, or Olympia oyster as it is called in Washington State, and was named by the conchologist P. P. Carpenter in 1864 from specimens taken in Willapa Harbor, Washington. This oyster is generally circular in outline and small in size, seldom exceeding a diameter of 2 inches in British Columbia. Externally, the shell is gray and seldom fluted. Internally, the shell is quite nacreous and often iridescent olive-green or yellow. The shell edges near the hinge have a series of tiny teeth not present in the *Crassostrea* types. The

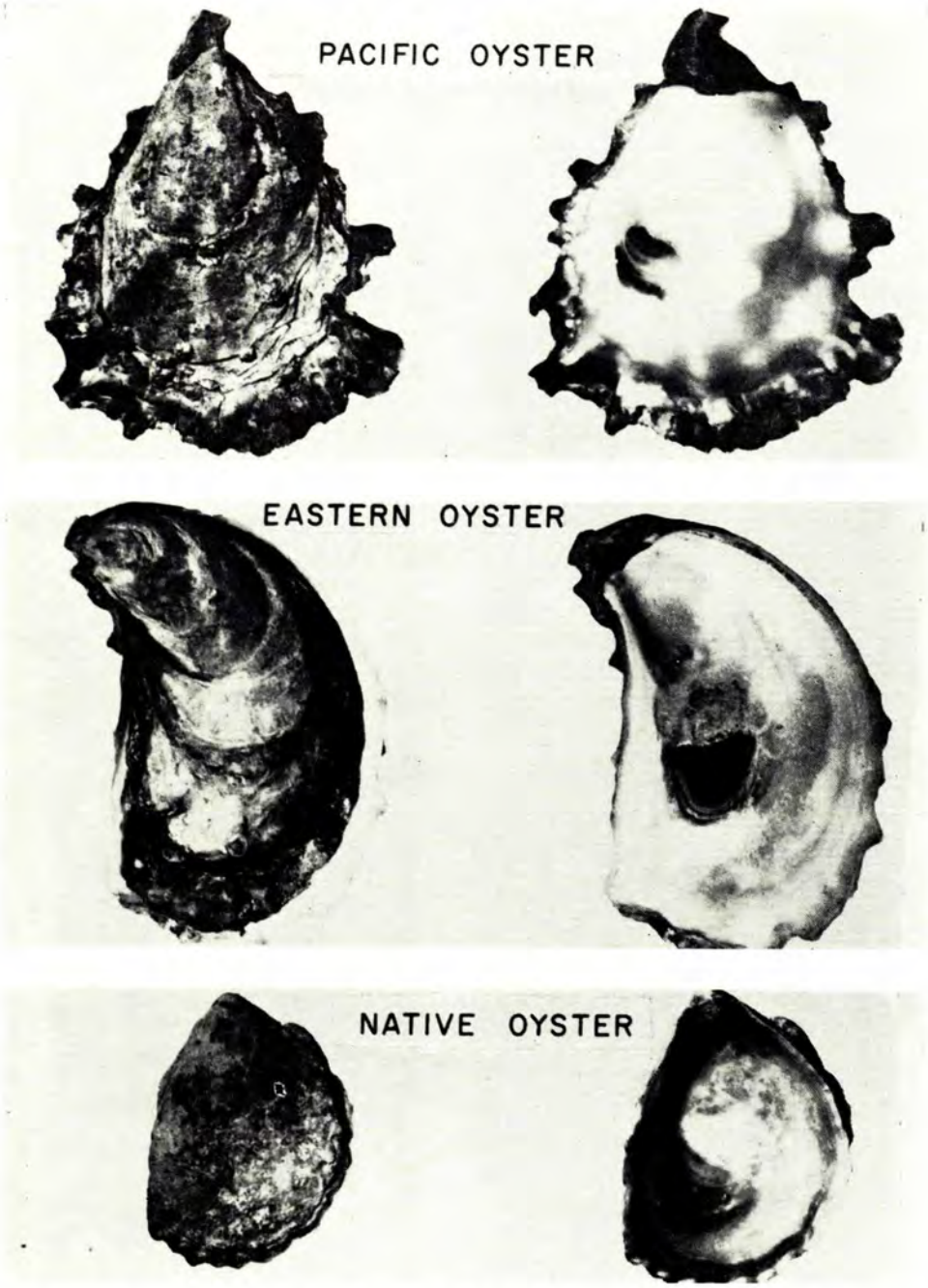


FIG. 2. The three species of oyster that occur in British Columbia: Pacific oyster *(Crassostrea gigas)*, × 0.5; Eastern oyster *(Crassostrea virginica)*, × 1; native or Olympia oyster *(Ostrea lurida)*, × 0.75.

species is distributed from Alaska to lower California, chiefly in estuaries and salt-water lagoons. It occurs in numerous places in British Columbia, but nowhere in abundance. Some of the areas where it may be found at present are the Gorge near Victoria, Ladysmith, Van Donop Creek on Cortes Island, Pendrell Sound, Toquart on the west coast of Vancouver Island as well as in most other inlets there, Blunden Harbour in Queen Charlotte Sound, and Campbell Island near Namu.

Eastern Oyster

Crassostrea virginica (Gmelin) is the Virginia, eastern, or Atlantic oyster and was named by Gmelin in 1792. This is a fairly large oyster, up to 6 inches in length and normally somewhat pear-shaped in outline. Externally, the shell is fairly smooth but with definite concentric sculpture; it is light brown or yellow. Internally, the shell is smooth and white, with the black, brown, or dark blue scar of the adductor muscle quite deeply impressed. On the Atlantic coast, it ranges from the Gulf of St. Lawrence to the Gulf of Mexico and the West Indies. On the Pacific coast, it was introduced to San Francisco Bay, Willapa Harbor, and Puget Sound in Washington, and to Boundary Bay, Esquimalt Harbour, and Ladysmith Harbour in British Columbia. In general, it may be said that it failed to become established, although a small breeding population still exists in the river estuaries of Boundary Bay.

Pacific Oyster

Crassostrea gigas (Thunberg) is the Japanese, Pacific, or Miyagi oyster named by Thunberg in 1795. As the name indicates, this is a large oyster and attains a length of at least 12 inches. The shape is very irregular and depends on the type of

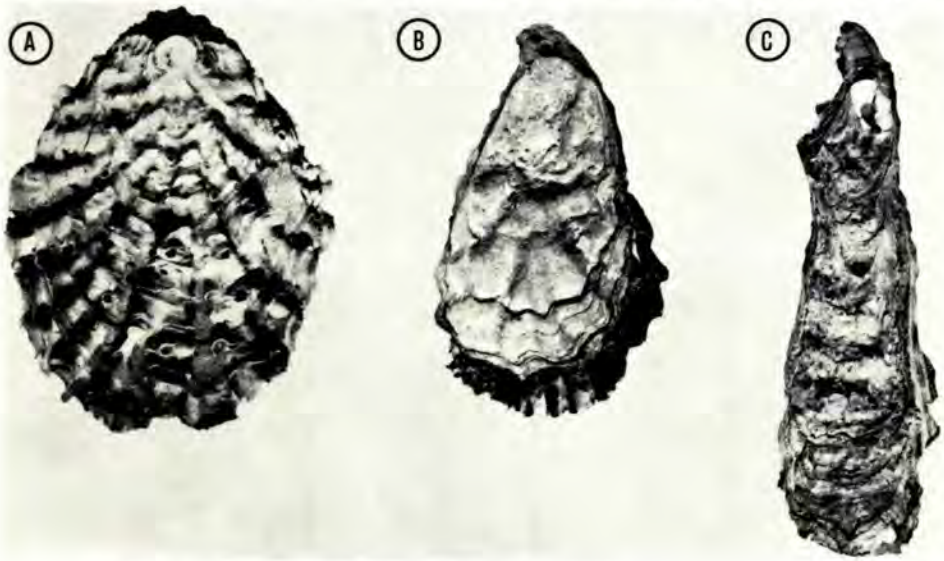


Fig. 3. Three basic shell types of the Pacific oyster.
A—round fluted type from hard gravel. × 0.5.
B—smooth type grown on fairly soft ground. × 0.5.
C—long smooth type grown crowded on muddy ground. × 0.3.

bottom on which it is grown, as well as on the degree of crowding. The external surface may be either quite smooth or highly fluted (Fig. 3). The colour, particularly the flutings, may be brown or purple but is mainly gray. The upper flat right valve is smaller than the lower cupped left valve. The interior of the shell is normally pure white with a smooth polished surface, often with a few irregularly shaped chalky areas. The adductor muscle scar is not as well defined as that of *C. virginica* and is usually light mauve.

In Japan, *C. gigas* exists in several forms or races in different parts of the country. On the northernmost island of Japan, there occurs the Hokkaido type which is characterized by very fast growth, large shallow shells, and by its colour, gray-white. Further south is found the Miyagi type with colour and shell depth intermediate between the Hokkaido and the more southerly Hiroshima type which has still slower growth, a smaller quite deep shell, and is blackish purple and brown. Finally, in the extreme south of Japan a stunted form of *C. gigas* occurs called the Kumamoto oyster after the name of its main production area.

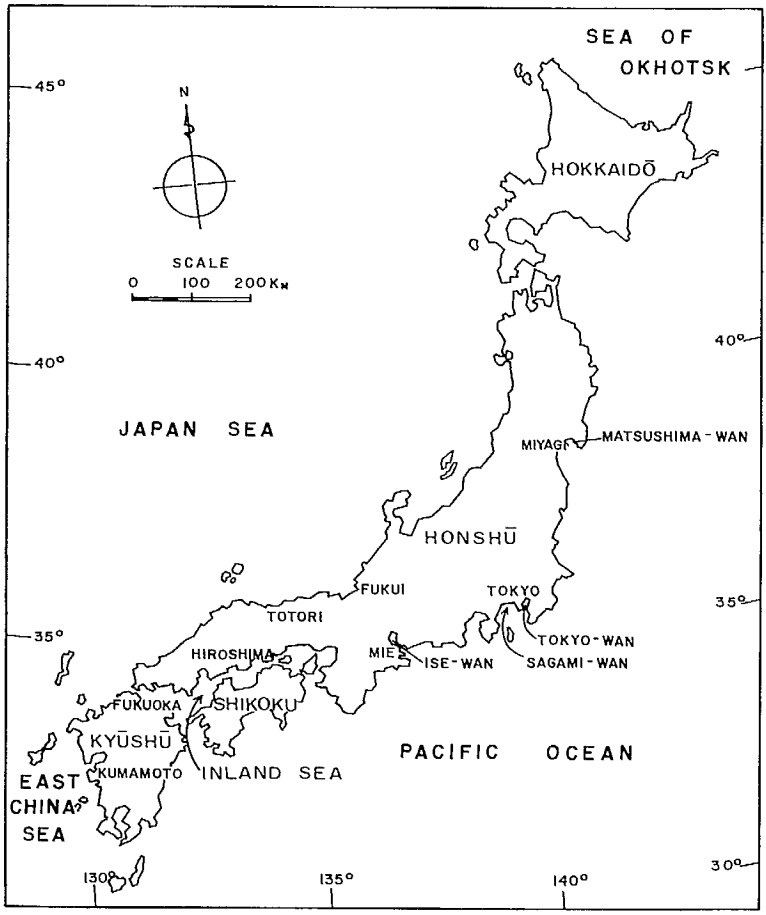


FIG. 4. Map of Japan showing place names of the main oyster growing areas.

The only Japanese seed that has been imported into British Columbia is the Miyagi type which originates from Miyagi Prefecture (Province) near Sendai (Fig. 4). Small quantities of the Kumamoto-type seed are imported into the State of Washington where the small size makes it a useful substitute for the native or Olympia oyster. For many years the importation of Kumamoto oysters into British Columbia was prohibited because it was not known whether it would cross-breed with the Miyagi type to produce a less desirable oyster. However, experience in the State of Washington indicates this possibility is unlikely and there is now no objection to its use in this province.

Hybrids

A number of attempts to cross-breed various species of oysters have been made. The most detailed attempt was made in Japan where the various races [Kumamoto (south), Hiroshima (central), Miyagi and Hokkaido (north)] of oysters which inhabit different sections of the country were cross-bred to the third generation. It was shown that the characters of the cross-bred oysters maintained a position intermediate between the two parents in shell dimensions, shell flatness, and colouration. The hybrid oysters showed greater adaptability to a variety of environmental conditions than did the parent strains.

Although cross-fertilization between *C. gigas* and several species such as *C. virginica, C. echinata, C. rivularis,* and *C. angulata* could be achieved, only that with *C. angulata,* the Portuguese oyster, resulted in viable hybrids. It would therefore seem possible to breed oysters selectively for certain specific characteristics, this being an area where oyster hatcheries may be of use.

ANATOMY

The anatomy of the oyster and the functions of the various organs are described in some detail, for this will enable the oyster grower to understand the influence on the oyster of various factors in the external environment, such as pollution, silting, and temperature changes.

Shell

Since the oyster is an invertebrate animal, it has no backbone or true internal skeleton. Its shell, however, forms a protective outer covering for the soft body. The two valves being different in form, the shell is said to be inequivalve; what is known as the lower or left valve is somewhat larger and more deeply cupped than the upper, flatter, right valve. One end of the valves is pointed (where they are hinged) and is designated as the head, anterior end, or umbonal area, for this is the region where the mouth of the animal is located. If the oyster is placed on its edge with the anterior end directed to the right and with the cupped valve away from the observer, then the lower part of the shell and body is the ventral or belly section and the upper edge of the shell and body is the dorsal or back section (Fig. 5).

The shells of oysters are extremely variable in shape and in surface sculpture. Shape is generally a result of the type of ground on which the oysters are grown or on the degree of crowding, particularly on the mother shell to which the oysters have

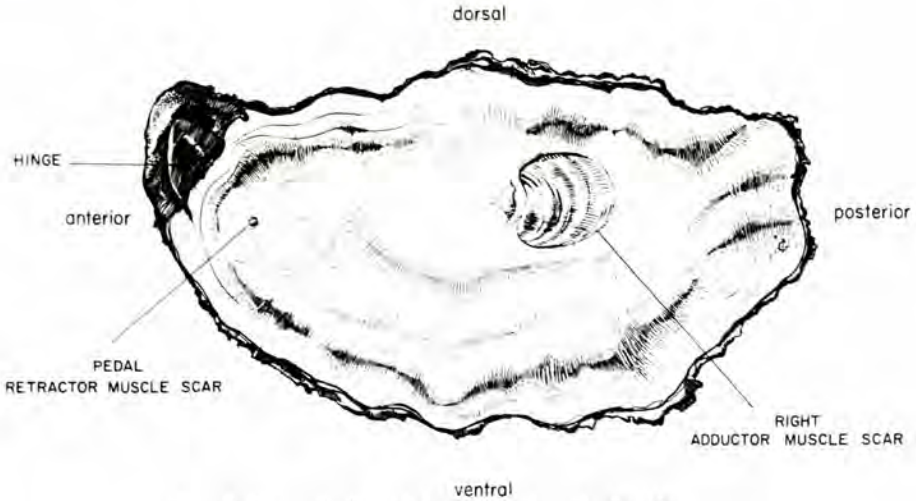


FIG. 5. Internal view of the right valve of a Pacific oyster.

become attached originally. If grown on hard, pebbly ground without being crowded, they tend to become round, deeply cupped with a high degree of fluting on the outer surface, particularly of the right valve. If they are grown on soft ground, they tend to become long and narrow with the surface of the shell smooth. If they are grown in water of low salinity, the shells are soft, and in high salinity, hard and brittle. If crowded, they grow long and narrow (Fig. 3). There are generally markings on the shell showing growth increments, but whereas it is generally possible to determine the age of a clam from these marks or checks which are the result of the cessation of growth during winter, this is not possible with oysters because of the frequency of what are known as disturbance checks. Thus the age of an oyster is determinable only from a knowledge of the time when it was spatted.

The shell itself is composed of the three main layers common to most molluscan shells (Fig. 6). Externally, there is a thin horny layer known as the periostracum. Initially, this completely covers the whole outside of the shell, but in many species it is so thin and delicate it is soon worn away. However, in such molluscs as the razor clam and the horse clam, the periostracum is quite thick and is retained to a considerable extent on the adult shell. Immediately under the periostracum lies a layer the framework of which is made up of a material called conchyolin, but which is largely composed of vertical prisms of calcite, a chalky material. The third and innermost layer of shell, which lies next to the body of the oyster, is composed largely of hard aragonite, but here the plates lie flat. This is called the nacreous layer and forms the mother-of-pearl from which pearls are formed.

Often superimposed on the nacreous layer are irregularly shaped deposits of chalky shell soft enough to be marked with the fingernail (Fig. 7). These are thought to be attempts by the oyster to contour the inner surface. Sometimes very definite chambers are formed by secreting well away from the nacreous surface an additional thin layer of nacreous material that contains very little calcium. The chamber may be filled with sea water or sometimes with a jellylike material. This condition,

called chambering, is believed to be caused by shrinkage of the mantle tissue, which secretes the shell, the probable function of the process being to reduce the internal volume of the shell. Shrinkage of mantle tissue may be caused by drastic changes in salinity, by injury, or by decimation of the whole body of the oyster.

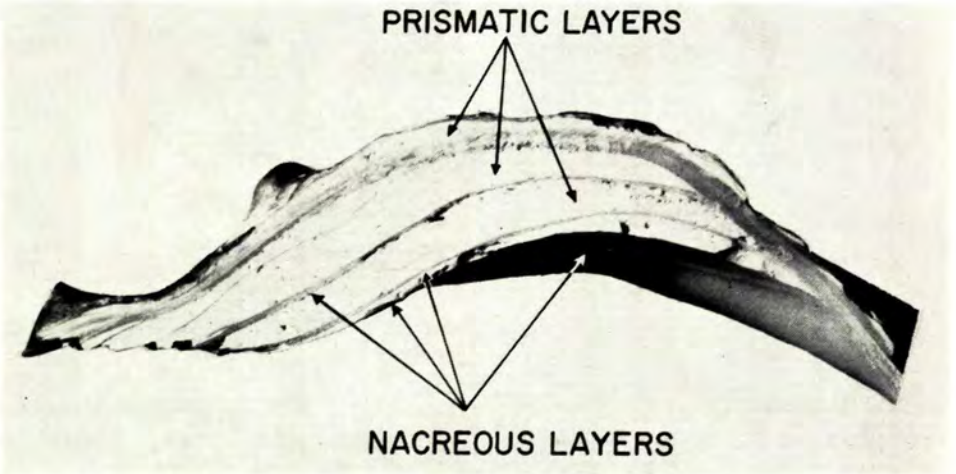


FIG. 6. Section of the shell of a Pacific oyster cut through the hinge to show the shell layers.

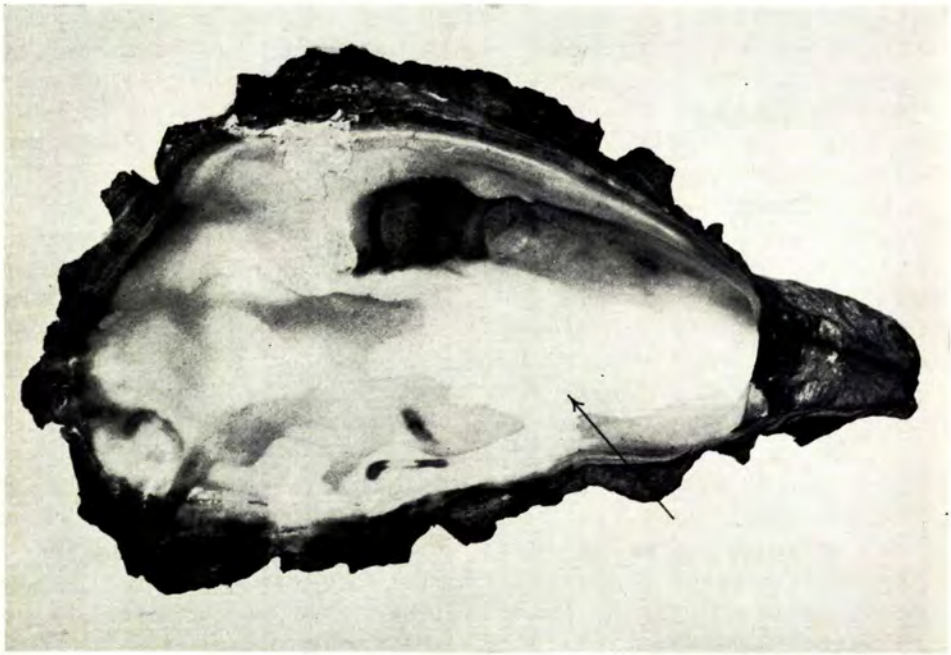


FIG. 7. Interior of Pacific oyster shell to show the white chalky shell deposits (indicated by arrow).

The hinge ligament of the oyster, located at the pointed umbonal region (Fig. 5), is quite different in structure and function from the shell. The purpose of the hinge is to spring the valves apart, and it acts in opposition to the adductor muscles which hold the valves together and adjust the distance the valves are allowed to separate. The hinge is formed of horny conchyolin similar to that of the main shell but the amount of calcification is very much reduced, resulting in an elastic, compressible material. The action of the hinge of a bivalve mollusc is more readily seen in clams such as the horse clam *(Tresus)* with an internal ligament or the butter clam *(Saxidomus)* with an external ligament.

When the oyster dies or the body is removed without damaging the hinge, the two valves tend to spread apart and such an oyster is called a "gaper" although this term often refers to an open oyster with at least some meat remaining. Completely empty shells are known as "boxes" or "cluckers." As the oyster grows, the hinge ligament also grows by addition to the edges and to the under surfaces. At the same time the exposed areas of the ligament are being eroded away.

Pearls

Pearls are essentially a bit of molluscan shell formed by the mantle tissue to protect the oyster from an irritant such as a sand grain or encysted parasitic worm.

It is often asked whether or not British Columbia oysters are able to produce pearls. Although *Crassostrea* is only very distantly related to the true pearl oyster (which, in fact, is not an oyster) it can and occasionally does produce pearls. However, they are of no value because the nacre of this species of oyster is very soft and not lustrous. Quality pearls are formed from hard lustrous nacre.

Body

If the oyster is opened with the hinge toward the right and the cupped valve down, then the exposed right side of the body takes the same orientation designations as given for the shell (Fig. 8). It will be noted that nearly the whole edge of the body is covered by two skirts or mantles that can be separated except for a short distance in the anterior or head region and at a point just above the adductor muscle where the right and left mantle edges are fused. This latter junction serves to separate the area of the exhalant or outgoing water current from the inhalant as shown by the heavy arrows.

Figure 9 shows the oyster in the same position with sections of the mantle cut away along the dotted lines. This reveals the pair of right labial palps just ventral and posterior to the hinge, and just behind these is the right pair of gills which extends from the palps in a posterior direction to the point of mantle fusion. There is a corresponding pair of palps and gills on the left side of the body, the function of which will be described later. Just above the gills and forward of the point of mantle fusion lies the adductor muscle which holds the two valves together and immediately above it is the opening of the anus at the end of the digestive tract. The space below the gills is known as the inhalant chamber and that above as the exhalant chamber.

If the oyster is now turned over to show the left side, with the anterior or head region to the left and as much of the mantle as possible cut away, the asymmetry, or the difference in structure between the right and left halves, of the oyster is

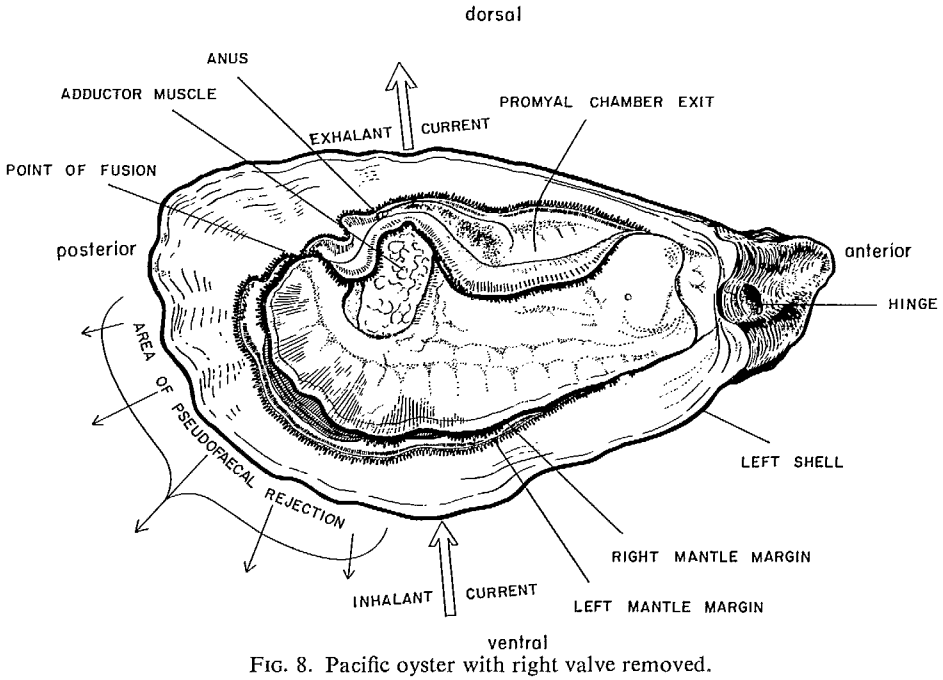


FIG. 8. Pacific oyster with right valve removed.

demonstrated by the fact that part of the exhalant chamber exists only on the right side of the oyster while the inhalant chamber is fully open on both sides. Also, the inhalant chamber is unobstructed throughout its length, while the exhalant chamber is divided by the adductor muscle, with water being discharged through two passages, the cloacal chamber posterior to, and the promyal chamber anterior to, the adductor muscle. This chamber is absent in the *Ostrea* type, such as the native oyster.

Contact or fusion of the body with the shell occurs mainly at the adductor muscle, but there is another point of contact, less obvious, just back of the hinge, the position of which may be determined from the tiny scar less than one-quarter inch in diameter. If the oyster is opened carefully, the mantle may be observed to adhere slightly to the shell at this point. This is the pedal muscle-scar, thought to represent the remnant of the foot retractor muscles of the clamlike ancestor of the oyster and sometimes called Quenstedt's muscle; the two muscle scars on the shell are shown in Fig. 5.

MANTLE

As indicated previously the mantle of the oyster is the general surface covering of the body and is formed of two lobes, one covering the right half and the other the left half of the body. The two lobes are fused in the anterior region to form a sort of hood over the mouth area; at the posterior end they are joined together at a single point (fusion of mantle margins, Fig. 9) to form a separation point between the inhalant and exhalant water chambers. The mantle, while appearing to be formed of a thin skin over most of its area, is threaded with muscles, particularly in the posterior regions.

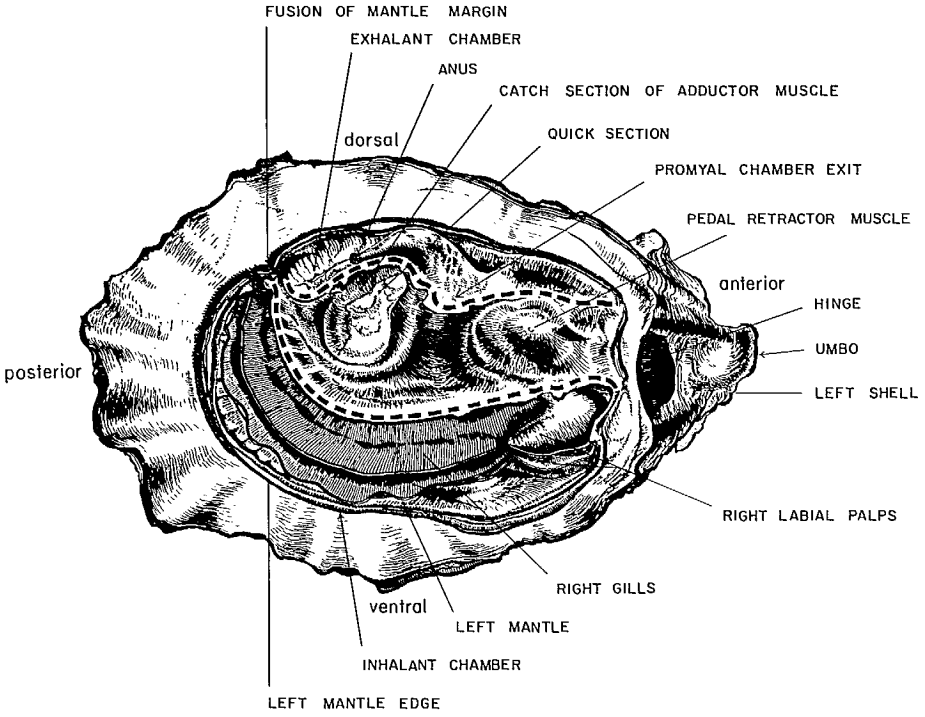


FIG. 9. Pacific oyster with right valve and part of mantle removed.

The edge of the mantle is thickened, and throughout its full length this border is divided into three parallel folds or ridges (Fig. 10) which are of great importance to the oyster. The outer fold, next to the shell edge, is the area of shell formation, the calcareous shell originating from the outer surface of this fold while the periostracum originates from its inner surface. The middle fold is heavily tentacled; it has a sensory function and is able to detect changes in the chemical composition of the water which flows over it. Each fourth or fifth tentacle is larger than the intervening ones. The inner fold is the largest and is strongly muscled with powerful, equally sized tentacles. This fold is sometimes referred to as the pallial curtain and the tentacles of the right and left lobes can interlock to form a barrier to the passage of water, either over the whole length of the mantle edge or in certain areas. The mantle edge, with the three folds, is often pigmented black in the Pacific oyster.

The whole surface of the mantle is involved in the formation of the greater part of the shell, specifically the calcite-ostracum. The region of adductor muscle attachment is composed of a special material known as hypostracum. Since the mantle is in constant contact with the inner surface of the shell, deposition of new shell is possible in this area throughout the life of the animal, whereas the shell-secreting mantle lobes are only able to lay down the shell layers for which they are responsible, at or near the shell margin. The mantle, particularly in young oysters, also takes part in respiration.

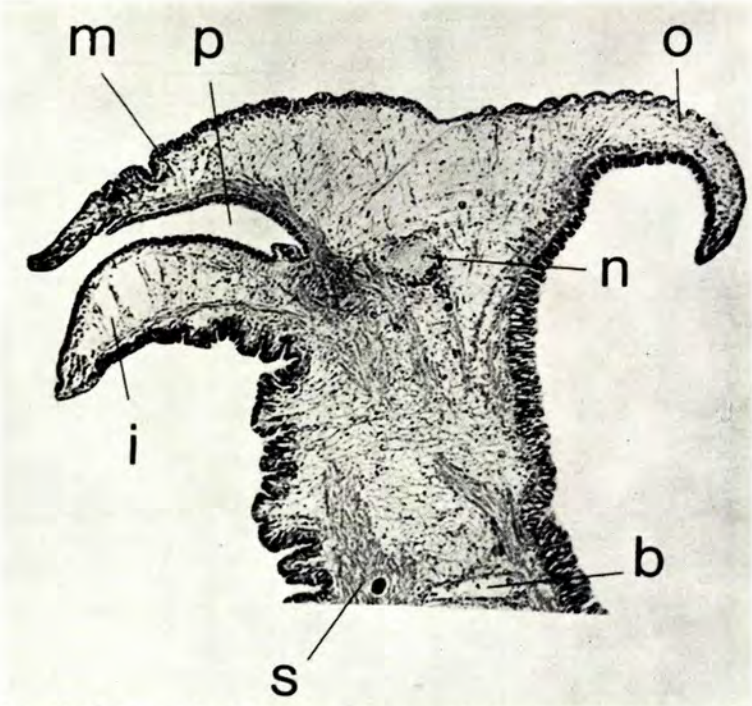


FIG. 10. Cross section of the mantle edge of the Pacific oyster. × 35. *b* = blood vessel; *i* = inner lobe; *m* = middle lobe; *n* = nerve; *o* = outer lobe; *p* = periostracal groove; *s* = muscle.

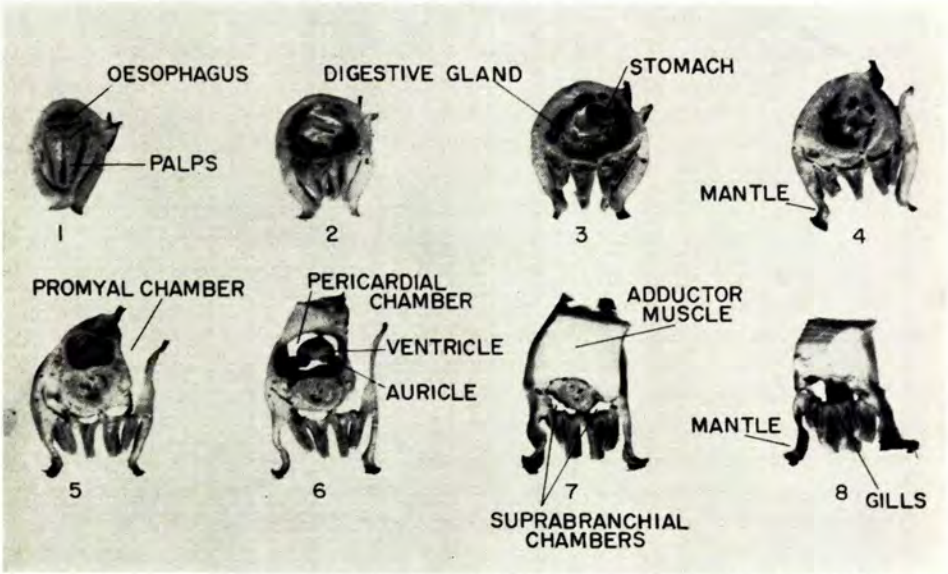


FIG. 11. Several cross sections of a Pacific oyster. Section 1 at the anterior end, slightly posterior to the mouth; section 8 near posterior end of adductor muscle.

GILLS

While the mantle is involved to some extent in respiration, the main organs responsible for this function are the gills. These are the lined, gray-green or brown, leaflike organs lying in the mantle cavity just below the visceral mass (Fig. 9). The gills are formed of eight leaves or lamellae, four on each side of the body. The four leaves of each group are arranged in the form of a "W" with each of the two lamellae joined at the ventral edge but separated dorsally to form a demibranch (Fig. 11). The dorsal edge of the outer left and outer right lamellae are joined to the mantle. In the region of the mouth, the dorsal edges of all gills are joined and there is a connection with the visceral mass between the bases of the palps. Towards the posterior, these lines of attachment separate although they still remain connected with the visceral mass. Thus, four distinct chambers are formed, and since these are above the gills, they are termed suprabranchial (or epibranchial) chambers. These four chambers are reduced to two at a point just anterior to the adductor muscle because the connection between the two lateral axes of the gills and the visceral mass is lost. Still further back, the two remaining chambers merge into a single suprabranchial cavity termed the cloacal chamber. On the right side, anterior to the level of the pericardial cavity, the two suprabranchial chambers fuse to form an additional discharge area called the promyal chamber. This chamber does not occur in the genus *Ostrea* and forms one of the major anatomical differences between *Ostrea* and *Crassostrea*. At this time, the asymmetry of *C. gigas* may be best seen by observing, particularly in the cross sections, how the visceral mass is displaced to the left. This asymmetry may also be seen in the position of the mouth, oral hood, palps, and heart, as well as in the gill system. Furthermore, the promyal chamber on the right side lends to the general impression of asymmetry.

The account of the gills given so far describes only the gross structure. Each demibranch encloses a V-shaped water space and to strengthen the system there are V-shaped cross partitions, called septa or inter-lamellar junctions, joining the two lamellae of each demibranch and forming what are known as water tubes. The junctions vary in height and may be seen by looking down into the gill system from above.

The individual lamellae are formed of single filaments which in turn are joined to each other by spaced strands of interfilamentary tissue, thus leaving spaces (ostia) which allow water to pass between the filaments, above and below the interfilamentary junctions, into the branchial chambers. Further, the filaments are joined together into folded groups called plicae, and in *C. gigas* there are between 11 and 17 filaments in a plica. There are three types of filaments, termed ordinary, transitional, and principal, in each plica; and their relationships are shown in Fig. 12. To support the filaments and the various junctions, small rods of chitinous material are embedded in the tissue; these are flexible enough to allow changes in the size and shape of the ostia by means of muscular activity of the gill tissue. In *C. gigas,* the size of the ostia is sufficient to allow the passage of ova, which are about $\frac{1}{400}$ inch in diameter.

The whole gill system is abundantly provided with cilia, which are tiny hairs or lashes that bend or beat in unison, and it is the combined effort of large numbers

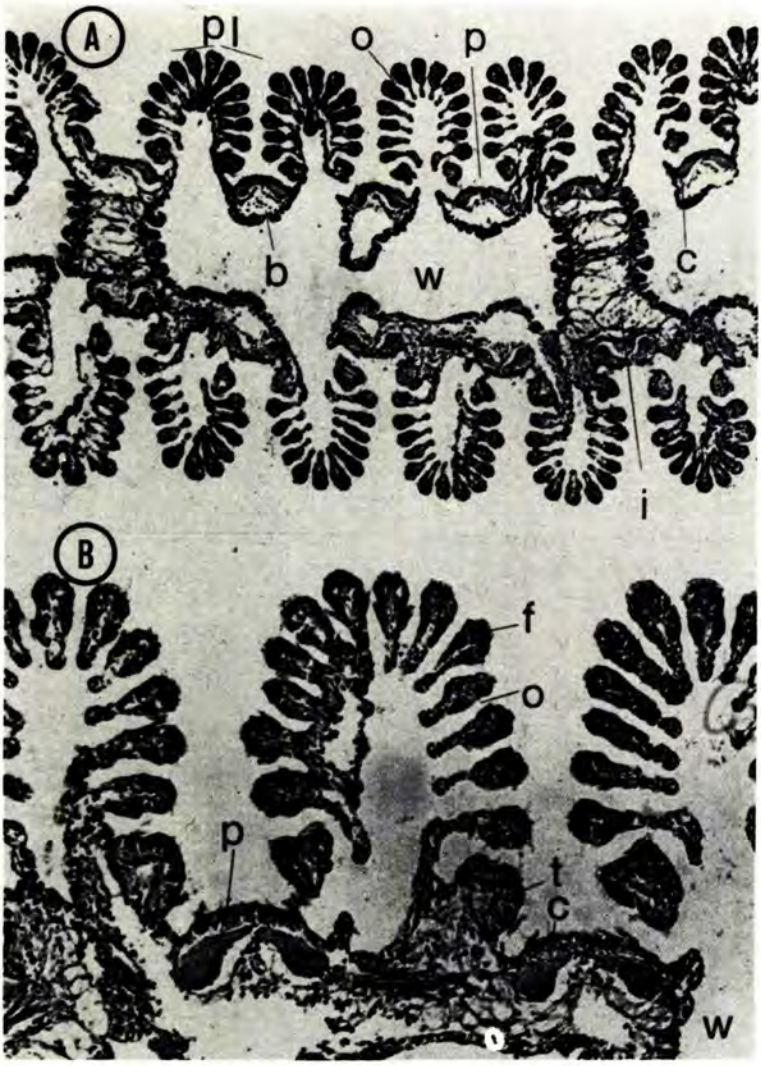


FIG. 12. A—cross section of part of a gill demibranch of a Pacific oyster. × 60. B—enlarged section of a single plica of A. × 150. *b* = blood vessel; *c* = chitinous rod; *f* = ordinary filament; *i* = interlamellar septum; *o* = ostium; *p* = principal filament; *pl* = plica; *t* = transitional filament; *w* = water tube.

of them that provides the motive power for the very considerable water currents that are produced and for the movement of food particles. All filaments are amply provided with these cilia, each of which has a particular direction of beat and function, some being current producing, some concerned with cleansing, and others with the transportation of food. The action of the cilia on a gill may be observed by placing a small amount of finely ground coloured powder on the surface of the gill of a newly opened oyster. The cilia on the principal filaments all beat toward the

base of the gill, to which material is consequently carried. On the other filaments, some cilia also beat in this same direction but they carry only the finest particles to the base of the gill while the others beat toward the free edge of the gills and carry larger particles.

Finally, at the bases of the gills and at their free edges are heavily ciliated tracts which transport the food particles, carried to them by the cilia on the gills, toward the mouth. On each full gill, then, there are three grooves at the base and two on the free edges, making five tracts, or a total of 10 altogether, to carry collected food toward the mouth. However, in the Pacific oyster the grooves at the free edge of the gills carry the major amount of material collected on them.

Closely associated with the gill system is the group of four palps which lie anterior to the gills and close to the mouth. These are fleshy, triangular-shaped bodies, with the free points directed downward and backwards (Fig. 9). The bases are attached dorsally to the body mass and covered anteriorly by the oral hood of the mantle. The outer pair of palps unite above the mouth in what might be termed the upper lip while the inner pair unite below the mouth as a lower lip. The inner opposed surfaces of the palps are deeply grooved, while the outer surfaces are smooth; but all surfaces are highly ciliated.

Although the functions of the mantle and gill systems have already been indicated, these can now be described in more detail. The beating of the cilia on the gills is responsible for creating a flow of water between the mantles, which is controlled by the inner fold of the mantle edge. This flow, in an oyster of average size, may amount to between 20 and 30 quarts of water per hour. The current enters the inhalant chamber along the ventral edge of the shell (Fig. 9) and then passes over the gill surfaces and through the gill ostia, into the water tubes, and up into the suprabranchial chambers. Thus, the gill system is a basketlike structure that acts as a sieve. Special cells on the gill surface secrete mucus which entangles food and other particles. Though the gill ostia are relatively large, the gill is able to prevent the passage of very small particles such as bacteria and viral particles. Both single particles and groups enmeshed in mucus are then carried along the filaments, fine particles chiefly to the base of the gills, and larger particles to the free edge. Here the ciliated grooves, both at the base and at the free edge, transport the strings of mucus laden with food toward the mouth. If the amount of material in the marginal grooves is too great it will fall out of the groove onto the mantle below it. The material that is carried forward in the grooves reaches the palps, where further size sorting takes place. In general, the grooved surfaces of the palps have ciliated tracts which direct fine particles forward to the mouth, while on the smooth surfaces the direction is backward toward the free apex of the palps, these tracts tending to carry heavier material which is to be discarded. This is dropped off onto the mantle surface at a point near where the gill lamellae meet the palps. This material is termed "pseudofaeces" for, although it is waste material, it has not passed through the digestive tract. The pseudofaeces rejected by the palps, as well as that dropped from the food grooves, is moved backward over the inner surface of the mantle, on whichever mantle lobe is below, by means of other ciliated tracts, until it reaches a general area in the inhalant chamber just posterior to the point of mantle fusion (Fig. 9).

There being no ciliary mechanism for discharging the pseudofaecal material from the mantle cavity, this is done by sharp contractions of the adductor muscle which brings the valves together and forces water under pressure from the inhalant chamber. When oysters are just being exposed as the tide recedes, they can often be seen ejecting spurts of water; this is simply the action of the cleansing mechanism voiding pseudofaecal material.

Since the gill filaments, and interfilamentary and interlamellar junctions are supplied with blood vessels, the passage of water through the gill ostia and water tubes allows for the exchange of respiratory gases, so the gills act as a form of lung as well as a food-collecting organ.

After passage through gills and into the exhalant chamber, the water, with its particulate matter and some of its oxygen removed, is discharged both behind the adductor muscle through the cloacal chamber, and in front of it, through the promyal chamber, and out between the dorsal mantle margins.

Adductor Muscle

The remaining visible portion of the anatomy of the oyster is the adductor muscle. As stated previously, this holds the two valves together and opposes the action of the hinge ligament in springing the valves apart. Careful observation of the adductor muscle discloses a small posterior crescent-shaped section, pure white in colour while the larger anterior area is light beige (Fig. 9). This larger section is composed of striated muscle fibres and is responsible for the rapid contractions that can quickly close the shells when the mantle edge is stimulated, or in the "clapping" action which discharges pseudofaeces. Consequently, this part of the muscle is called the "quick" part, while the smaller white portion is termed the "catch" part and is composed of smooth muscle fibres. This part of the muscle is said to have a ratchetlike action and holds the valves in a set position for long periods while the "quick" portion is at rest. It has been shown for the Atlantic oyster that those oysters which live high in the tidal zone have a larger "catch" section than those living lower down, because the shells on these individuals are held closed for longer periods.

The adductor muscle of the Atlantic oyster can withstand a pull of up to about 22 pounds before the muscle tears in the middle, but the attachment of the muscle to the shell is not broken under this strain.

Digestive System

The digestive system proper begins with the mouth, which is a horizontal slit between the upper and lower lips, formed by the fusion of the anterior portions of the pairs of palps. It leads into a short tube, sometimes called the oesophagus, which in turn leads into the stomach proper. The form of the much grooved stomach is shown in Fig. 13 which is a photograph of a rubber cast of an oyster stomach. Entering the stomach from the side are a number of ducts leading from the dark mass of material that nearly surrounds the stomach (Fig. 14). The dark mass, sometimes brown (in winter) or green (in spring) is sometimes called the "liver" but is more properly named the digestive gland or digestive diverticulum. It is a system of fine tubules lined with special cells concerned with digestion; the colour is usually associated with the type of food being consumed.

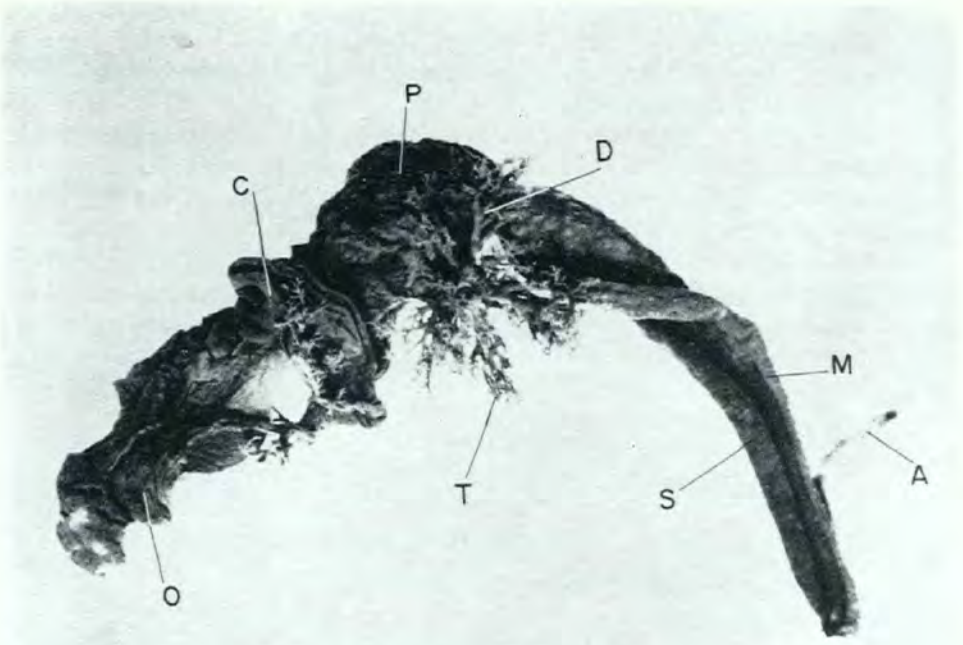


FIG. 13. A rubber latex cast of the stomach of the Pacific oyster. × 0.2. A = ascending limb of intestine; C = anterior appendage of caecum; D = caecal duct of digestive diverticula; M = mid-gut; O = oesophagus; P = posterior chamber of stomach; S = style sac; T = tubules of digestive diverticula.

Opposite the oesophagus is the entrance to the intestine (also called the mid-gut), a narrow tube which loops around the stomach to end in the anus, which is located in the cloacal chamber just above the adductor muscle. Close to the entrance to the intestine and associated with it is another narrow tube which has a blind end and is about an inch long in an oyster of average size. This is called the crystalline style sac which produces an extraordinary structure called the crystalline style, a stiff gelatinous rod (Fig. 15). It is golden brown or yellow in colour, flexible and with a tapered shape. Many mistakenly believe this to be a worm which infests the oyster. The crystalline style projects across the middle of the stomach to the opposite side where it rests against a hard transparent pad called the gastric shield. The style is rotated by the cilia in the style sac, in a clockwise direction when viewed from the blunt or gastric shield end. The style itself is formed of concentric layers of muco-protein which when dissolved releases digestive enzymes that convert starch into digestible sugars. Dissolution of the style in an actively feeding oyster occurs at the gastric shield where the acidity of stomach liquids is lower than in the region of the style sac. Dissolution of the whole style also occurs soon after an actively feeding oyster is removed from the water, which is why the style is so seldom observed. However, if the live oyster is returned to the water and allowed to feed the style is reformed, for it is an integral part of the digestive system.

Contained in the crystalline style of the Pacific oyster (and other molluscs) are spirochaetes *(Cristispira)* (Fig. 16) which are elongated motile bacterialike organisms of microscopic size. Their function in the style is not known but they are harmless to oysters and to man.

In addition to the style sac there are other shallow blind sacs or pouches in the stomach called caeca which are concerned with food sorting.

The course of food and digestion in the oyster stomach is a very complicated process and the following is a simplified account.

Mucus-enmeshed particles permitted to enter the oesophagus first meet the head of the crystalline style. The rotation of the latter mixes the food particles with enzymes which it releases in this area. These enzymes effect what is called extracellular digestion of starches. By a combination of ciliary pathways in the sorting pouches and in the stomach itself, very small and partly digested particles are carried

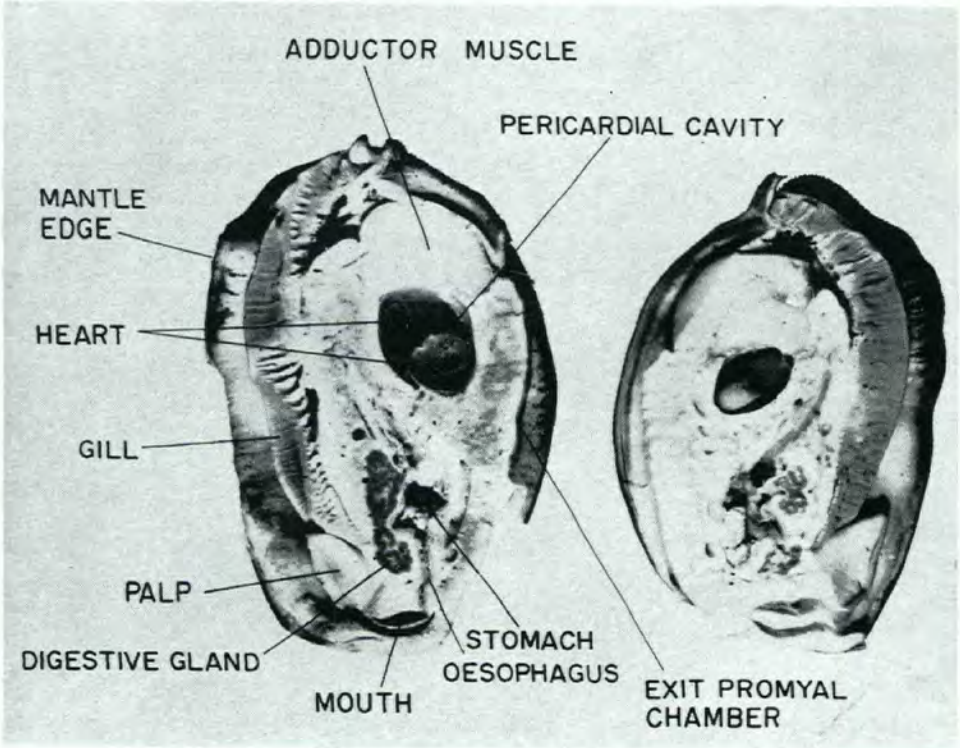


FIG. 14. Sagittal section of a Pacific oyster through the approximate centre.

FIG. 15. The crystalline style of the Pacific oyster *(C. gigas)*. × 2.

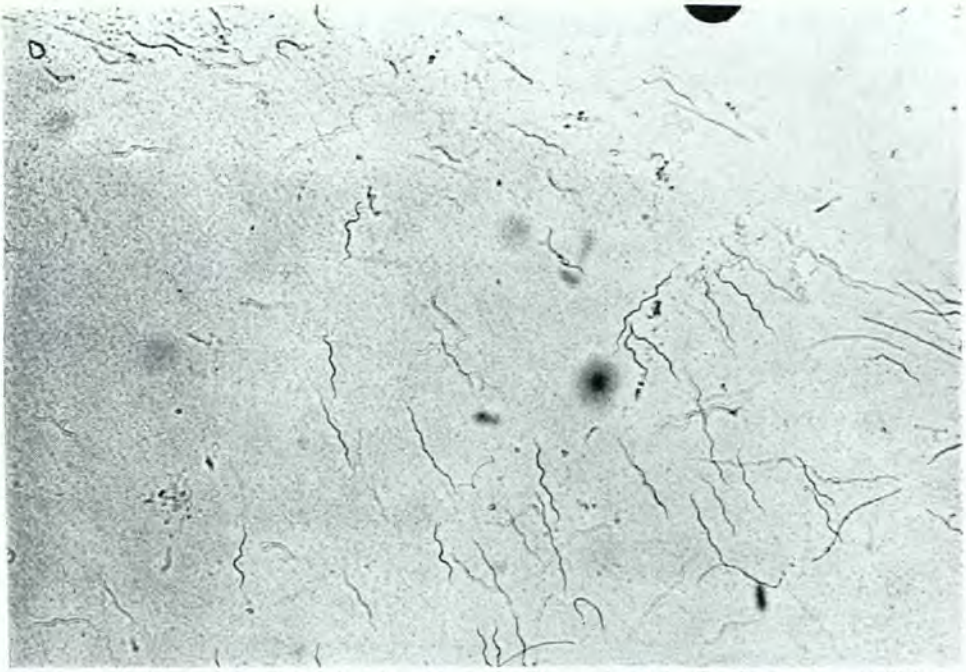


FIG. 16. Spirochaetes *(Cristispira)* from the crystalline style of the Pacific oyster. × 226.

to the tubules of the digestive gland where intracellular digestion of fats and protein takes place.

In addition to these modes of digestion, some is also carried on by blood cells which are able to migrate in and out of the stomach and, by an engulfing action similar to that used by an amoeba, are able to ingest individual particles of food. Once inside the blood cell, the particles undergo intracellular digestion.

The caeca, in addition to directing particles destined for the digestive diverticula, also direct unwanted material along a special path, called a typhlosole, to the opening of the intestine. Wastes from the digestive tubules are also carried to the intestine by this and other pathways. The main function of the intestine is to compact waste materials into solid strings and to carry them, via the anus, to the cloaca whence they are carried outside the shells by the exhalant water current.

CIRCULATORY SYSTEM

In the oyster, as in other animals, the function of the circulatory or blood system is to carry food, oxygen, and waste materials to the various parts of the body. With the exception of the heart and pericardial cavity, the circulatory system in oysters is difficult to trace, for the blood vessels are not well defined.

The heart, located above and close to the adductor muscle (Fig. 17), is enclosed in a chamber called the pericardial cavity. There are two auricles, one on each side of the single muscular ventricle. In a newly opened oyster, the pulsations of the heart may be observed when the pericardium is opened, as it often is during the shucking process. Oxygenated blood is received from the gills and pumped

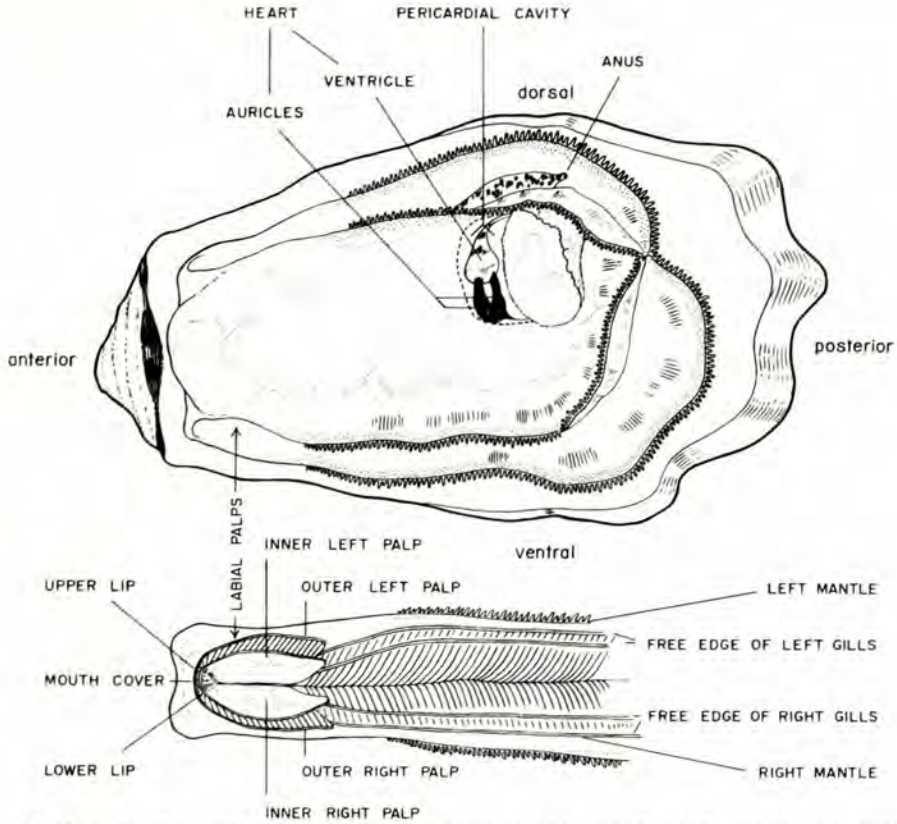


FIG. 17. *(Top)* Pacific oyster with the left valve removed and part of mantle cut away to expose the pericardial cavity. *(Bottom)* A ventral view of the mantle cavity to show the relationship between the palps and gills.

through the main arteries to smaller vessels. In the oyster there are no fine vessels such as capillaries; instead the organs are simply bathed by the blood. The deoxygenated blood is collected in veins and carried by them to the gills for reoxygenation or to the kidneys, sometimes called the organs of Bojanus. The kidneys are a pair of tubes located under the adductor muscle, with an internal opening into the exhalant chamber, from where the discharged wastes are carried away by the exhalant water current.

There is also a pair of so-called accessory hearts which are slowly pulsating enlargements of radial blood vessels and are largely concerned with the circulation of blood through the kidneys.

NERVOUS SYSTEM

Since the oyster is not a very active animal and has relatively little muscle, it does not require a highly developed nervous system. The adult oyster has a pair of nerve cell aggregations near the mouth, called the cerebro-pleural ganglia. Another, larger, pair of nerve cell aggregations, more closely united than the cerebro-pleural

pair, occur under the adductor muscle and are called the visceral ganglia. The latter are connected to the cerebro-pleural ganglia from which nerves pass to the stomach, mouth and anterior areas generally. Nerves from the visceral ganglia are also connected to the adductor muscle and posterior areas. The only known sensory organ is located in the exhalant water chamber and is called the "abdominal sense-organ." Its function is unknown.

Reproductive System

This part of the anatomy of an oyster can be readily observed only during the breeding season, for at this time the reproductive organs may form at least 50% of the body volume. During the winter, when there is no reproductive activity, the gonadal mass is replaced by a mass of connective tissue with vesicle cells containing fat and glycogen. Embedded in this, close to the internal organs of the oyster, is a duplicate system, one on each side, of branching tubules, beginning at the anterior end of the body and finally uniting into a single tube, also one on each side, which ends in what is called the genital pore. These enter the suprabranchial chamber at the posterior base of the adductor muscle, in close proximity to openings of the urinal ducts. In a fully ripe oyster, the gonadal tubules, small in diameter at the anterior end of the oyster and thickening as they approach the genital opening, may be clearly seen on the surface of the body mass of the oyster (Fig. 18). At this time, the two systems are almost completely inseparable, except at the genital pores.

In spring, the glycogen-filled cells of the connective tissue are gradually replaced by proliferating reproductive cells. Whether or not the glycogen is actually used in gonad formation is not known, but the disappearance of one coincides with the appearance of the other.

Sexual maturity in the Pacific oyster appears to be a function of size rather than of age, and if there is early summer spatting with rapid growth, mature sex cells may be found by the end of the same summer. However, there is little possibility of these oysters spawning—and the number of eggs or sperm would not be high. Spawning is reasonably certain to occur during the second summer but again the quantity of gonadal products would not be great. Under most British Columbia conditions, the first real spawning of magnitude will occur during the third summer, when the oyster is two years old.

BIOLOGY

Sexuality

The sexes in the Pacific oyster are separate, that is, there are male and female oysters, though hermaphrodites do occur occasionally (Fig. 20F), the sex being determinable only by examination of the reproductive tissue. The sex may change from year to year, the change taking place during the winter. There is a general belief that environmental conditions have a considerable influence on the determination of sex in oysters. There appears to be a tendency for females to change to males where and when the food supply is poor and for males to become females where and when the supply of food is good. In areas with a good food supply, the

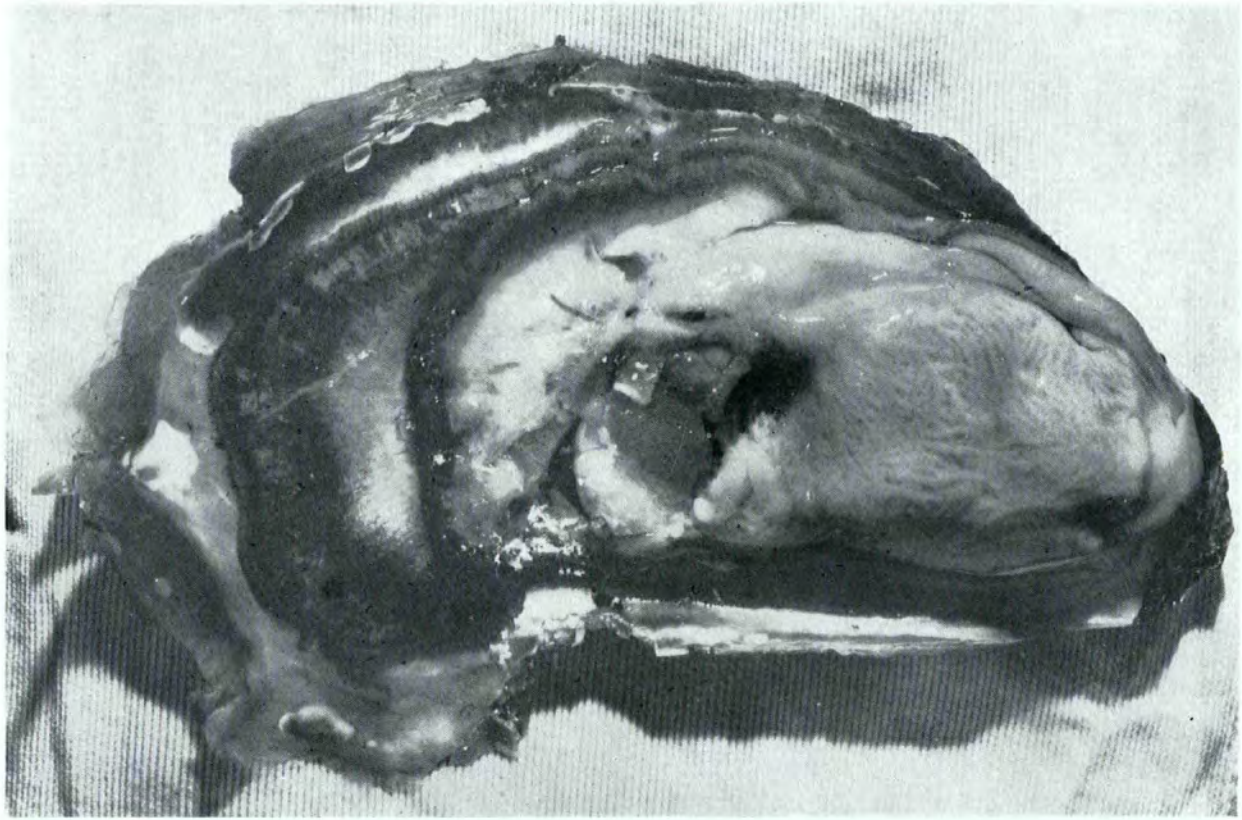


FIG. 18. Ripe Pacific oyster showing "spawn veins."

sex ratio in older oysters shows a preponderance of females, while in areas with a low food supply, the reverse is true.

In other species, such as the native oyster *(O. lurida)*, an individual may spawn initially as a female, immediately change to a male and spawn as such within one summer. Also, the initial sexual phase in this oyster is always male. However, the important thing is that there always seems to be a satisfactory sex ratio to ensure successful breeding.

Gonad Development

Pacific oysters develop sexual products (eggs or sperm), presumably by conversion of the winter store of glycogen, when water temperatures begin to rise in March. Under normal weather conditions, full ripeness is attained, in most British Columbia waters, by the end of June. Eggs of the female (Fig. 19) appear as tiny cream-coloured granules, just visible to the naked eye; while the sperm, extremely minute, form a pure white material which runs in thin streams.

The number of eggs and sperm developed in a Pacific oyster is related to the size of the oyster and to its state of nutrition. The number of eggs produced by an average market-sized oyster has been estimated at 50–100 million; the number of sperm at very much greater.

During winter, the surface of a fat oyster is smooth and even, but with the onset of sexual maturity it becomes deeply veined (Fig. 18). This veined gonad covers both sides of the anterior end of the oyster and forms a considerable proportion of the body weight. Figure 20A shows a thin section of a Pacific oyster

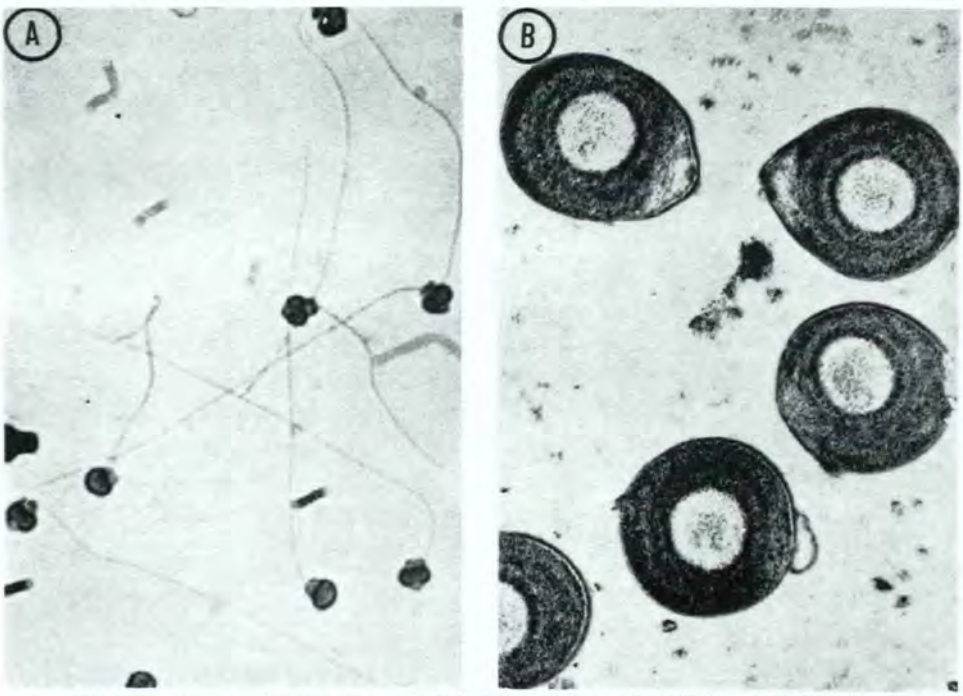


Fig. 19. Photomicrographs of sperm (A, ×1350) and eggs (B, ×270) of the Pacific oyster.

gonad in which the mature eggs are tightly packed in blind sacs called follicles, and the tubules through which the eggs are discharged.

Details of the seasonal gonadal changes are as follows (Fig. 20, 21). Spawning in the Pacific oyster is usually total and may occur any time between late June and early September but most often in late July and early August. After complete spawning the body of the oyster is nearly transparent and the gonad follicles are collapsed and contain only a few relict gametes and tissue fragments. The condition of the oyster is then at the lowest level of the year.

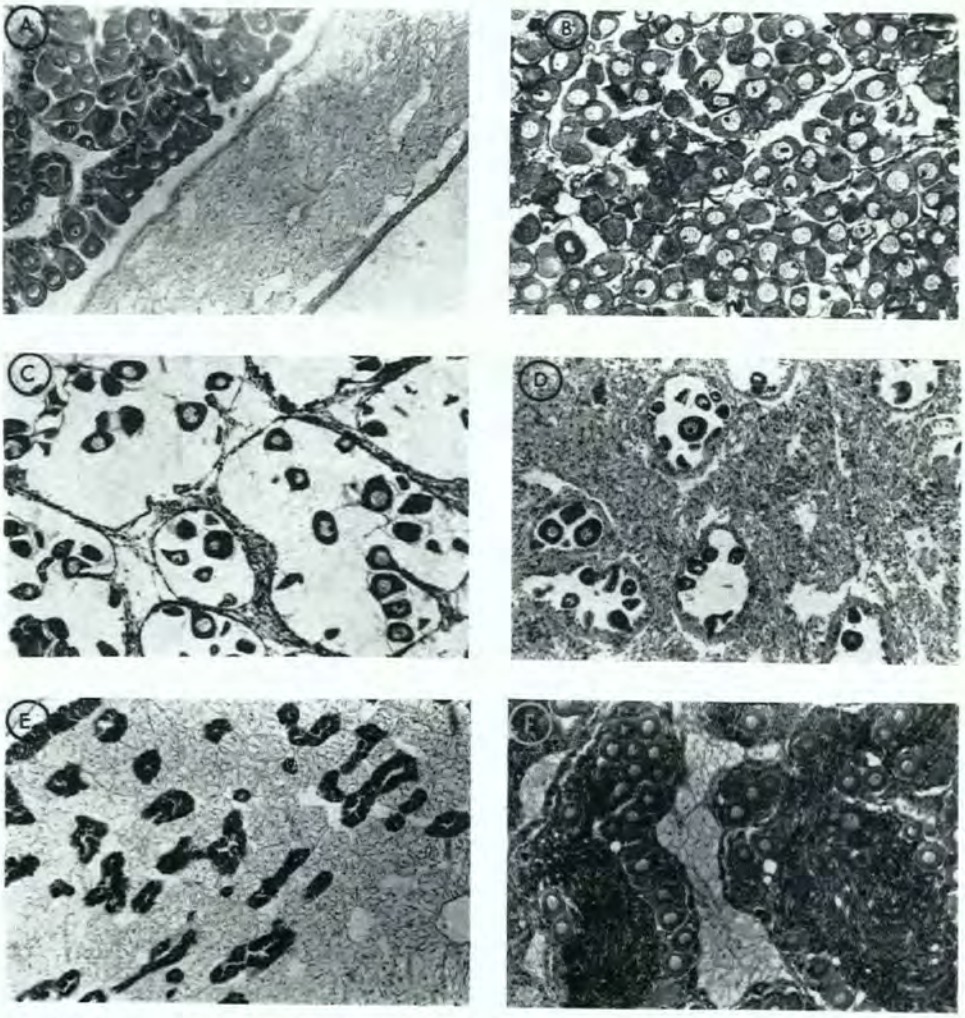


FIG. 20. Photomicrographs of sections of female Pacific oyster gonads to show seasonal changes. × 68. A = ripe female with gonad covered with a thin layer of glycogen-rich tissue; B = fully ripe female; C = spawned out female with a few relict eggs; D = female in fall condition with follicles closing in on the relict ova; E = female in spring condition with early-stage developing eggs on follicle margins; F = hermaphrodite with both eggs and sperm.

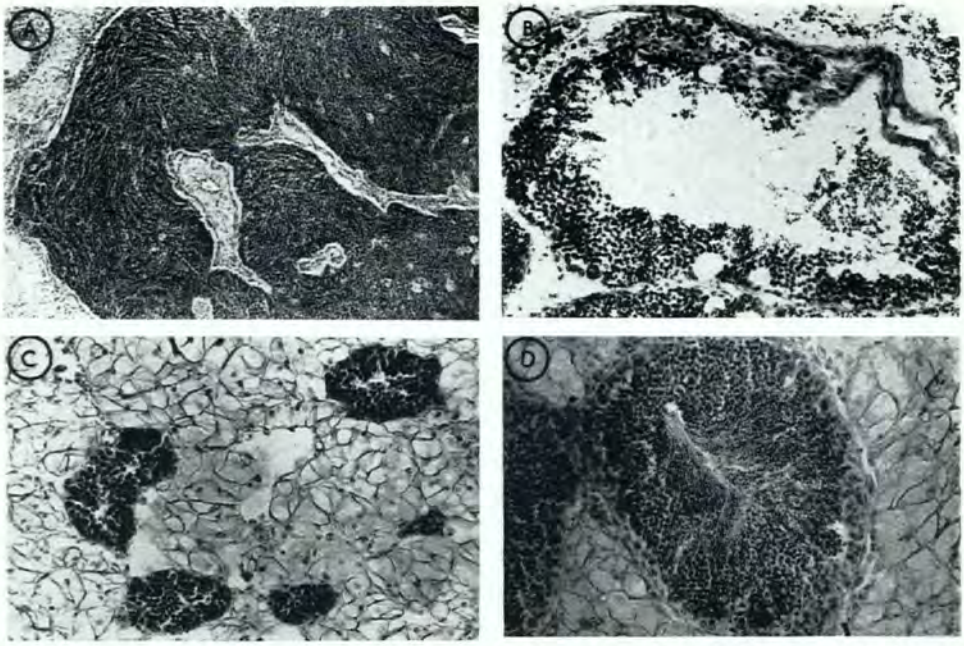


FIG. 21. Photomicrographs of sections of male Pacific oyster gonads to show seasonal changes. × 69. A = ripe condition before spawning; B = spawned out condition with the follicle nearly empty; C = early development of male gonads; D = gonad approaching ripeness with developing cells in the outer portion of the follicle.

By November the level of winter condition has been established. The follicles have shrunk to small compact islands of germinal tissue scattered throughout the mass of vesicular connective tissue which has filled in the interfollicular spaces as well as the area between the gonad proper and the body epithelium. The relative amount of this connective tissue particularly in the latter area determines the condition of the oyster. The main outer gonaduct separates the gonadal area from the outer connective tissue area where no germinal material occurs. At this stage some of the follicles that have not completely closed up may contain a few relict eggs or sperm; in the few cases of partial spawning only the outer follicles would be involved.

The gonad is generally undifferentiated as to sex at this time (November) and the condition exists throughout the winter. It is not until April that early stages of gonad proliferation and differentiation may be noted. The maximum stage of development observed late in April occurred in females found with about 25% of the gonad area occupied by follicular material. By mid-May gametogenesis is well under way and on the average about 50% of the potential gonadal area is filled with expanding follicles.

By the end of June all animals are fully ripe with the follicles tightly packed with eggs and sperm and only a very thin layer of vesicular connective tissue covers the gonad. This condition persists until spawning although an occasional partly spawned individual may show proliferation of connective tissue between the spent follicles.

Spawning

In the spawning act, rather than releasing the ova through the normal exhalant channel, the female discharges them into the suprabranchial chambers from which they are forced through the gill ostia (apertures) into the mantle chamber, from which they are ejaculated in a small cloud (Fig. 22). This process is accomplished by adjustment of the mantle edges and by vigorous action of the adductor muscle. The discharge of eggs is intermittent, with a rate of 5–10 times per minute, the eggs being forced distances of 12 inches or more from the oyster. The male oyster, on the other hand, discharges its sperm in a thin steady stream, also into the suprabranchial chamber, but instead of passing through the gill apertures against the current as do the eggs, they are carried out in the normal exhalant stream of water. Thus the eggs and sperm are discharged on opposite sides of the oyster.

FIG. 22. Pacific oysters *(C. gigas)* in the act of spawning.

The actual initiation of spawning may be brought about by temperature, by chemical stimulation, or by a combination of both. It is thought that the large mass spawnings that occur in molluscs such as the oyster, and indeed in a number of other marine animals, are necessary to provide the concentrations of spawn needed to ensure fertilization when sexual products are discharged freely into the open water. The presence of sexual products of the oyster in the water in which other oysters are feeding is often enough to stimulate spawning. This fact makes it possible to force large quantities of oysters to spawn (Fig. 23).

In Japan, the salinity range for development (breeding) of Pacific oysters is between 11‰ and 32‰ (‰ = parts per thousand); the optimum is considered to be between 20‰ and 25‰. Development can take place within the

FIG. 23. Spawn streak from Pacific oysters through the centre of the head of Ladysmith Harbour.

temperature range 58–86 F, with the optimum at about 75 F. In British Columbia, the salinity requirements are easily met, but the optimum temperature occurs rarely.

Temperature is most important in the initiation of the spawning process. Pacific oysters have been observed to spawn at a temperature as low as 60 F, but this may have been as a result of chemical stimulation.

In Pendrell Sound, the main breeding area in British Columbia, 18 recorded spawnings occurred at temperatures between 67 F and 75 F, with an average of 71 F. These temperatures were recorded on a floating thermograph with the bulb 3 ft below the surface. It is likely that the actual temperature at the spawning site would be 1–2 degrees F higher.

TIME OF SPAWNING

Some consideration has been given to the possibility of a connection between phases of the moon and spawning in the oyster, and this is believed to exist in the case of the European flat oyster *(O. edulis)*, the spawning of which tends to reach a maximum at both spring tides, about 10 days after full or new moon.

In British Columbia, of 30 Pacific oyster spawnings the times of which have been accurately recorded, 12 in Ladysmith Harbour and 18 in Pendrell Sound, all occurred on or within 3 days of a specific phase of the moon, with 6 occurring on the new moon, 10 on the first quarter, 7 on the full, and 7 on the last quarter.

There appears to be a tendency for spawning in Ladysmith Harbour and Pendrell Sound to occur at about the same time. During the period 1951 to 1956, 14 spawnings were recorded in Pendrell Sound and 9 in Ladysmith Harbour, of which 7 took place on the same day as, or within 1 day of, spawnings in Pendrell Sound. This is probably a reflection of weather and tidal conditions operating together to create similar water temperatures in the two areas. Sunny, warm weather in conjunction with long tidal run-outs generally causes a sharp upward trend in surface water temperatures and the oysters themselves are subject to long periods of high air temperatures.

Spawning of Pacific oysters does not occur throughout British Columbia every year, but in Ladysmith Harbour and Pendrell Sound, at least a proportion will spawn each year, but this occurs only occasionally in most other growing areas. As a general rule, once a Pacific oyster begins to spawn, all of the gonad products are discharged at that time, and, on an oyster bed that has spawned, few oysters can be found with significant amounts of gonad material remaining. However, spawning does not always mean successful breeding. There may be several distinct spawnings occurring at different times in different parts of any one general breeding area in one year.

Larval Development

Although the eggs are pear-shaped when lying in the gonad (Fig. 20), on being spawned they assume a spherical shape, with a diameter of about 0.05 mm (500 eggs placed side by side would span an inch). The much smaller, swimming sperm seek out and fertilize the eggs, which are just able to float. Immediately after fertilization, which must occur within 10–15 hours after spawning, rapid cell division and development takes place. In about 24 hours, two tiny shells may be seen and the various organ systems are being formed; within 48 hours the body is almost entirely enclosed by the enlarging shells. By means of tiny vibrating hairs called cilia, the embryo is able to swim about 5 hours after spawning. Later, a definitive swimming organ, called the velum, is formed. This organ (Fig. 24) is a circular, ciliated platform which can be protruded from between the shells; its locomotive power enables

Fig. 24. Photomicrograph of an advanced stage of Pacific oyster larva with the velum extended. × 180.

the young oyster, now called a veliger larva, to maintain its position in the upper layers of water, although water currents remain the dominant force in moving larvae about. In addition to its function as a swimming organ, the velum also acts as a food collecting apparatus. At this time, the larva is $\frac{1}{250}$ of an inch in diameter, and the

shell is shaped like the letter "D" with the hinge on the straight side, and the larva is now said to be in the "straight-hinged" state.

In 3 or 4 days time, the umbones or beaks, which are protuberances of the shell near the hinge line, become visible, and the larva is now called "early umbo." Development continues rapidly and the umbones become more prominent and pointed (Fig. 25). In the meantime, a digestive system, complete with mouth,

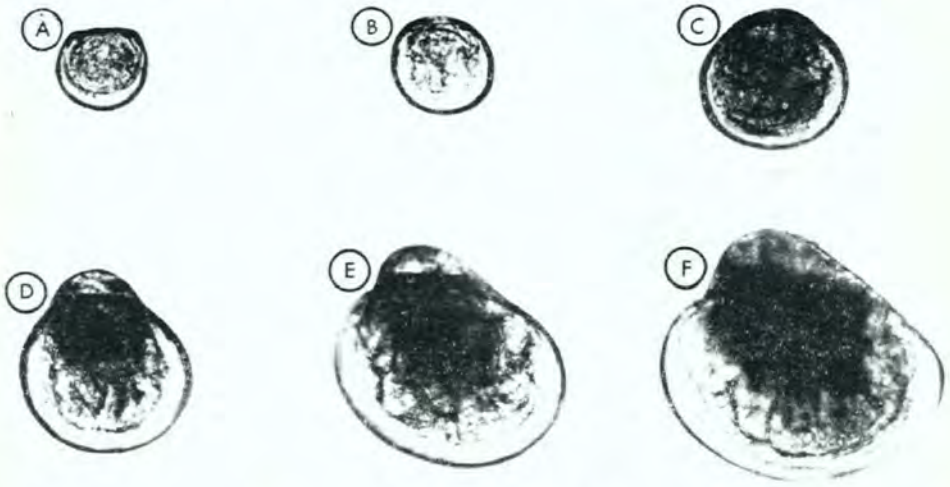


FIG. 25. Stages in the development of the larvae of the Pacific oyster. × 117. A = straight-hinged stage (90 μ); B = very early umbo (110 μ); C = early umbo (160 μ); D = umbone (200 μ); E = umbone (250 μ); F = advanced umbone (300 μ).

oesophagus, intestine, and digestive gland, is formed. In addition, there is a ciliated protrusible foot, which is a most active organ, and there are two adductor muscles; so at this stage the young oyster resembles a clam more than it does an oyster. At the base of the foot is a cement gland whose function will be described later; there are also rudiments of gills, and a sensory organ called the statocyst.

GROWTH OF THE LARVA

Not long before the larva reaches its maximum development, a black eye spot is formed on each side of the body. The growth of the larva seems to be directly associated with water temperature; the higher this is, the faster the growth. The growth rate of Pacific oyster larvae, as determined in Pendrell Sound, is shown in Fig. 26; and in Fig. 27 is shown the length of the larval period at various temperatures, as determined from field observations.

SETTING

When the young oyster reaches a length of 0.30 mm ($\frac{1}{80}$ inch), it has attained its full development as a larva and has approached the end of its free-swimming existence. It is therefore ready to become attached and the process is called "setting" or "spatting." Indeed, when this stage has been reached, it must become attached to a solid object within a relatively short time, or it will perish.

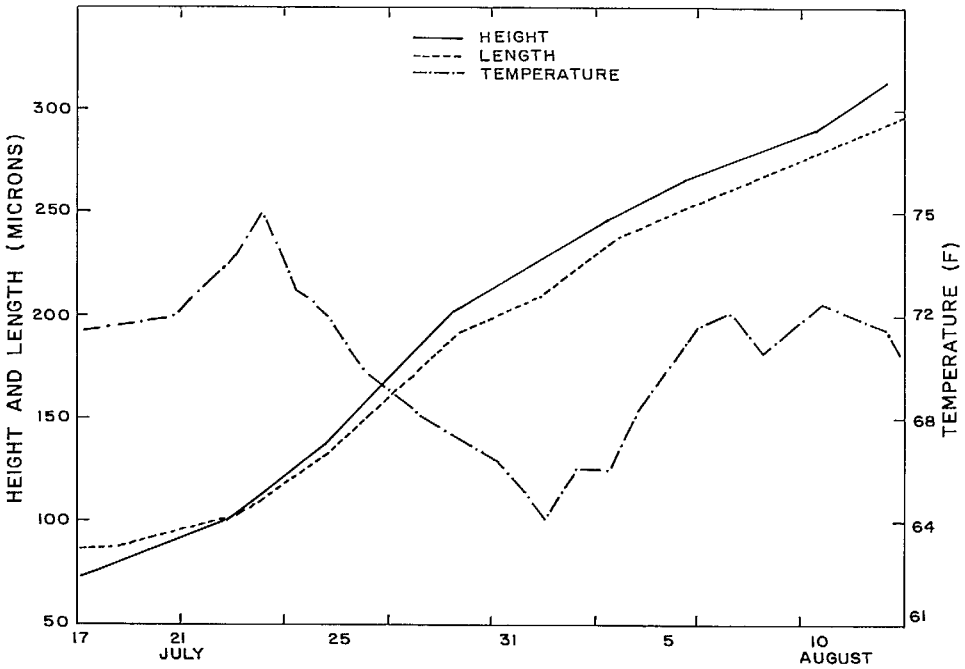


FIG. 26. Growth rate of the larvae of the Pacific oyster *(C. gigas)* in Pendrell Sound, August 1955.

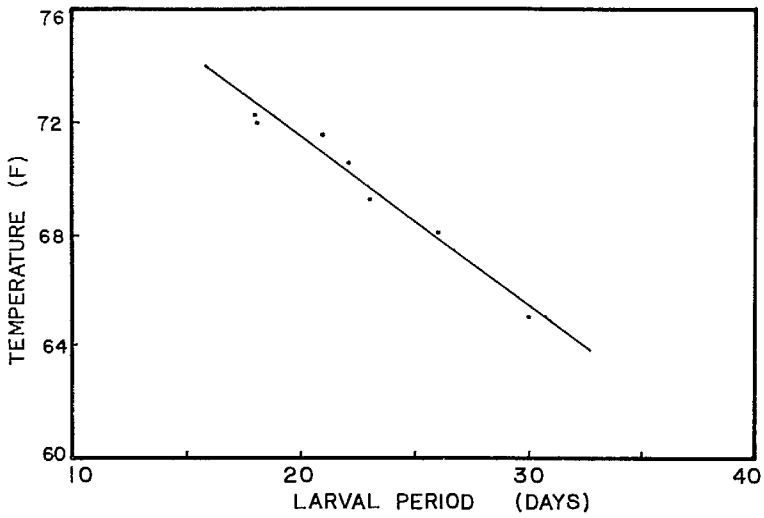


FIG. 27. Larval period of the Pacific oyster at various temperatures. Data from Pendrell Sound, 1950–1955.

The larva is carried along by the current, with the velum active and the foot protruded, until it strikes a solid object. If it does so, it clings to it with the adhesive ciliated foot, by which it is also able to crawl. In this manner, with the shells upright above the crawling foot, the larva searches the surface; if the surface is unsuitable the larva will drop off, swim away, and attempt to find another. When a suitable surface is located (the basic requirements are that it be clean and hard) the larva will carry on what appears to be an aimless sort of search. When the right spot is found, and this is often where there is a slight unevenness or groove, a rocking motion of the shells forces out a small drop of cement from the gland in the foot. The left valve, and never the right one, is then placed in the cement which sets in a matter of seconds, and the young oyster is attached for life (Fig. 28). Initial attachment is common to nearly all larval bivalves, but in the case of clams or of mussels attachment is by means of an elastic thread or byssus which is formed from the same type of gland in the foot.

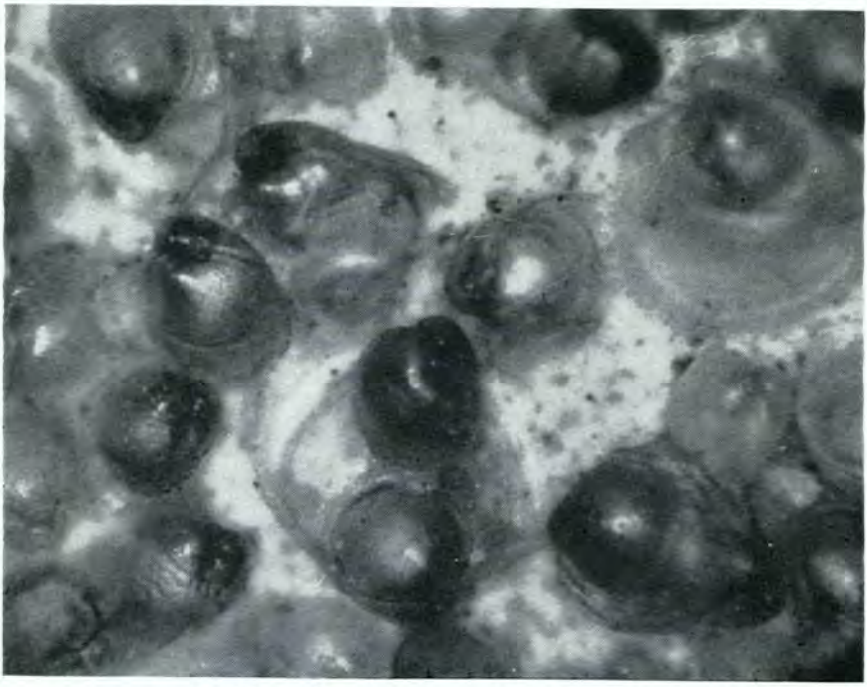


FIG. 28. Pacific oyster spat 1–4 days old. × 70.

Immediately after settlement, rather drastic anatomical changes occur in the oyster. The velum and foot are lost, as well as the anterior adductor muscle, while the posterior adductor takes a position closer to the centre of the shell. This change involves a rotation of the larval body in an anti-clockwise direction, so the mouth is directed to the anterior rather than ventral as in the larva. The eye spot also disappears.

The gill system enlarges rapidly at this time and an associated increase in the size of the mantle permits quite rapid growth of the calcareous adult-type shell. The

larval shell, of different composition from that of the adult and sometimes called the prodissoconch shell, remains in position at the umbone of the growing oyster and may persist for some time; indeed it has been found on fossil shells. It is only by means of the persisting larval shell that very young Pacific oysters may be distinguished from the very young native oysters.

GROWTH

Growth in General

It is difficult to make definitive statements about the growth of oysters, because it varies widely with tidal height and the area in which they are grown. In addition, there are seasonal growth patterns which may differ from year to year. Growth studies are made difficult by the fact that there is no known way of accurately determining the age of an oyster. Most molluscs, such as clams, show periods of growth by forming definite rings on the shell which indicate the cessation of growth during the winter, in a manner similar to the growth rings in trees. This is not so with most oysters so that a knowledge of when it was spatted must be known for age determination.

There are two aspects of growth in the oyster, one concerning the shell and one the body. Shell growth appears to be largely dependent on temperature but at the same time the body must have sufficient energy, derived from food or reserves of food, to convert the calcium in sea water to shell and to provide the organic matrix. Body growth is largely the result of food supply but this also is in part temperature dependent. In other words, growth is essentially a summer phenomenon, for the water temperature at that time of the year results in both a supply of food and the availability of calcium for shell deposition. It is possible that, even in summer, there may be a dearth of food which will lead to a cessation of body growth and, in turn, of shell growth. Shell growth, though, has been observed in oysters with emaciated bodies.

Growth in shell length and width is accomplished by activity of the outer surface of the outer fold of the mantle edge, while the inner surface of this same mantle fold secretes the covering periostracum (Fig. 10). The inner shell surface (calcite-ostracum in edible oysters) is secreted by the outer surface of the mantle as a whole. The chalky calcium carbonate or calcite which constitutes the greater part of the shell is believed to be secreted directly from sea water which contains an abundance of this material in solution. Harder material called aragonite forms the inner lustrous surface or nacre of pearl oyster shells or abalones. Conchyolin forms the organic matrix on which the calcite and aragonite crystals are deposited.

Thus, shell deposition or thickness is controlled by activity of the general mantle surface, and increase in shell area by marginal increment as a result of secretion by the outer mantle lobe.

Growth in the Pacific oyster is extremely variable, both in rate and in amount. If an oyster is attached to a solid object, the left or lower valve will follow the contour of that object. If oysters are grown in soft mud they grow long and narrow; this also happens when they are allowed to grow in clusters. When grown on very hard ground, such as gravel, the shape is round and deep, often with extensive fluting of the shell (Fig. 3).

The amount and rate of growth varies with the season; it varies from year to year during similar seasons; it varies with tidal exposure; and it may vary between two closely situated locations at the same tidal height. It is therefore difficult, if not impossible, to present a growth picture that is representative of all of British Columbia, and each grower must learn the growth characteristic of his own ground and its various parts.

There are various definitions regarding length, width, and thickness but the ones given here are generally understood by the oyster industry. Growth of oysters may be studied in terms of linear measurements (length, width, height) (Fig. 29)

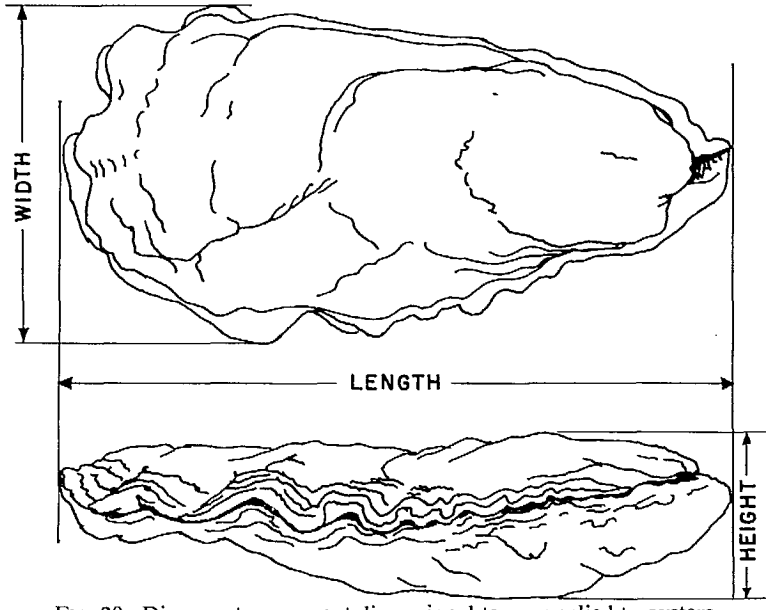


FIG. 29. Diagram to represent dimensional terms applied to oysters.

and/or volume. The latter measure is possibly the most valuable since it incorporates in one figure the three linear measurements. Further, it is the measure in which the grower is most interested for it is the basic measure of productivity.

There are also other means of measuring growth. If an oyster is weighed in water it is essentially the weight of the shell that is being measured, for the specific gravity of the oyster meat approximates very nearly that of water and, of course, the liquid contained within the shells makes no difference. A time series of such weights provides an indication of whether or not shell is being added, which may be in thickness, length, or width. Such data for an oyster growth study are shown in Fig. 30, and corroborate the information from other studies that essential shell growth occurs between April and October. However, there is an indication that slight growth may occur during the winter months. This may be due to linear growth that is so slight as to be unmeasurable by conventional methods, or to increase in the actual thickness of the shell by accretion of an additional internal deposition. Other studies of the growth of Pacific oysters in both British Columbia and Washington have indicated some winter growth.

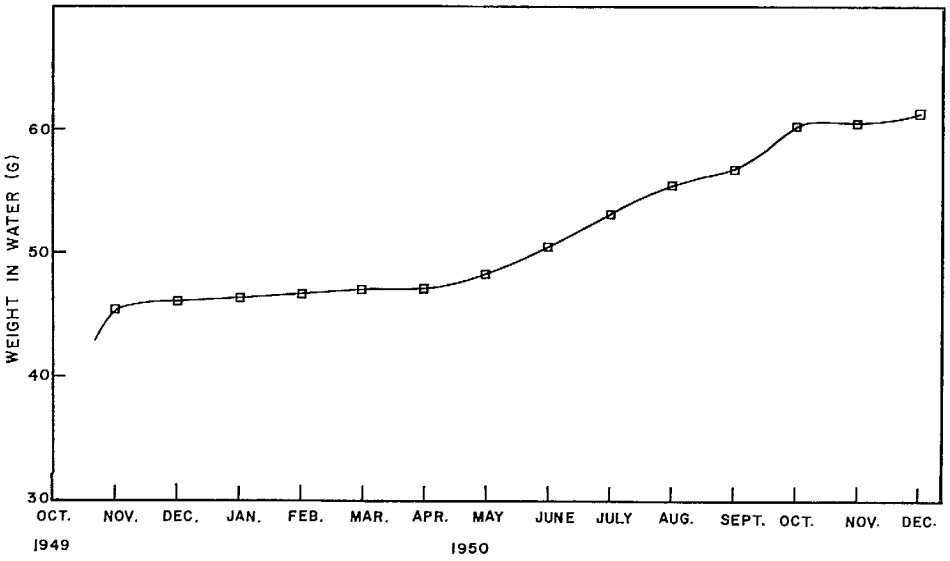


FIG. 30. Shell growth of the Pacific oyster *(C. gigas)* as determined by the weight in water, Ladysmith Harbour.

The ratio whole volume:shell volume has been suggested as a measure that might evaluate the potential yield of an oyster population. Whole volume is measured with the live oyster and includes the volume of the valves as well as the internal volume. Shell volume is measured with the animal removed and represents only the volume of the shells themselves. The ratio indicates the capacity of an oyster to produce meat for it reflects the volume of oyster meat an oyster in peak condition could produce. In Table II are shown ratios derived from oysters from several

TABLE II. Whole volume to shell volume ratios of Pacific oysters on British Columbia beds.

Location	Ratio
Naden Harbour (Queen Charlotte Islands)	1.90
Seal Island	1.96
Henry Bay (Denman Island)	1.91
Chemainus	1.76
Thetis Island	1.86
Ladysmith (soft ground)	1.63
Ladysmith (hard ground)	1.80
Sherard Point (Crofton)	1.76
Eelgrass Flats (Crofton)	1.55
Islands (Crofton)	1.68
Raft Culture (Ladysmith)	2.12

localities. The high value of 2.12 for raft culture oysters does indeed reflect the fact that these oysters do produce a relatively large quantity of meat for the size of the oyster. Oysters grown at Naden Harbour, Queen Charlotte Islands, on very firm ground had a round, deeply cupped shape and gave a ratio of 1.9. Ladysmith Harbour oysters grown on much softer ground did not have the nearly perfect shape of Naden Harbour oysters and gave a ratio of about 1.6.

TABLE III. Growth of Pacific oyster spat, August 1955 to October 1956, Pendrell Sound.

Date	Mean diameter (*mm*)	Increase in diameter (*mm*)	% Increase in diameter
1955			
August 15	0.3	–	–
August 18	1.1	0.8	1
August 30	3.8	2.7	3
September 8	7.9	4.1	4
September 20	13.4	5.5	6
October 6	18.6	5.1	6
November 9	24.7	6.1	7
December 14	23.5	0	0
1956			
January 31	23.7	0.2	0
May 7	34.0	10.3	11
June 8	50.0	16.0	18
July 20	73.0	23.0	26
October 11	90.0	17.0	18

GROWTH OF THE SPAT

The growth of larvae has already been described.

The growth of early spat has been studied in Pendrell Sound during the period between setting and the following October. Measurements were made of the linear dimensions of spat suspended from rafts at a point 2 ft below the surface. The results of this study are shown in Table III and Fig. 31. As shown in the table, there

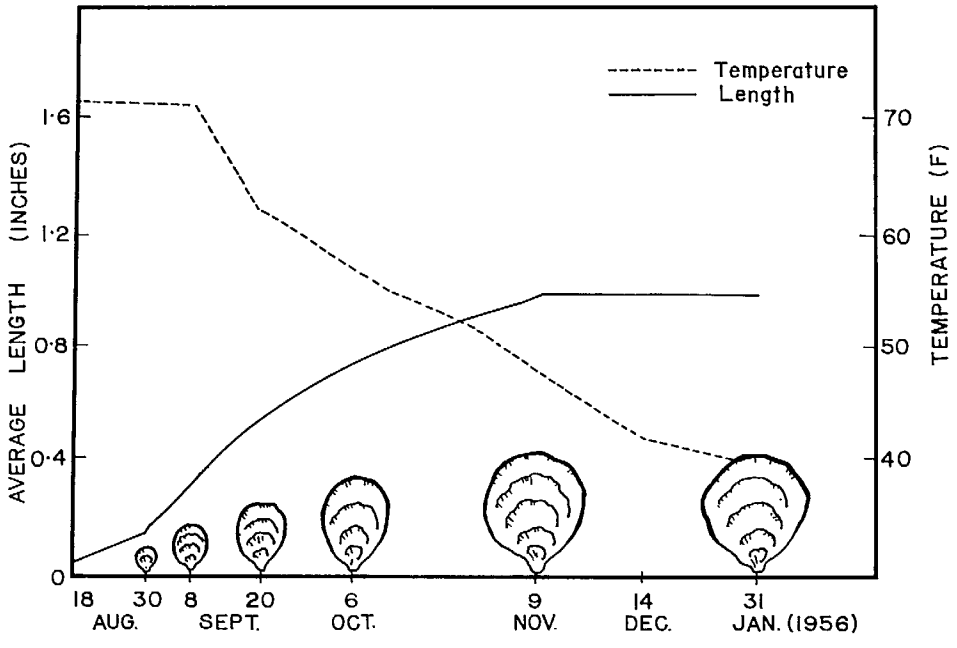


FIG. 31. Growth of Pacific oyster spat, Pendrell Sound, 1955–1956.

was no growth after the November 9 measurement, but by that time, at an age of about 3 months, the spat had attained an average diameter of 1 inch; and after another full summer of growth they were 3.5 inches in diameter.

TABLE IV. Pacific oyster growth in Ladysmith Harbour, Lot 164. Mean length, volume, and weight of oysters in three cases of Japanese oyster seed, April 1952 to June 1955.

Date	Length *(inches)*	Volume *(bushels)* (per case)	Weight *(lb)* (per case)
1952	0.2	1.3	118
1953	2.1	11.6	493
1954	3.8	19.8	1014
1955	4.3	23.3	1566

Another study was conducted on the experimental oyster area (Lot 164) in Ladysmith Harbour, when the growth of oysters from three cases of Japanese seed was measured. The full data, including survival, are given in Table IV and Fig. 32.

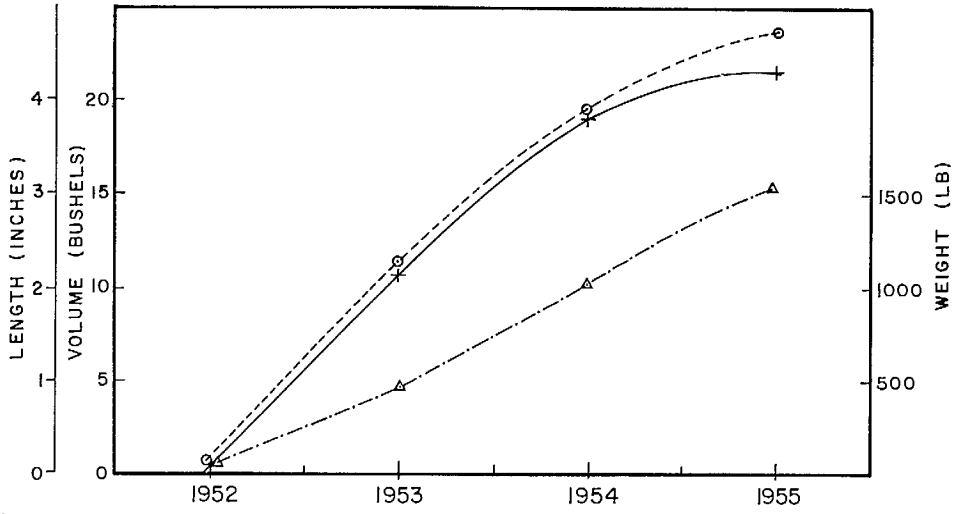


FIG. 32. Growth rate of Pacific oysters in Ladysmith Harbour. Mean shell length (+), case volume (⊙), and case weight [lb] (△) of a 3-case lot of Japanese oyster seed.

When planted the spat in this instance were not greater than one-quarter inch in diameter and were placed at a tidal level of 3 ft on fairly firm mud-gravel ground. Initial weight and volume measurements were essentially of mother shell for the

TABLE V. Percentage increase in length and volume of Pacific oysters of equivalent size, Ladysmith Harbour, May 5—August 2, 1955.

Location	% Increase in length	% Increase in volume
Station A	12.5	44.5
Station B	17.7	75.4
Station C	15.7	46.6
Station D	8.5	27.4

TABLE VI. Growth rate of Pacific oysters from four year-classes, Ladysmith Harbour, 1951–1954.

Year-class	Length *(cm)*	Volume *(cc)*
1951	0.50	1.0
1952	3.44	5.0
1953	6.18	19.2
1954	10.80	104.0

actual weight and volume of the spat at that stage were negligible. These data represent just over two growing seasons. Like most animals, oysters grow rapidly when young and more slowly as they become older. In oysters, reduction of growth rate occurs at 4 or 5 years of age.

GROWTH VARIABILITY

To demonstrate the variability of Pacific oyster growth with locality, data are given in Table V on oysters of similar size, grown under similar conditions, at similar tide levels at four locations each 1 mile apart along the shore of Ladysmith Harbour.

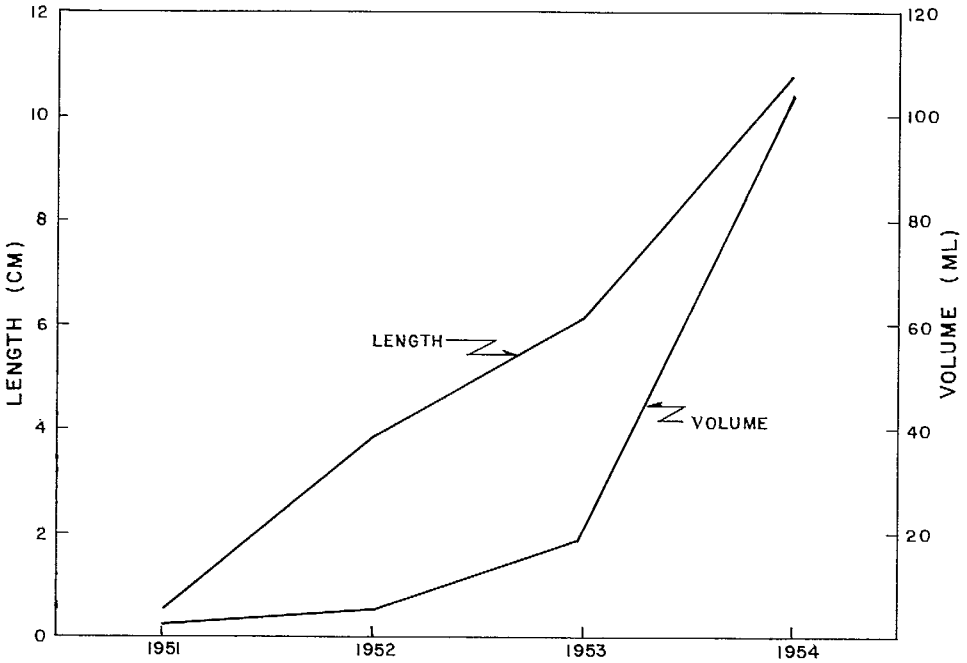


FIG. 33. Length and volume increase of Pacific oysters as measured from samples of four consecutive year-classes on the beds at Ladysmith Harbour.

Table VI and Fig. 33 show the growth rate, in length and volume, of Pacific oysters as measured from four year-classes of Japanese seed in contiguous beds in Ladysmith Harbour. The relatively even growth in length during the whole period may be noted but of interest is the slow increase in volume until the last year when nearly 82% is added.

Seasonal Shell Growth

The seasonal growth of Pacific oysters was studied in Ladysmith Harbour. Oysters were marked and the length, width, thickness, and volume measured at monthly intervals. The results are shown in Tables VII and VIII and in Fig. 30 and 34.

Table VII. Mean dimensions of Pacific oysters at monthly intervals, Ladysmith Harbour, 1949–1950.

	Length *(cm)*	Width *(cm)*	Thickness *(cm)*	Volume *(cc)*	Temperature *(F)*
November	6.90	4.74	2.89	29.2	48
December	6.82	4.66	2.96	29.3	42
January	6.90	4.64	2.92	29.8	38
February	6.78	4.65	2.70	29.5	41
March	6.86	4.62	2.87	30.3	44
April	7.03	4.72	2.90	30.8	48
May	7.28	5.00	2.97	32.4	55
June	7.51	5.22	3.07	35.4	64
July	7.91	5.51	3.23	38.5	68
August	8.19	5.61	3.33	44.4	66
September	8.65	5.78	3.47	48.3	61
October	8.75	5.90	3.48	51.3	50
November	8.77	5.94	3.50	51.6	46

There was no significant increase in length and width until April and, in thickness and volume, until May. From then on, there were fairly regular increases in all measures until October. Shell growth began when the water temperature reached about 50 F and ceased at approximately the same point in the fall. The shell growth as measured by the weight of the whole oyster in water, and as shown in Fig. 30, indicates a very slight increase in shell weight during winter.

Table VIII. Mean monthly percentage increase in dimensions of Pacific oysters, Ladysmith Harbour, 1950.

	Average temperature *(F)*	Length	Width	Thickness	Volume
April	48	9.0	7.8	–	–
May	55	13.2	21.9	12.3	7.8
June	64	12.2	17.2	17.6	14.7
July	68	21.2	22.7	28.1	15.1
August	66	14.8	7.8	17.5	28.8
September	61	24.3	13.3	24.5	19.0
October	50	5.3	9.3	–	14.6

These data represent averages and there was a wide variation in the amount of growth shown by individual oysters, for a few grew very little while others nearly doubled their size. The times at which various individuals began and stopped growing also showed wide variability.

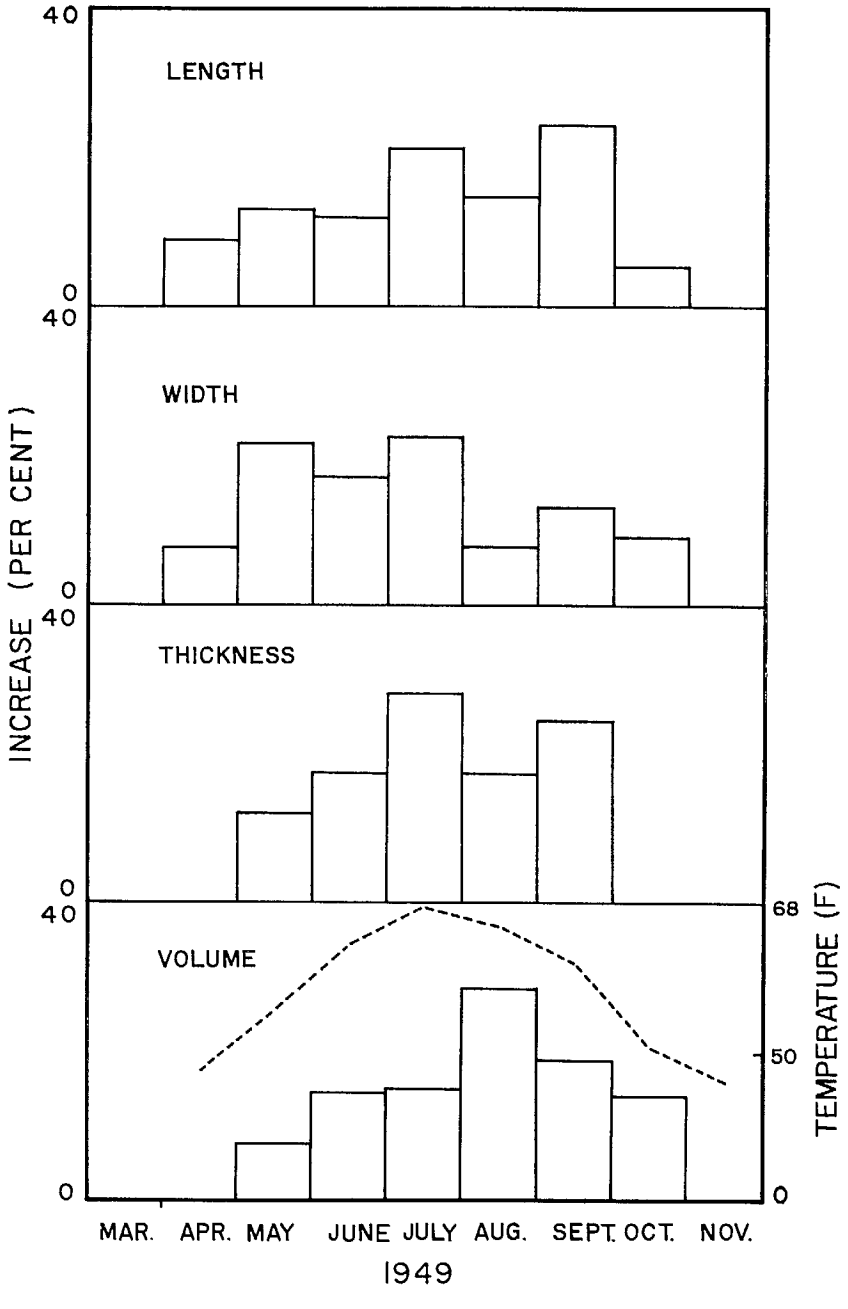


FIG. 34. Growth of Pacific oysters, Ladysmith Harbour, 1949.

The significance of the marked decrease in growth in length, width, and thickness during August (Fig. 33) is not known, unless it was associated with spawning, which, however, was not observed in the group being studied. It is noteworthy that shell growth continued during the period of gonad (spawn) development and also during the so-called fall fattening period of September and October.

The correlation between onset and cessation of shell growth at about 50 F has already been suggested. It is known, however, that the Pacific oyster is able to pump water at temperatures considerably lower than 50 F. It may be that the temperature limits indicated are applicable only to shell growth and not to tissue growth, but more research is required to clear up these points. For instance, much of the rapid growth occurred during periods when the diatom content of the water was low.

Growth was shown to begin rather slowly with the onset of increasing water temperatures in April, and during the first 3 months less than 40% of the total annual growth in length, thickness, and volume occurred. However, nearly 60% of the increase in width occurred during this period. Length, thickness, and volume increased most rapidly during July, August, and September, thereby accumulating nearly 60% of the total growth in the 3 warmest months of the year. After this period, growth, in most instances, ceased quite abruptly, although the water temperature declined gradually.

Growth is also related to tidal height, and, as a general rule, the higher the tidal level, the slower the growth. However, the differences are not as great with young oysters as they are with older ones. This is fortunate because it makes it possible to plant spat at a relatively high tidal level where ground is generally firmer than at low levels, thus making for better survival, and yet still attain a fairly good growth rate.

TABLE IX. Mean daily hours of beach exposure at various tide levels for each month, Fulford Harbour, 1964.

Tide level	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Average
−1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0	0.0	0.0	0.0	0.0	0.1	0.2	0.2	0.0	0.0	0.0	0.1	0.0	0.4
+1	0.1	0.1	0.0	0.3	0.4	0.6	0.5	0.3	0.0	0.0	0.4	0.4	0.2
2	0.9	0.9	0.1	0.7	1.3	1.3	1.2	0.6	0.3	0.3	0.8	1.0	0.8
3	1.9	2.4	0.7	1.9	2.5	2.7	2.1	1.6	1.0	0.9	1.6	2.1	1.8
4	3.2	3.9	2.4	3.7	3.8	3.8	3.3	3.1	2.6	2.4	2.7	3.2	3.2
5	4.6	5.4	4.4	5.3	5.5	5.2	4.6	4.5	4.7	4.4	4.5	4.6	4.8
6	5.9	7.2	6.4	6.9	7.3	6.6	6.4	6.2	6.5	6.4	6.2	6.2	6.5
7	7.8	9.8	9.1	9.8	9.8	8.9	8.7	8.0	8.8	9.2	8.9	7.9	8.9
8	9.8	13.2	12.4	15.0	14.4	12.9	12.2	11.6	11.6	12.6	12.9	10.3	12.4
9	12.8	19.0	19.5	20.2	18.8	16.4	16.5	17.1	18.2	18.2	16.5	13.5	17.2
10	17.1	21.5	22.4	23.6	22.0	20.8	20.8	21.6	22.6	21.9	20.0	17.5	21.8
11	21.0	23.9	23.9	24.0	23.9	23.6	23.7	24.0	23.9	23.8	20.9	21.1	23.3
12	23.1	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	23.8	23.2	24.0
13	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	23.9	24.0
14	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0

TABLE X. Mean daily exposure at various tide levels for five British Columbia reference ports, as estimated from hourly height records.

Tide level *(ft)*	Mean daily exposure (hours) at following stations in years shown				
	Victoria (1965)	Pt. Atkinson (1965)	Tofino (1965)	Bella Bella (1965)	Fulford Hbr. (1964)
−2	0.0	0.0	0.0	0.0	0.0
−1	0.0	0.0[a]	0.0	0.0	0.0
0	0.1	0.1	0.0[a]	0.0[a]	0.0[a]
+1	0.3	0.4	0.2	0.1	0.2
2	1.0	0.8	0.8	0.3	0.8
3	2.4	1.7	2.1	0.9	1.9
4	4.3	2.8	3.9	1.9	3.3
5	6.5	4.0	6.1	3.2	5.1
6	9.6	5.3	8.7	4.8	7.0
7	13.6	6.7	11.5	6.7	9.5
8	18.8	8.4	14.4	8.8	12.6
9	22.6	10.6	17.4	11.0	17.0
10	23.8	13.3	20.2	13.0	20.9
11	24.0	16.6	22.6	15.2	23.2
12	24.0	19.6	23.6	17.6	23.8
13	24.0	22.1	23.9	19.8	23.9
14	24.0	23.5	24.0	21.8	24.0
15	24.0	23.9	24.0	23.1	24.0
16	24.0	24.0	24.0	23.7	24.0
17	24.0	24.0	24.0	23.9	24.0
18	24.0	24.0	24.0	24.0	24.0

[a] Less than 0.1 ft.

An idea of the potential effect of tidal height may be seen in Tables IX and X and Fig. 35, which show the amount of time ground is exposed at various tide levels. The data in Table IX were derived in a different way from those in Table X, hence the slight difference in values for Fulford Harbour.

OYSTER FEEDING

FOOD

Though various species of oysters throughout the world have been much studied, relatively little is known about what actually constitutes their usable food. Since the oyster is a filter feeder it must accept whatever food comes to it in the water in which it is living. It can select to a modest degree the food it ingests but, to judge from the faecal material, this ability has limitations, for apparently many things which it ingests or takes into its stomach are not digested. What the oyster ingests is relatively well known and this includes bacteria, Protozoa, a wide variety of diatoms (Fig. 36), larval forms of other invertebrate animals, and inanimate organic material lumped under the name of "detritus." However, little is known of the value of various components of this material as oyster nutriment. There is one school of thought

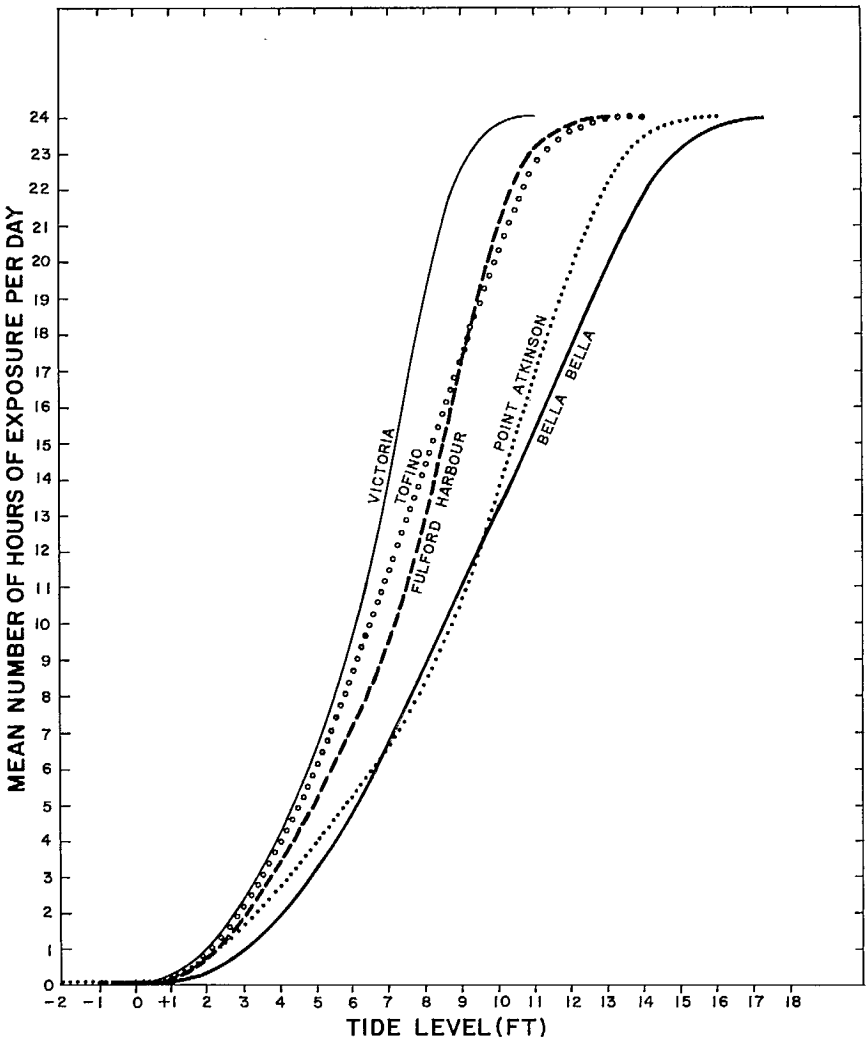


FIG. 35. Mean daily hours of exposure of beach at various tide levels for five British Columbia reference ports, as estimated from hourly height records provided by the Canadian Hydrographic Service.

which holds that diatoms and, indeed, only certain diatoms, are of paramount importance. Others believe detritus, possibly by itself or with adhering bacteria, is all important. Detritus is the fine organic matter suspended in the sea and is composed mainly of minute fragments of plants and animals. In inshore waters, eelgrass is thought to be the source of considerable quantities of this material.

Laboratory studies have shown that oyster larvae are very particular and selective about what they utilize for food and, of the numerous organisms used in the experiments, only relatively few have been found satisfactory. There is the classic experiment in which two foods of suitable size, but of different colour, were fed to

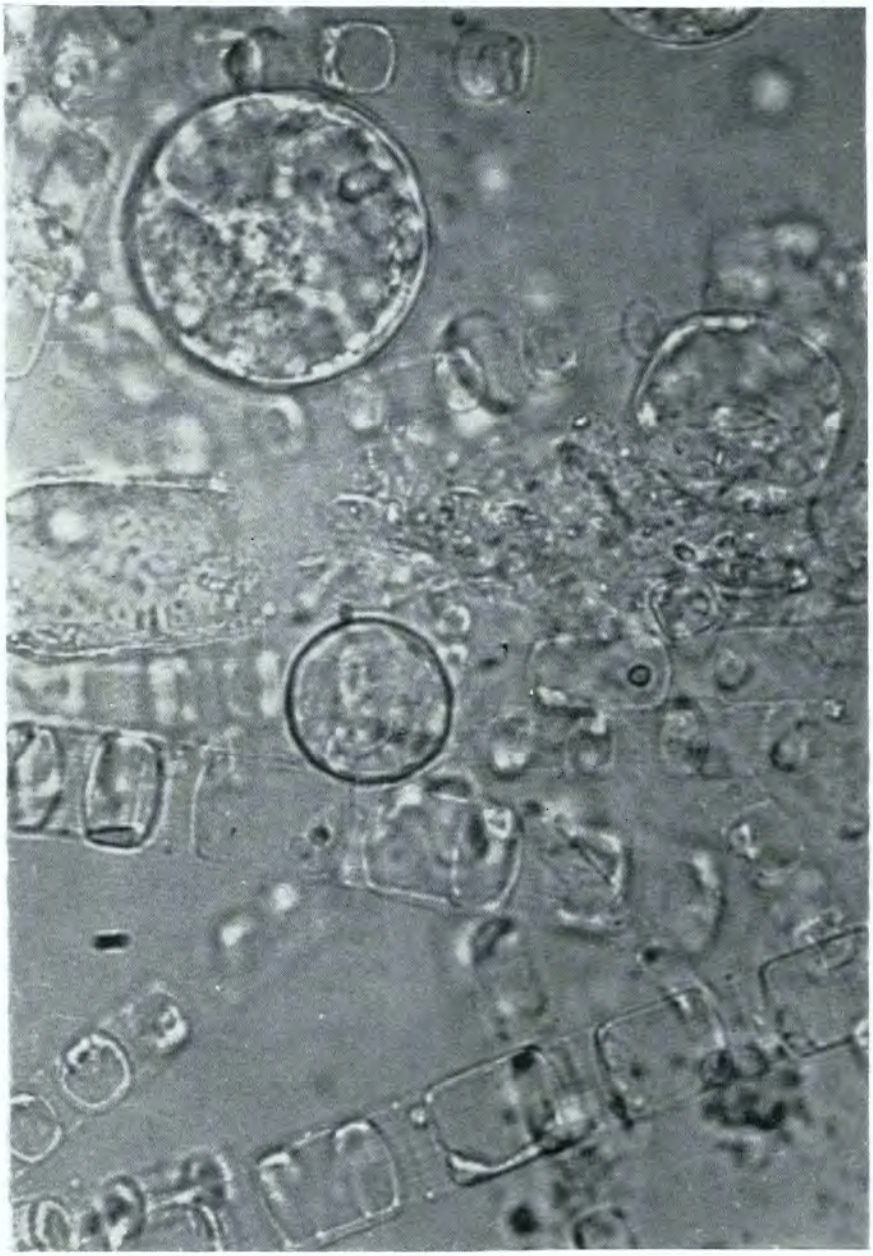


FIG. 36. Photomicrograph of several species of plankton diatoms. × 750.

Atlantic oysters. Food of one colour was regularly refused by the palps and rejected as pseudofaeces, while the other was accepted and ingested.

Fatness Cycle

Whatever the actual food, the experienced oyster grower knows the results of the availability of good oyster food, when year after year, although with variation from year to year, his oysters go through a regular fatness cycle. He knows this by experience, and from the gallonage return.

After spawning the oyster is extremely thin but by the end of October it has regained considerable weight and goes through the winter in this condition. In late March or April, the oyster again begins to add to its weight and by May it is usually in its finest condition of the year, filling its shell with cream-coloured, even-textured meat. Most growers also associate improved condition with turbidity of the water, which comes about, usually in March, because of what is called the spring bloom of diatoms, caused by the right combination of light, temperature, and nutrients. The water over the oyster beds remains more or less turbid until November, when again it becomes crystal clear. Turbidity may be caused by the rapid and intensive multiplication of microscopic marine organisms, by silt, or by suspended detritus, or a varying mixture of all three. Further, almost invariably, the spring fattening is of greater magnitude than the fall fattening.

The seasonal cycle of diatom abundance as determined for 1 year in Ladysmith Harbour is shown in Fig. 37 and this approximates the picture in most parts of the world. Also, for the same year, is shown the seasonal change in condition factor (fatness) of oysters from a single bed. The spring increase in condition is shown clearly after the dramatic drop of nearly 100 points after spawning in early August. In general, the seasonal cycle of fattening of oysters in Ladysmith Harbour coincides with the seasonal abundance of diatoms and with turbidity of the water. Whether or not this is a direct or indirect correlation is not known, but the relationship does exist and repeats itself year after year.

As indicated previously, however, the level of fatness can vary very much from year to year and it has been shown that there may be cycles when, for several years, the condition, both during the spring and fall, remains well below average. Other instances occur when there is failure to fatten significantly in the fall. This places the grower in a difficult situation, because he does not wish to market oysters of inferior quality, and low meat return makes marketing unprofitable. If he has no alternative beds with better oysters, there is little he can do but to wait until the spring fattening, or purchase oysters from other growers to hold his market.

Another situation can occur, and often does, on many beds. This is when the summer is an exceptionally cool one and the oysters fail to spawn; they then enter the fall season in a spawning condition, not ideal for market. They may remain "spawny" throughout the winter, and even in February and March typical spawn veins on the outside surface of the oyster may be seen. Usually by this time, however, they are quite firm, and if the body is cut the spawn does not run as freely as it does in summer. Oysters which fail to spawn may, alternatively, resorb the spawn and reconvert it to glycogen. This may occur to a slight extent, when only the surface

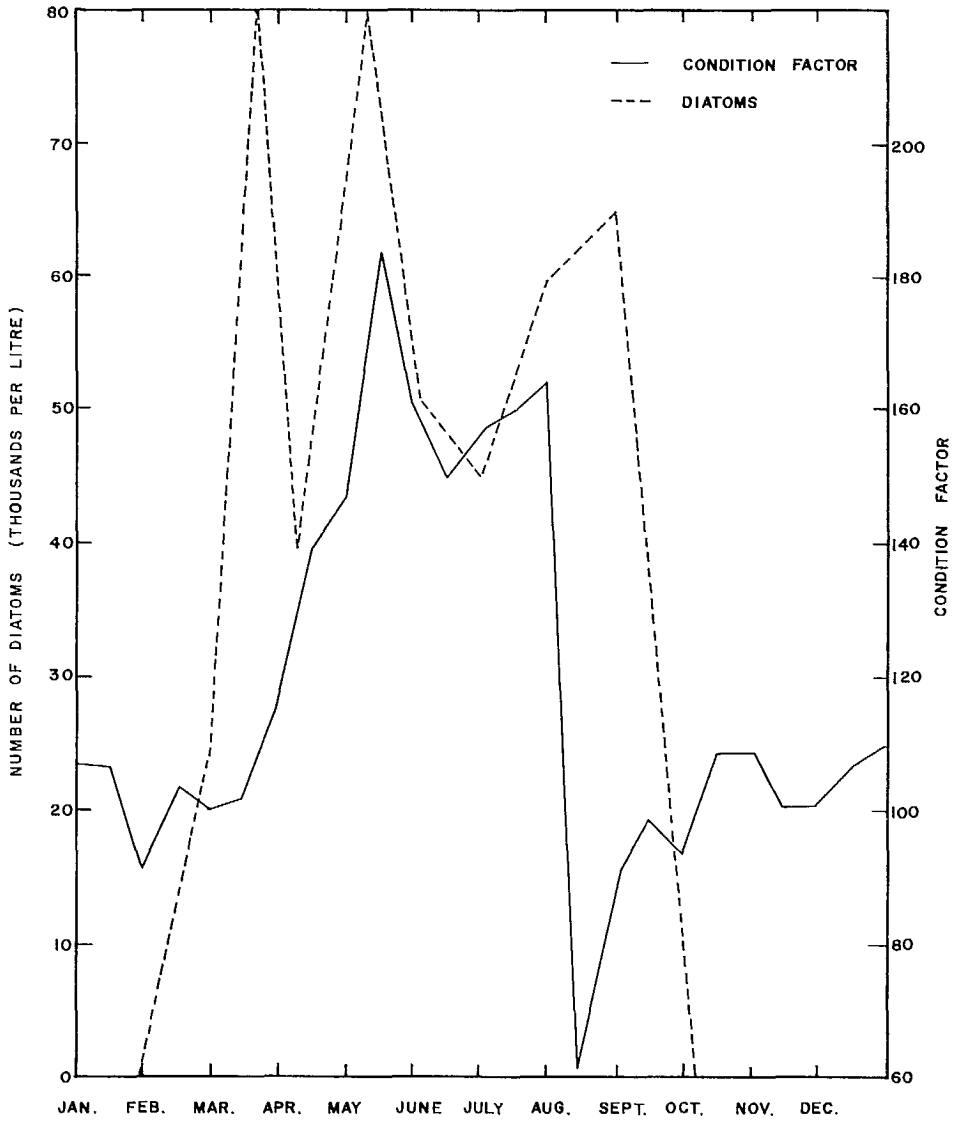


FIG. 37. Relationship between the standing crop (abundance) of diatoms and condition factor of Pacific oysters in Ladysmith Harbour.

material is resorbed and a thin layer of glycogen covers the inner layer of spawn; or resorption may occur to a considerable extent, when most of the gonadal tissue is converted. The amount of resorption is possibly dependent on the amount of food available during the fall.

Factors Influencing Feeding

Feeding is also dependent to a considerable extent on water temperature; more water and, consequently, more food, is taken in at higher temperatures than at lower ones. Transport of water through *Crassostrea* type of oysters of market size is estimated to reach 8 gallons per hour (although much less on the average) at optimum temperature, which for the Pacific oysters appears to be about 68 F, and at the optimum salinity of between 25 and 35‰. Condition of Pacific oysters held at salinities below 10‰ for more than 2 weeks will tend to drop.

In addition, too much silt in the water will cause oysters to reduce or stop filtration activities, as will an overabundance of microorganisms. Dense concentrations of marine organisms apparently discharge excretory products into the water in sufficient concentrations to inhibit or depress pumping action. Industrial wastes, such as pulp mill effluent, may also affect water transport in oysters, by its depressive effect on the ciliary activity of the gills.

An overpopulation of oysters in enclosed bays is also thought to affect productivity by reducing the amount of food available to each oyster.

BREEDING

Breeding History

Since the Pacific oyster was native to a country where relatively high summer water temperatures occur, the possibility of successful breeding in British Columbia appeared somewhat remote, at least on a regular basis. This has been shown to be largely true.

In the early years, between 1920 and 1930, when Japanese oysters were first introduced, the occurrence of spawning was of prime concern. The first recorded natural spawning of the Pacific oyster in British Columbia occurred in Ladysmith Harbour, in 1926, when it was estimated that between 10 and 15 thousand oysters spawned and produced several hundred spat. The first major breeding which produced a commercial set occurred in Ladysmith Harbour in 1932.

Details of the history of Pacific oyster breeding in British Columbia are given in Table XI.

Stimulated Spawning

The initiation of spawning, notwithstanding the 1932 success, continued to be a problem, for when spawning did occur it was usually late in the summer and the larvae were unable to complete development owing to the rapid onset of cool weather. Also, delayed spawning or nonspawning caused the adult oysters to enter winter in poor condition with subsequent complications in marketing. This problem was partially solved by the discovery that spawning could be stimulated on a large scale on the beds. By stimulating spawning in early summer, advantage was taken of better water temperatures for larval development, and of a longer fattening period for the spawned-out oyster.

TABLE XI. Breeding of the Pacific oyster in British Columbia waters.

	Spatfall	
	Ladysmith	Pendrell Sound
1912–25	a few hundred (whole harbour)	–
1926	a few hundred (whole harbour)	–
1927	a few dozen (whole harbour)	–
1928	a few dozen (whole harbour)	–
1929	nil	–
1930	a few hundred (whole harbour)	–
1931	a few hundred (whole harbour)	–
1932	commercial (13 per shell)	–
1933	light noncommercial	–
1934	light noncommercial	–
1935	nil	–
1936	commercial (2 sets, 100 per shell)	–
1937	light noncommercial	–
1938	light noncommercial	–
1939	light noncommercial	–
1940	nil	–
1941	noncommercial	–
1942	commercial (50 per shell) (also in Pender Harbour and Baynes Sound)	–
1943	commercial	–
1944	commercial	–
1945	noncommercial (2 per shell)	–
1946	nil	–
1947	noncommercial	–
1948	noncommercial	commercial
1949	commercial (10 per shell)	commercial
1950	noncommercial (5 per shell)	commercial (44 per shell on shore cultch)
1951	noncommercial (5 per shell)	commercial (500 per shell)
1952	noncommercial (1 per shell)	commercial (100 per shell)
1953	noncommercial (nil)	commercial (95 per shell)
1954	nil	noncommercial (6.5 per shell)
1955	nil	commercial (14 per shell, 10 per shell)
1956	commercial (25 per shell, 10 per shell)	commercial (3 sets, up to 1000 per shell)
1957	nil	commercial (21 per shell)
1958	commercial (several sets, up to 500 per shell)	commercial (several sets, 1000 or more per shell)
1959	nil	commercial (2 sets, 107 per shell, 100 per shell)
1960	nil	commercial (2 sets, 70 per shell, 33 per shell)
1961	commercial (46 per shell, 30 per shell)	commercial (4 sets, 1041 per shell, 213 per shell, 261 per shell, 581 per shell)
1962	nil	commercial (2 sets, 1000 per shell, 100 per shell)
1963	nil	commercial (2 sets, 1000 per shell each)
1964	nil	commercial (75 per shell)
1965	light	commercial — very heavy — more than 1000 per shell
1966	light (15 per shell)	commercial (60 per shell)
1967	commercial (50 per shell)	commercial (38 per shell)
1968	light	commercial (2 sets, 40 per shell, 23 per shell)

Stimulated spawning on a large scale may be accomplished by loading a scow with several tons of oysters on the low tide of the day on which stimulation is to take place. Shortly before high water slack, usually in the late afternoon or evening, the oysters are transferred to a sink float or live box. After the oysters have begun to feed, several dozen oysters are opened and macerated thus freeing spawn which is added to the water in the sink float. Feeding on a suspension of eggs and/or sperm stimulates ripe oysters to spawn. Should this fail, it was discovered, strangely enough, that if the sink float was towed at a speed of 2 or 3 knots for 5 or 10 minutes so the water rushed over the oysters, spawning was almost certain to begin. When spawning is well underway the oysters are dropped to the oyster bed below. The sink float should be so anchored that the ebbing tide will carry the spawn over the main oyster bed and timing of the operation should be such that the slow current just at the turn of tide from flood to ebb permits concentration of spawn among oysters adjacent to the spawners from the sink float. Gradually, more and more oysters on the bed are stimulated by spawn from their neighbours, and, within an hour, several acres of oysters may be spawning.

Beds of up to 3 acres in extent have been stimulated to spawn in this manner in Ladysmith Harbour. In 1936, a commercial set resulted from a series of stimulated spawnings. However, the practice of stimulated spawning has been used very little by the industry.

It appeared that, by the middle of the 1940s, the initial indifferent success in natural spawning had been overcome, although the reason is not clear; now, only in the very coolest of summers do oysters in most areas fail to spawn. However, successful spawning does not necessarily mean successful breeding. As described elsewhere, after spawning and fertilization there is the free-swimming larval period and mortality may occur in the larval broods, particularly during the first week or 10 days.

Temperature

Water temperature appears to be the main limiting factor in breeding success. It may not have a direct effect on larvae but it may have an effect on the production of larval food. Involved in both this and in the development of higher water temperatures is the effect of sunlight. The direct effect of temperature on larval survival is shown best in Ladysmith Harbour, which is a long, narrow, shallow estuarine-type bay. During calm, sunny weather in summer, the water temperature can build up rapidly, partly because of the heat transfer from the extensive tidal flats which are exposed to the sun's rays for considerable periods during the spring tides. But because it is so shallow, a continuous breeze of any duration either from the southeast or northwest can cause vertical mixing and a rapid decline in water temperature (Fig. 38). If the temperature fall is rapid enough or extensive enough, it can affect larval survival directly and immediately. If the temperature change is more gradual, the effect may be more indirect, probably acting on the development of suitable food.

In comparison, as will be described below, Pendrell Sound is able to maintain high water temperatures in spite of adverse weather conditions, unless these continue for extended periods.

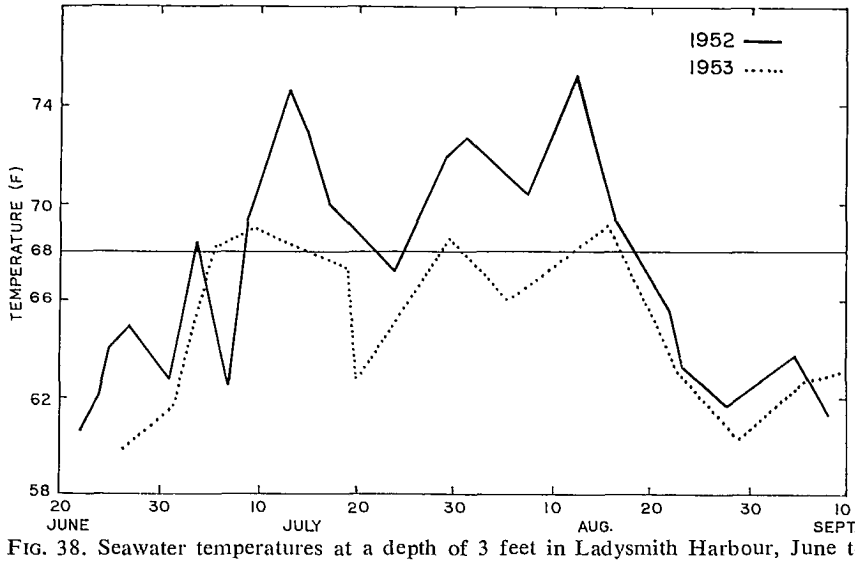


FIG. 38. Seawater temperatures at a depth of 3 feet in Ladysmith Harbour, June to September, 1952 and 1953.

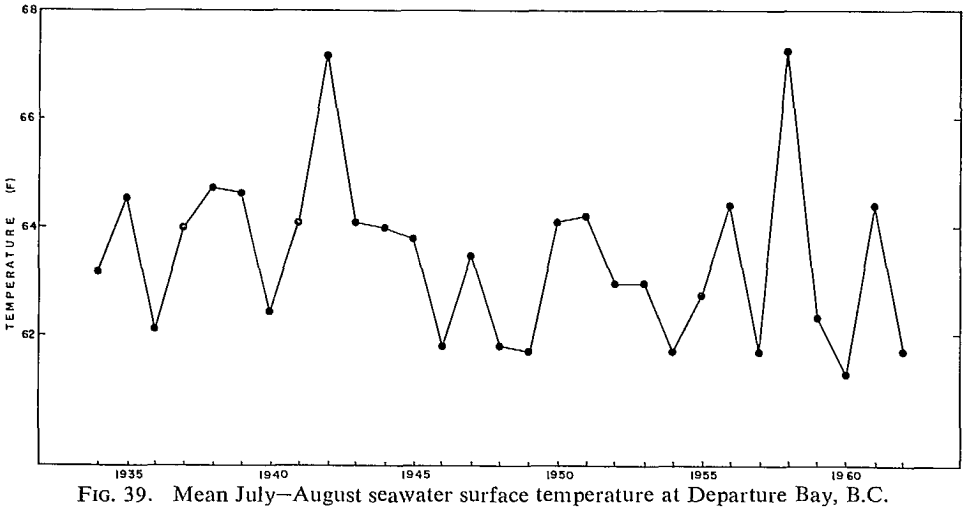


FIG. 39. Mean July—August seawater surface temperature at Departure Bay, B.C.

In 1942, a particularly warm summer produced abnormally high water temperatures (Fig. 39) and breeding of Pacific oysters occurred in all oyster producing areas in British Columbia. As a result, larvae, which subsequently spatted, were distributed over the whole northern half of the Strait of Georgia and into the long mainland inlets and sounds such as Jervis, Hotham, Malaspina, and Pendrell. The progeny from this spawning was so abundant it served to maintain a supply of oysters to the industry during the wartime period when Japanese seed was not available. Indeed, there was a sharp rise in oyster production during the latter war years, due largely to these "wild" oysters, as they were called, from the 1942 spatfall, and this was repeated again after the 1958 occurrence.

In addition, these oysters were abundant enough in many areas to form the nucleus of breeding populations. In Pendrell Sound, in particular, and, to a lesser extent, in Hotham Sound, conditions occur which are suitable for the propagation of Japanese oysters (Fig. 1).

LARVAL MOVEMENTS

The development of the larvae after spawning has already been described but there has been nothing said about larval behaviour. Since Pacific oyster larvae have a free-swimming period of up to 4 weeks and since their movement is largely dependent on the action of currents, they may be carried considerable distances from the spawning area. An excellent opportunity for direct information on this point was obtained from the 1932 and 1936 spawnings in Ladysmith Harbour (Fig. 40, 41). As a result of these breedings, oysters were found spatted on rocks many miles

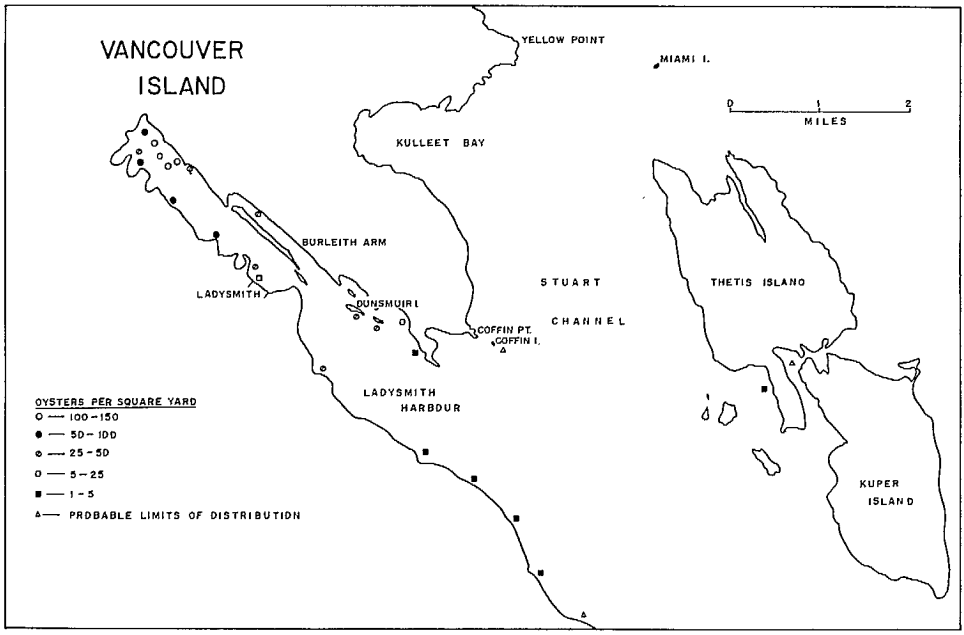


FIG. 40. Distribution of the 1932 Pacific oyster spatfall.

from the head of Ladysmith Harbour, which at that time held the only stock of oysters from which these larvae could have originated. The greatest intensity of spatting in these two years occurred near the head of the harbour, where oyster beds were located, and the number of spat per unit area decreased with distance from these beds. The most northerly point at which spat were found was just south of Nanaimo at False Narrows, indicating the larvae had been carried about 20 miles in that direction. The most southerly point of spatting was at the head of Saanich Inlet, about 35 miles from the head of Ladysmith Harbour (Fig. 1).

The other notable instance of the movement of larvae from known stocks occurred in 1942, when larvae were presumed to move from Pender Harbour into areas such as Pendrell Sound.

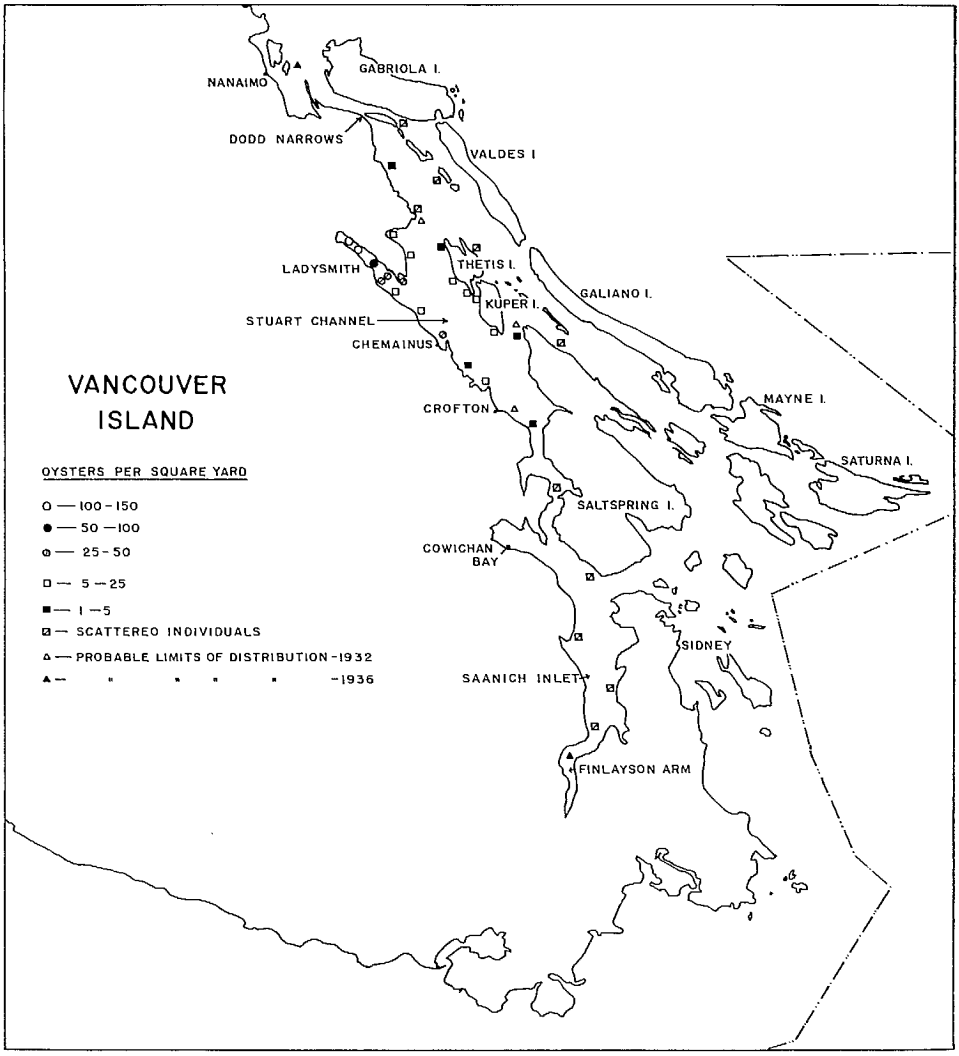


FIG. 41. Distribution of the 1936 Pacific oyster spatfall.

The horizontal distribution of oyster larvae has also been studied in some detail in Pendrell Sound. Here, it seems that larvae become spread from the spawning area throughout the Sound within a week. Sampling indicates an aggregated rather than a random, or even, distribution.

It would be expected that there might be a direct relationship between the number of advanced larvae at any spot and the density of spatfall there, and undoubtedly there is. However, repeated attempts to correlate the two have shown only a slight indication of it. This is partly because methods of sampling larvae are inadequate. The quantity of larvae-bearing water passing the cultch per unit of time, rather than the absolute number of larvae per unit volume of water at a specific time, may be the critical factor.

The vertical distribution of larvae in Pendrell Sound has also been studied by sampling at depths 0, 3, 6, 9, 12, 18, and 24 feet below the surface, sometimes at 3-hour intervals for several days. It seems that the majority of larvae do not descend below a depth of about 12 feet, for only small numbers are found below this depth. Here there is an area of sharp temperature change (Fig. 62) called the thermocline. The water above has a temperature of 70 F or more, while below that depth, the temperature decreases very rapidly. There is also a salinity change, but it is not quite so apparent. These water characteristics no doubt prevent the occurrence of significant numbers of larvae below the thermocline.

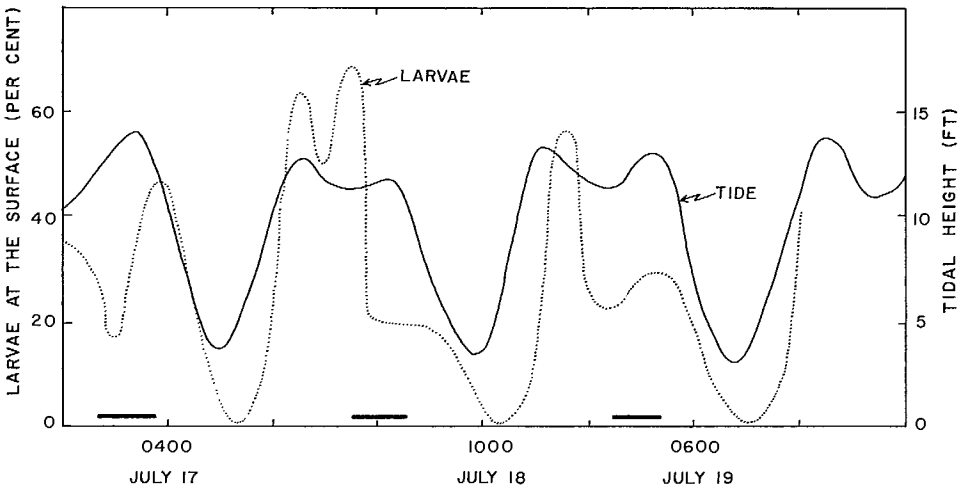


FIG. 42. Relationship between the tidal cycle and percentage of straight-hinged Pacific oyster larvae occurring at the surface. Percentage is the surface fraction of larvae in six samples taken between the surface and a depth of 18 feet at 3-hour intervals. The solid bars along the base-line indicate the periods of darkness. Station 2, Pendrell Sound, July 16–19, 1956.

There may be some vertical movement of larvae as shown in Fig. 42 for, in a series of samples at various depths, the proportion of larvae that occur at the surface shows a fairly regular fluctuation that follows the tidal cycle. However, the high tides occur in the evening or at night and it may be that, like many other marine invertebrate organisms, there is a tendency for oyster larvae to move near the surface at night and to retreat to deeper levels during daylight hours. If such movements are real or consistent, they must be taken into account when sampling oyster larvae for spatfall forecast purposes.

LARVAL MORTALITY

Because it is virtually impossible to estimate the number of adults participating in a spawning, it is difficult to assess larval mortality. It is thought, however, to be of considerable magnitude. In Pendrell Sound, when the initial number of straight-hinged larvae was compared with the number of advanced-stage larvae just at setting time, the survival rate has been found to vary between 0.5% and 9%. In some years, however, there has been total larval mortality.

Mortality, granted satisfactory water temperatures, is apparently due mainly to dispersal and to predation. Water currents can disperse larvae and carry them away from the spawning site into unfavourable water conditions where they may perish. Among predators of oyster larvae may be mentioned adult oysters which, in the feeding process, filter out all planktonic organisms, including oyster larvae, that cannot escape by active movement. Oyster larvae may be found in faeces and pseudofaeces, very often alive, but so enmeshed in mucus they are unable to survive. When it is considered that each of the many millions of adult oysters in

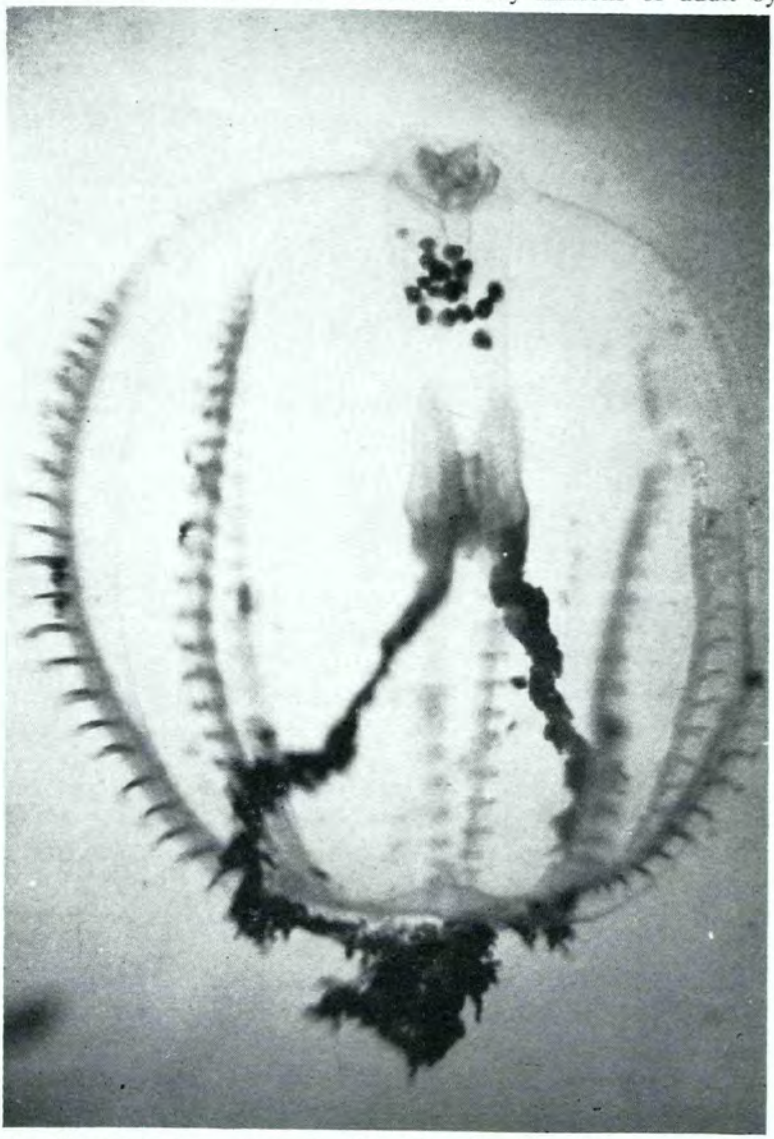


FIG. 43. Ctenophore or comb jelly *(Pleurobrachia pileus)* with Pacific oyster larvae in the digestive tract, Pendrell Sound, July 1965. × 10.

FIG. 44. Enlargement of Fig. 43 to show Pacific oyster larvae in the digestive tract of the ctenophore or comb jelly *(P. pileus)*. × 33.

Pendrell Sound may filter up to 20 gallons of water per day and that this water may contain several hundred larvae per gallon, mortality from this cause alone may be of some significance over the larval life of approximately 3 weeks. In addition to oysters, there are other filter feeders such as clams and barnacles.

Still another predator is the sea gooseberry or comb jelly, the ctenophore *(Pleurobrachia pileus)*, which captures oyster larvae by means of its two long tentacles (Fig. 43, 44). As may be seen from this photograph, a single ctenophore can account for about 20 oyster larvae at one time.

Eventually, even though it is thought that many larvae can postpone metamorphosis for a time, the oyster larvae must find an object to become attached to, or otherwise perish. In an area like Pendrell Sound, the only setting area is the shoreline or floating cultch. With the small tidal action, it is likely that a considerable proportion of the larvae fail to make contact and so perish. This must be a very significant source of larval loss.

In spite of mortality by these causes, enough larvae survive to give spatfalls of high intensity near the spawning source and some spatting at considerable distances away.

OYSTER CULTCH

Cultch is the material used for the collection of oyster spat, in other words, the substratum provided for the attachment of the larval oysters.

To collect oyster seed, then, cultch is placed in the water at the appropriate time and place. After settlement on the cultch, the spat are usually allowed to grow for a time before being removed to growing areas.

Considering the process in detail, first comes the selection of the type of cultch. There is a multitude of materials to which oyster larvae will attach themselves but very few are suitable as cultching material from the practical and economic point of view.

SHELL CULTCH

As already mentioned, Japanese oyster seed is collected on oyster shell cultch, and this is still the most frequently used cultch in North America, on both the Atlantic and Pacific coasts (Fig. 45). The main advantages of shell cultch are low

FIG. 45. Oyster shell with oyster spat about ½ inch in diameter at 2 months. × 0.7.

cost, and availability. The disadvantages are heavy weight, hardness, and strength. The great weight requires considerable flotation power if the cultch is to be suspended from rafts and quite heavy lifting gear if it is to be handled in quantity, both before and after exposure. The hard, strong shell, together with its large size, creates problems in separating clusters. The softer and smaller Japanese shells (from raft culture) are generally preferred to British Columbia and Washington shell cultch.

Shells, which are preferably clean, weathered, and aged (making them softer), are punched through the centre with a hammer to which a one-quarter-inch spike has been welded (Fig. 46), with a recently developed punching machine (Fig. 47), or an electric drill. These punched shells are strung like beads on 5- or 6-foot lengths

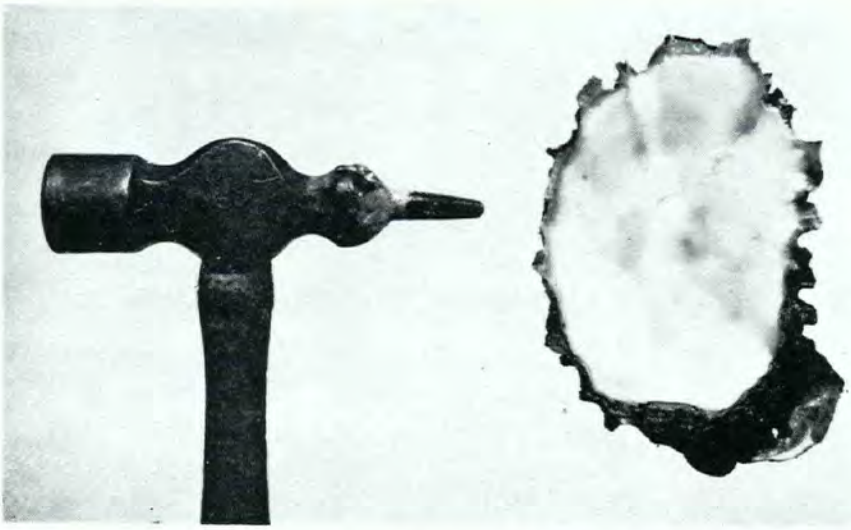


FIG. 46. *(above)* Shell-punching hammer.

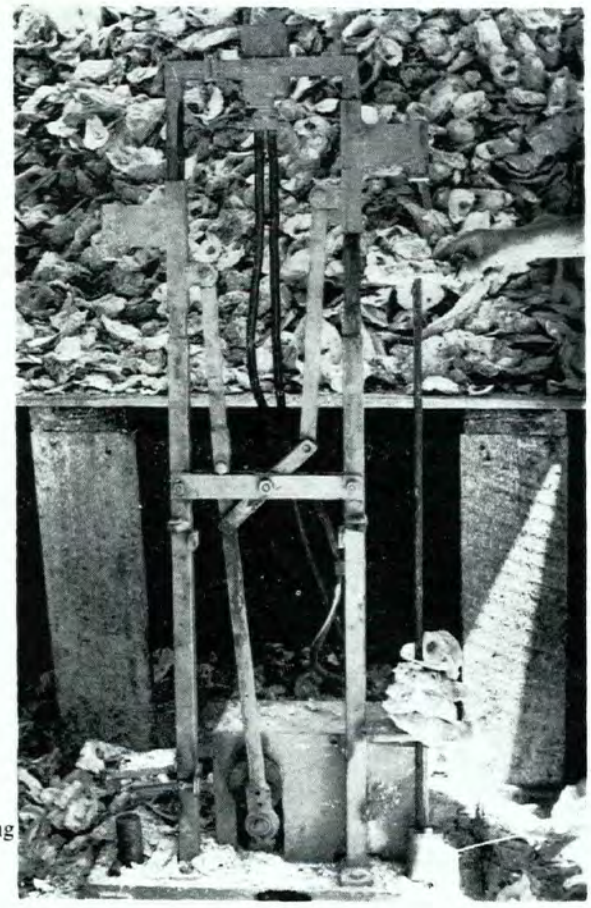


FIG. 47. *(right)* Machine for punching oyster-shell cultch.

FIG. 48. Double shell-cultch string.

of number 14 gauge galvanized wire (Fig. 48). Sometimes, double strings are used, and, in this case, each end of a 13-foot-long wire is strung with 5 feet of shell leaving a blank space of 2–3 feet between. This type of string can be draped over a float log and is not so easily lost by accident as a single string.

Shell may also be packed in bags made of chicken wire or discarded fish net. The bags must be rather small to permit adequate water circulation and the diameter, when filled, should not be greater than 8–10 inches. Wooden frames covered with wire netting have also been used, as have many other methods.

CEMENTED CIRCLES

Another type of cultch recently used in British Columbia is a cement-dipped, wood veneer ring. Veneer strips, 24 inches long by 3½ inches wide by $\frac{1}{26}$ inch

thick, are obtainable from specialty sawmills. These strips are made into 3-inch-diameter circles with an ordinary desk stapler (Fig. 49). They are then dipped in a slurry of cement, of about the consistency of thick soup, after which they are dried slowly. Fast drying causes the cement to flake off. The veneer costs about $8.00 per thousand pieces and, with labor, cement, and staples, the overall cost is about 2¢ per dipped circle. Each circle provides a setting area of slightly more than 1 square foot.

The area of shell in a case of unbroken Japanese seed is estimated to be between 50 and 60 square feet, the equivalent of the same number of circles. The circles are simply and rapidly strung on galvanized wire and a string of 30 makes a handy bundle of about 5 pounds in weight as compared with an equivalent area shell surface which would weigh nearly 50 pounds. Also there is good circulation through a bundle of circles, for there is sufficient variation in size and shape to prevent locking.

Other types of cultch are in use. In Japan, considerable use is made of scallop shells. In Europe, limed roofing tile is a common cultch which can be used year after year, for the coating of lime with the attached spat is scraped off when the spat become about 1 inch in diameter. Cement dipped building laths are used in the U.S.A. as are cement coated cardboard egg separators, particularly for Olympia (native) oysters. Brush and discarded fish net dipped in cement are also satisfactory collectors.

All of these forms of cultch have their advantages and disadvantages, and the choice depends very much on the type of culture to be practised. For example, the use of limed roofing tiles would be economically prohibitive in British Columbia. Also, apart from economics, the cultch must be suitable for the type of seed ground available; there is no object in putting small pieces of cultch on soft muddy ground for they will only become silted over, with high mortality.

Methods of Exposing Cultch

For the collection of oyster seed there are three basic plans for exposing cultch to make it available to the larvae:

(1) Bottom spread loose shell
(2) Intertidal racks
(3) Raft suspension

(1) loose shell

In this method loose shell is simply spread on the bottom in the intertidal area in a location known by experience to provide good sets (Fig. 50). The shells are usually spread 3 or 4 (2–3 inches) deep. In most cases, this is an inefficient method but the efficacy varies with the type of bottom, the intensity of the spatfall, and the timing of the operation. If the shelling operation is to be on a large scale, spreading must begin the moment a larval brood is reported to be in the water in order to provide sufficient time to expose enough shell. If the larvae fail to survive, the shell is lost in most cases, because it is not worth recovering owing to fouling and silting. For the same reason, the shell will not form a very efficient cultch if left on the beach

FIG. 49. Wood-veneer cement-dipped circles used for oyster cultch. × 0.3.

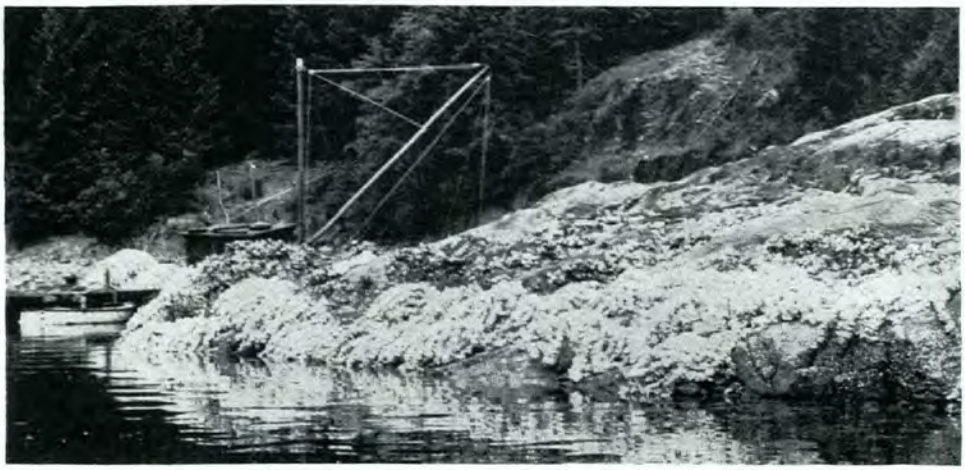


FIG. 50. Oyster-shell cultch spread on the shore, Pendrell Sound.

until the following year, unless the bottom is very hard and the shell is kept free of silt. Cement-dipped circles would be more efficient than shell in this type of operation.

The efficiency of loose shell was compared with that of shell strings in a commercial operation where silting was about average. The spatfall on 11,000 shells, from 85,000 bushels of loose shell that were spread, was counted; the data are shown in Table XII.

The average set on loose shell, excluding the shells with no spat, was 13 spat and by comparison the shell strings on racks caught a minimum of 100 spat per shell.

TABLE XII. Percentage occurrence of spatfall on spread shell.

Spatfall per shell (both sides)	Percentage of sample
0	40
1–3	13
4–6	9
7–9	7
10–12	6
13–15	4
16–18	3
19–21	3
22–24	2
25–27	3
28–30	2
31–33	1
34–36	1
37–39	1
40–42	1
43–45	1
46–48	1
49–51	2

It will be seen that 40% of the spread shells caught no spat and the survival rate on shells with one to three spat may be considered negligible so that for practical purposes it may be considered that 53% (approximately 45,000 bushels) was wasted. Also to recover the 47% of the shell with spat it would be necessary to harvest all of the shell thus complicating and increasing the cost of the operation.

Other comparisons over a number of years have shown that floating cultch is from 3 to 10 times as efficient as shore cultch. The main advantage of loose shell is the low initial cost, for packaging is not necessary and it can therefore be handled in bulk. In suitable locations, it can be left for several years in order to pick up a spatfall.

As indicated previously, the use of loose shell depends on the individual situation and the system has been used successfully in small scale operations in such areas as Ladysmith Harbour and Pendrell Sound.

(2) INTERTIDAL RACKS

The use of intertidal racks involves the building of wooden racks in the intertidal zone to hold packaged cultch such as shell strings. In years of low larval abundance, rack cultch will collect a fair set while there will be virtually nothing on spread cultch. Preparations may be made well in advance and exposure can be delayed until the probability of a set has become high. In the event of a set failure, the cultch can be recovered. Growth rate of the spat is greater on rack cultch than on the bottom, and since there is little silting, survival rate is higher. Another advantage of racks is that if they are reasonably well protected from wave action, the cultch may be left on the racks over winter.

There is however the cost of building the racks, in addition to packaging the cultch, so, in terms of investment, the cost is somewhat higher than in the loose cultch system, though the return is much higher.

The racks are usually made of 2-inch by 4-inch lumber or cut poles, and are 3 or 4 feet high. In most areas, unless the wood is creosoted, the racks last for only one season, owing to wood borer attacks. The system has been used successfully in Ladysmith Harbour and is a standard practice in Japan.

(3) RAFT SUSPENSION

The method of raft suspension is the most efficient and also the most expensive (Fig. 51, 52). Spatfall intensities, growth rate, and survival are greater than in the other two methods. In addition there are no tidal problems to consider when the cultching operation is in progress.

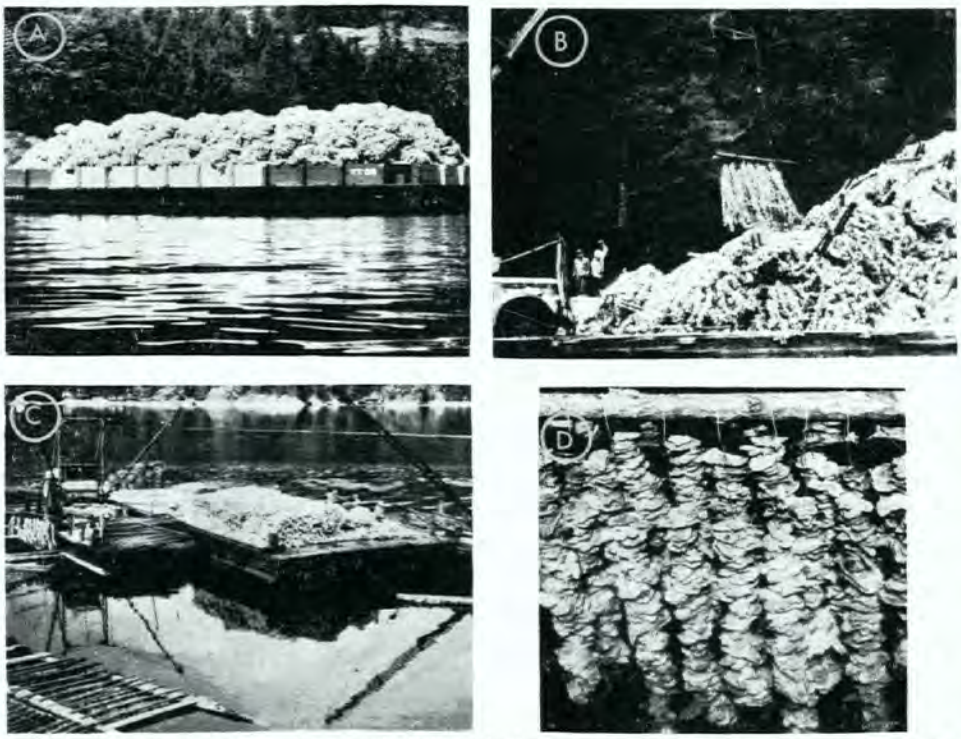


FIG. 51. Shell cultch operation, Pendrell Sound. A = scow load of shell strings; B = unloading shell strings which have already been hung on wooden poles; C = setting the string-loaded poles on the raft; D = shell strings hanging in the water.

Oil drums, logs, or creosoted or fibreglassed plywood pontoons may be used to construct the rafts of any size or shape. Lightweight concrete aggregate for float construction is also a possibility.

As in the rack method, exposure of packaged cultch can be delayed until there is reasonable expectancy of a spatfall. The cultch is usually left on the raft until October. One disadvantage of raft suspension is that the spat are submerged continuously and thus not adapted to intertidal life where they are exposed for some time each day. To compensate for this, and to reduce the difficulties of transfer from continuous submergence on the raft to intermittent submergence on the beach, seed

FIG. 52. Log rafts loaded with shell-string cultch. Pendrell Sound, 1966.

should be moved during cool damp weather, if at all possible. Also, the time should be chosen to coincide with the beginning of a series of neap tides, when the lower and middle intertidal area is exposed for a minimum length of time. During transportation from the seed area to the seed beds, the cultch should be kept damp and cool by spraying occasionally with salt water. If these suggestions are followed, there should be little seed mortality, except that occasioned by mechanical damage, some of which is inevitable and must be expected.

IDEAL CULTCH

So far an ideal universal cultch has not been found, for there are so many types of culture each requiring cultch with different characteristics. Eventually, no doubt, a cultch may be developed which will have the basic attributes common to all good cultches, but which can be modified to suit a particular type of culture. The following would be some of the characteristics of such an ideal cultch:

(i) Low cost is a basic requirement; at the present time, a primary cost of about 2¢ per square foot of surface area is near to the maximum permissible cost for Pacific oyster culture.

(ii) Larvae require a clean solid object on which to settle. Waxy or slick-surfaced materials are unsuitable and slightly rough surfaces are better than smooth ones; colour appears to be immaterial.

(iii) The material should be light in weight although it must be sinkable. Weight is important because of handling, shipping, and buoyancy problems.

(iv) The maximum surface per unit of volume is required, for this will affect packaging and transportation costs. Packaging means collecting and uniting individual units of cultch into larger units for exposure and for shipping. Stringing the individual shells on a wire is a form of packaging; other forms of packages are wooden or wire crates and wire or net bags. Satisfactory and economical packaging of a cultch are prime requisites of a good one.

(v) It is necessary for the cultch to permit a free flow of water so that larvae may reach all parts of the collecting surface.

(vi) If the cultch could disintegrate of its own accord after a specified length of time, the cost of separating clusters can be reduced. The time when the cultch should disintegrate is related to the growth rate of the spat and the pore diameter of the cultch, if it is of the lattice type. The spat must be large enough to survive a modicum of silting, and separation should take place before the spat have grown together in clusters. A fine balance between strength to withstand handling and fragility for ease of separation is required.

(vii) The pore diameter should be large enough to permit adequate circulation, either in the unit or the package, and of a shape to prevent collection of silt. The pore should also be large enough to allow the spat to grow to the size at which it will be separated.

The silting problem, which has already been discussed, varies very much with the circumstances. Silting of suspended cultch is not a serious problem in Pendrell Sound but it is in Ladysmith Harbour. When the cultch is placed on the seed bed the spat should be nearly an inch in diameter (although it is usually less in practice) or silting mortality will be significant on most ground. This is only approximate, for the size will vary with the rate of growth, density of planting, wave action, and degree of silting.

SPATFALL FORECASTING

Necessity for Forecasts

In British Columbia the Pacific oyster is under a decided handicap with respect to breeding, which in most areas is extremely uncertain. The exception is in Pendrell Sound, a small area in the northeast Strait of Georgia (Fig. 53). Here, summer water temperatures often exceed 68 F for some time. In Ladysmith Harbour breeding temperatures are usually reached but are not often maintained for a period long enough for the larvae to survive to setting.

Since spatting may be erratic and the timing variable, and since it is important to avoid fouling of the cultch by marine organisms, "blind" cultching is both impractical and uneconomical. Therefore, prediction of the time and intensity of spatfalls is desirable for British Columbia and collection of seed has come to be based almost entirely on spatfall forecasting. At present this is carried out by the Biological Station at Nanaimo and the forecasts are either relayed individually to firms interested in collecting seed, or broadcast over the CBC Fisherman's Program, if many growers are interested. Since setting occurs with relative frequency only in Pendrell Sound and Ladysmith Harbour, predictions are made for those areas only. The technique of prediction is essentially the same for both locations.

Technique

Oyster spawning in British Columbia is usually sudden and complete for any single oyster bed, and is often observed visually (Fig. 54). Therefore, individual larval broods may be followed closely with respect to number and distribution of larvae. This is done by means of plankton sampling.

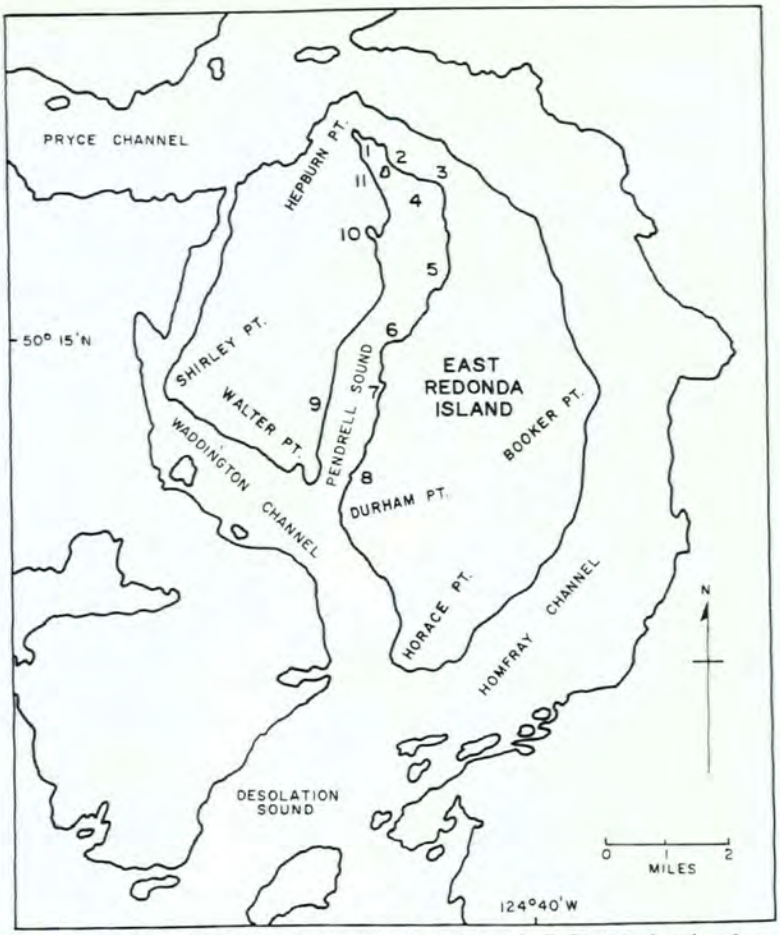


FIG. 53. Map of East Redonda Island and Pendrell Sound showing location of sampling stations.

FIG. 54. Spawning of a group of Pacific oysters in Pendrell Sound.

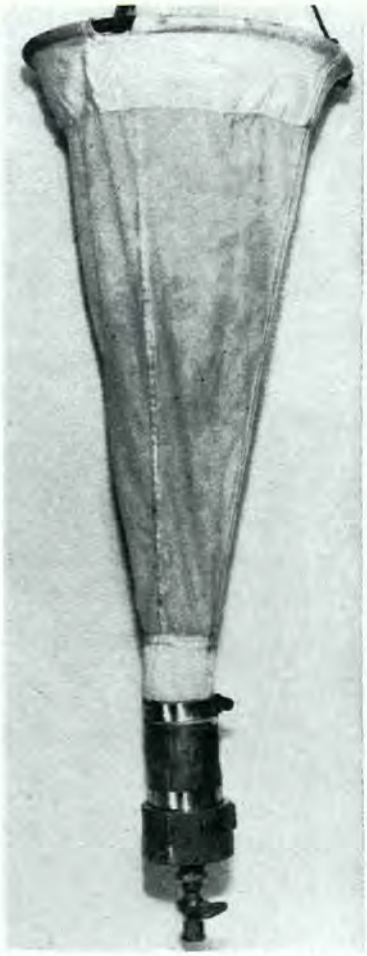


FIG. 55. Plankton net used in sampling oyster larvae. × 0.2.

In Pendrell Sound, which has an area of about 5 square miles, plankton samples are taken at a number of stations. A known volume of water, as measured by a water meter in the line, is pumped from a standard depth of 3 feet through a fine mesh net where the larvae are trapped (Fig. 55). For adequate prediction the samples should be taken at intervals of not more than 3 days, but this is not always possible. The larvae in these samples are counted and the numbers have been found to describe trends in the number of larvae well enough for prediction. There are many difficulties in sampling a microscopic organism such as an oyster larva which can carry out some swimming activity but whose distribution is largely the result of current action. A recent development is a plankton sampler which collects evenly from all depths down to 8 feet and which can also be operated on a moving boat, so horizontal as well as vertical sampling can be carried out simultaneously, thus increasing the accuracy of the determination of the abundance of larvae (Fig. 56, 57).

Although the number of larvae per unit volume of water about a week before setting is the ultimate basis for prediction, rate of reduction of numbers is also important for this usually indicates a continuing trend. Along with this, trends in water temperature and weather conditions which may affect larval survival must be considered. Declining water temperatures, caused by rain or cloud cover, frequently coincide with diminution of the size of larval broods, or even their decimation. Gale force winds, particularly in an area like Ladysmith Harbour, reduce water temperatures so rapidly and drastically that larval broods may be eradicated within a day or two. Pacific oyster larvae appear to be able to withstand large, slow drops in temperature better than a small rapid decrease.

Spawnings are reported to the industry as soon as straight-hinged larvae are observed in the plankton. The number of larvae in the immediate vicinity of the spawning is used to make a preliminary estimate of the probability of a commercial set. Reports are provided at approximately 5-day intervals.

Knowing the rate of growth of larvae and the length of larval life at different water temperatures (Fig. 27) it is possible to predict, or to modify predictions of, the date of the start of setting. About a week before the expected date of the set a final decision on the time and approximate intensity of the set is given. Intensity is usually given in terms of whether or not the set will be commercial. An average of

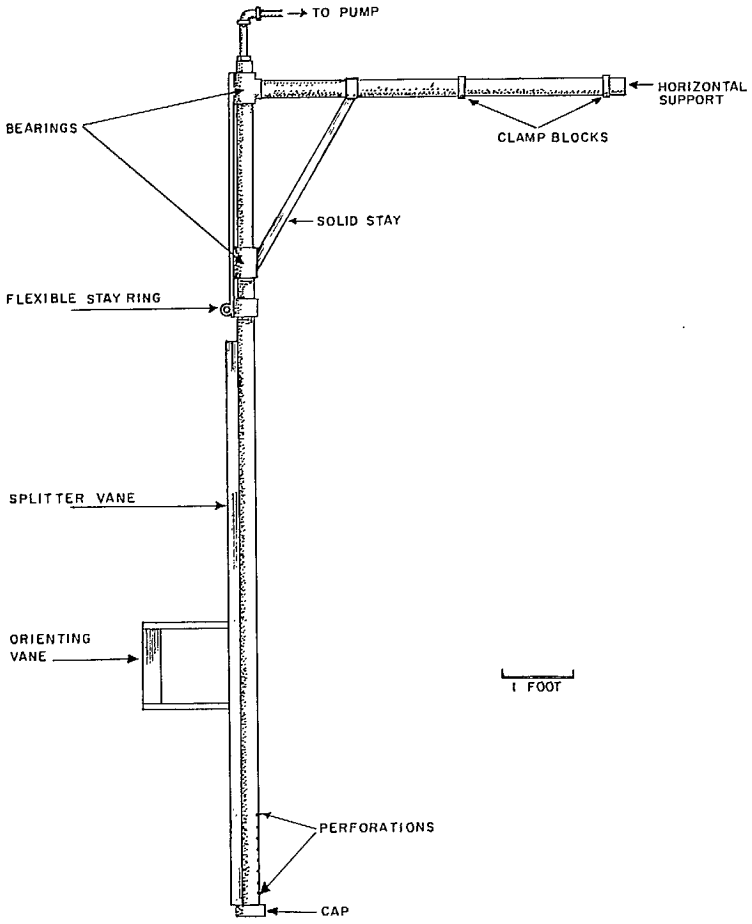


FIG. 56. Pipe sampler for oyster larvae.

10 spat per shell or more has come to be the accepted criterion of a commercial spatfall. However, seed collected for sale usually requires 25 spat per shell, while seed collected for private use is often quite acceptable with five spat per shell, so that, in reality, there are several criteria.

It appears that an average initial concentration of 10–25 straight-hinged larvae per gallon of sea water is required to produce a minimum commercial set under optimum conditions. This number of early stage larvae usually has been reduced to about one advanced or setting stage larva per gallon at the end of the usual 18–21 day larval period.

In Ladysmith Harbour, commercial spatfalls (an average of not less than 10 spat per shell) have occurred on floating cultch in 10 of the last 34 years. In Pendrell Sound there have been commercial sets in 17 of the last 18 years.

In general, spatfall predictions have been remarkably accurate. In Pendrell Sound, 18 of 20 results have been close to the forecast. In Ladysmith Harbour, the

FIG. 57. Pipe sampler for oyster larvae mounted on the starboard bow of a launch. The pipe leads back to a water meter and to the motor-powered pump; the long marked hose is used for taking spot samples from various depths.

record is not quite so good, but at no time has cultch been lost as a result of inaccurate predictions. Accuracy depends to a considerable extent on the effort put into larval sampling; more frequent sampling results in more accurate forecasting. An indication of the usefulness of the forecasts is that growers and seed collectors have come to rely on the forecasts and do not expose cultch unless the prediction indicates a spatfall.

PENDRELL SOUND SEED

The Pacific oyster industry in British Columbia is based on the principle of bringing seed oysters from external sources to the growing area. The quantity of oysters harvested is then directly related to the quantity of seed planted, provided that normal cultural conditions are met.

British Columbia and the west coast of North America generally are fortunate in having available two independent sources of oyster seed, one local and one Japanese. In many oyster industries, an adequate seed supply is often a limiting factor and cause for much concern; hence the recent development of oyster hatcheries, particularly on the Atlantic coast.

Description

The history of breeding in Pendrell Sound has been followed in some detail since 1950 and there has been consistent spatting since then except for 2 or 3 years when the spatfall intensity was near or a little below the minimum commercial level. Consequently, from this area at least, a dependable supply of seed is available and Pendrell Sound then has a significant potential as an oyster seed producing area and could conceivably replace Japan as a source of seed for the whole Pacific coast. The productivity is limited only by the amount of cultch exposed and there are at least 2–3 square miles of area for this purpose. It is possible for the value of seed produced in Pendrell Sound to be equivalent to that of marketed oysters in all British Columbia.

As soon as the potential of Pendrell Sound was realized in 1950, the British Columbia government set aside the sound as an area for the use and enjoyment of the public. This means that anyone, public or oyster growers, can collect seed or oysters there; leases are, however, not granted. The official reserve notice is shown in Appendix A.

Pendrell Sound penetrates deep into East Redonda Island in the northeast corner of the Strait of Georgia and is a deep fiordlike inlet about 6 miles long and a mile wide. At the head, a neck of low land less than half a mile wide separates it from Pryce Channel (Fig. 53). Hills, rising to 5000 feet high within a mile or so of the shores, surround most of the inlet and no doubt serve as a wind break. On at least one peak, some snow may remain throughout the summer. The shores, now largely covered with oysters (Fig. 58, 59), are steep and there is little beach area. Except for seepage-type runoff there is no significant freshwater drainage into the inlet. The depth profile from the head to the mouth is shown in Fig. 60.

Prevailing winds during summer in the Strait of Georgia are westerly and northwesterly, and, in winter, southeasterly in direction. Because of the protective nature of the high hills surrounding Pendrell Sound, wind forces less than about 20 miles per hour, as recorded in the Strait of Georgia, have little effect in Pendrell Sound.

Westerly winds strong enough to have an effect in Pendrell Sound result in breezes from the south, up the outer and into the middle sound, and in northwesterly breezes down the sound, from the upper sound into the middle sound. Under these conditions a calm area occurs in the middle sound area in the vicinity of the lagoon. Only near-gale-force southeast winds in the Strait of Georgia cause south wind effects to reach the head of the sound. Local westerly winds of considerable force may occur occasionally at night in the upper sound in July and August.

Temperature

One of the significant factors in Pendrell Sound, relative to oyster breeding, is the maintenance of high water temperatures at the surface during July and August (Fig. 61). Surface water temperatures as high as 78 F have been recorded. The reason for this may be associated with the fact that heat resulting from solar radiation is not dissipated to any extent by vertical or horizontal mixing. Since the inlet is so deep and is without a significant sill (shallow bar) at the entrance, there is very little horizontal tidal movement. The absence of shallows and surface drainage

FIG. 58. Oyster reef in Pendrell Sound, July 1955, showing abundance of the spawning stock.

FIG. 59. Population of Pacific oysters in natural habitat. Pendrell Sound, 1956.

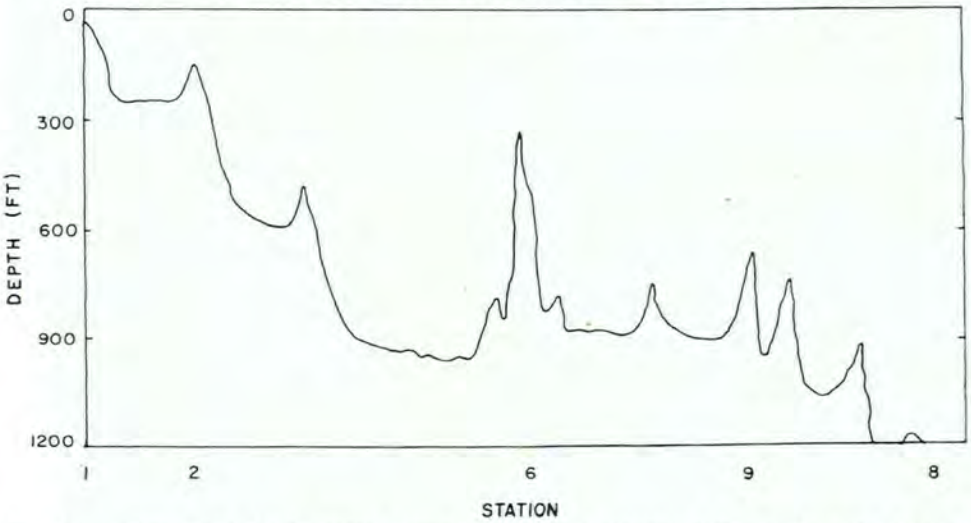


FIG. 60. Longitudinal depth profile through the centre of Pendrell Sound from the head at station 1 to the mouth at Durham Point (station 8).

inhibits vertical mixing. Also a layer of water, 10 to 20 feet deep, with relatively low salinity, established during early summer, no doubt acts as an insulating layer which prevents the vertical movement of deeper cold water. As early in the year as May 30, 1956, a temperature of 70 F was recorded at a depth of 3 feet, although

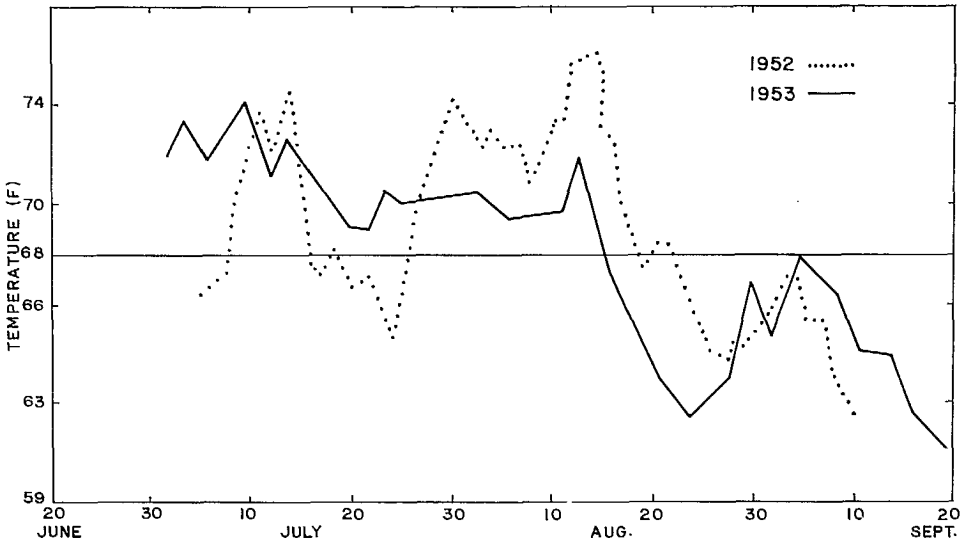


FIG. 61. Seawater temperature at a depth of 3 feet at station 2, Pendrell Sound, June to September, 1952 and 1953.

usually the temperature only begins to rise significantly toward the end of June. By mid-July, temperatures of 68 F and above are usually quite firmly established. Vertically, the 70 F level lies within 1 or 2 feet of the 10-foot depth (Fig. 62). Of quite frequent occurrence (4 years of the last 5) is a midsummer drop to below the 68 F level. This is usually associated with southeast winds and cloudy or rainy weather. This water temperature depression certainly causes an hiatus in spawning activity and may affect survival of larval broods already present in the plankton.

Surface water temperatures are quite uniform in the middle and upper sound. In the outer sound temperatures are slightly lower.

SALINITY

Salinity of the surface waters in Pendrell Sound undergoes a pronounced seasonal cycle. This is shown in Fig. 63. During the winter, salinity, down to at least the 80-foot level, is quite uniform at 28–29‰. In May, an intrusion of low salinity water occurs along the surface. This water originates from Toba Inlet into which several large rivers flow. At the entrance to Toba Inlet, surface waters have a salinity of about 10‰. The relationship between river runoff into Toba Inlet and salinity in Pendrell Sound is shown in Fig. 64. The salinity profile of waters surrounding Pendrell Sound is shown in Fig. 65. The salinity drops slowly until the beginning of August, when it begins to rise slowly. The rise is accelerated by the advent of autumnal storms which cause vertical mixing and, by November, salinities are restored to normal winter level. As with the vertical temperature distribution, the halocline (area of sharp salinity change), in summer, occurs at about the 10-foot level (Fig. 66).

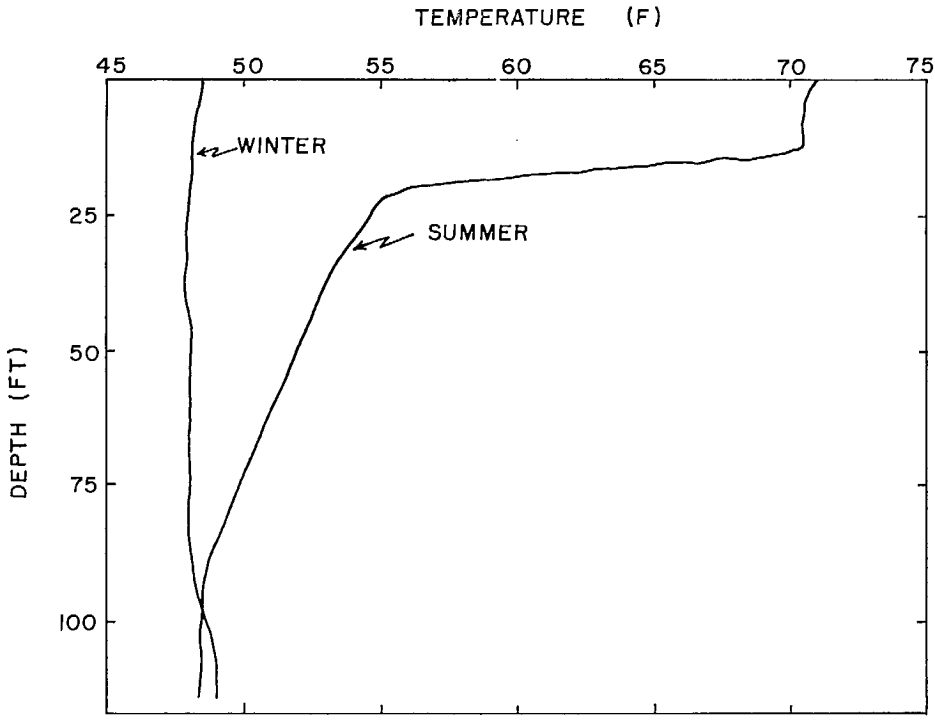


FIG. 62. Winter (March 26, 1956) and summer (July 30, 1956) temperature structure, station 4, Pendrell Sound.

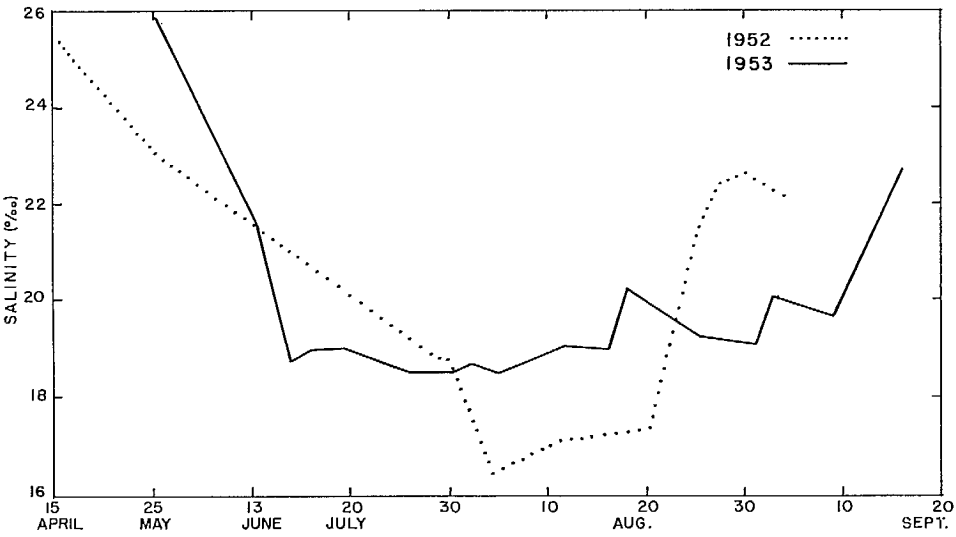


FIG. 63. Seawater salinity at a depth of 3 feet at station 2, Pendrell Sound, April—September, 1952 and 1953.

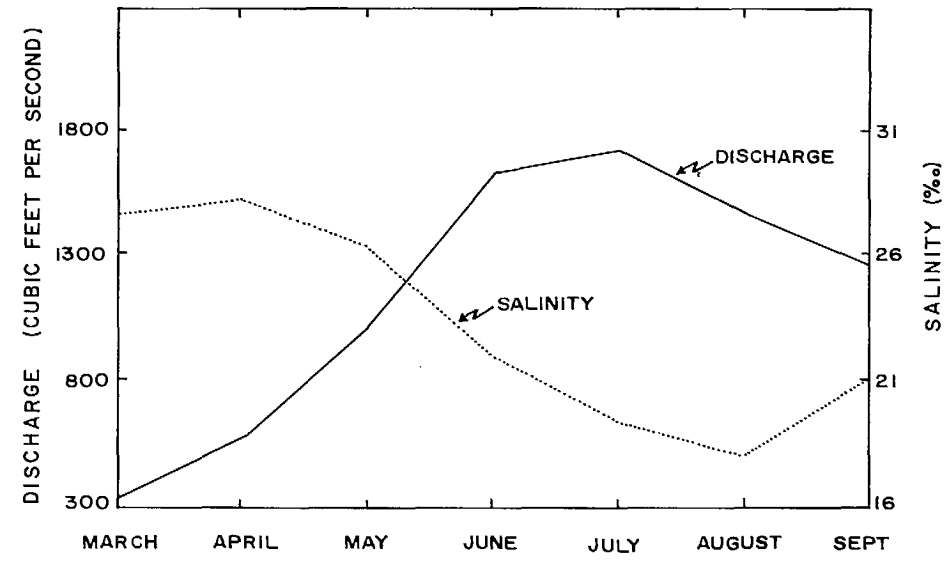


FIG. 64. Relationship between the mean monthly discharge of the Tahumming River, Toba Inlet, for the years 1923–1931 and the typical salinity pattern at station 2, Pendrell Sound.

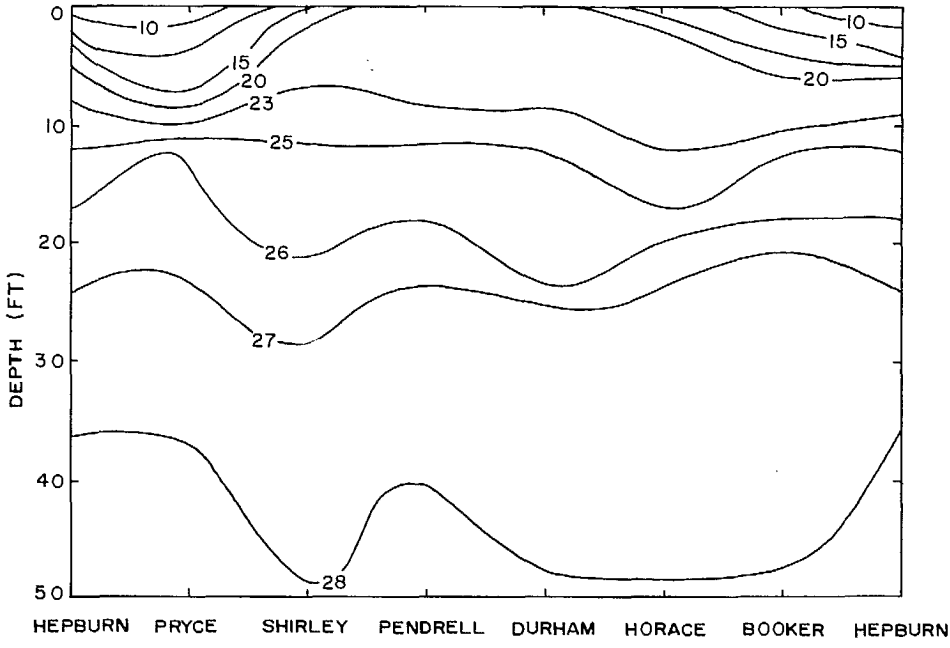


FIG. 65. Salinity–depth profile in the waters surrounding East Redonda Island and Pendrell Sound, July 16, 1956.

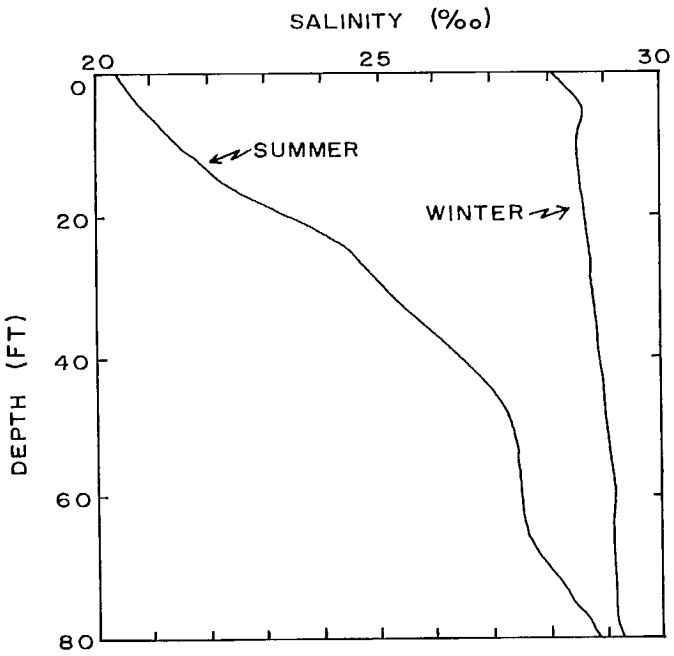


FIG. 66. Winter (January 31, 1956) and summer (June 20, 1956) salinity structure. Station 2, Pendrell Sound.

The relatively low salinity in Pendrell Sound, compared with Ladysmith Harbour, may be one of the factors involved in the high level of breeding success in Pendrell Sound. However, in years of exceptionally heavy river run-off, as in 1967, the salinity in the upper sound may fall as low as 10‰ at which point larval survival is affected.

CURRENTS

In the Pendrell Sound type of inlet, the times of slack water at the head and at the entrance are almost the same. This is so because the whole surface of the inlet rises and falls according to the tidal impulse operating at the entrance. Consequently, surface currents are very weak. These have been studied in Pendrell Sound by means of free-floating drift poles, 18 inches, 3 feet, 6 feet, and 10 feet in length.

The conclusion from these studies is that surface currents in Pendrell Sound, particularly in the middle and upper sound, are weak and variable and generally of the order of 1 or 2 nautical miles per day, with a maximum of less than 1 nautical mile per hour. Movements of surface floats are greatly influenced by wind. When there is no wind in the upper sound, movement of the surface floats is inward on the ebb and outward on the flood. In the middle sound there is a tendency for surface floats to move inward. Free-floating debris has been observed to circulate about the middle sound within a radius of 1 mile for periods up to 6 weeks. Consequently, the currents are such that the slow movements of oyster larvae in the sound allow only a relatively small portion of the population to move out of the sound. Only on the south side between stations 5 and 6 do fairly rapid outgoing surface currents develop on large flood tides.

SPATTING

In order to determine the location of the best areas in Pendrell Sound for spat collecting, studies have been made of the horizontal distribution of spatfall on floating cultch; the data are shown in Table XIII, with the position of the stations indicated on Fig. 53. Stations in the central sound area (3, 3A, 5, 6) collected somewhat more spat than those in the upper sound (1 and 2) which in turn collected more than those in the outer sound.

TABLE XIII. Horizontal distribution of spatfall of Pacific oysters at standard stations on floating shell cultch, Pendrell Sound, 1952–1956.

	No. Spat per Shell							
	1952					1956		
Station	Set A	Set B	1953	1954	1955	Set A	Set B	Mean
1	30	12	36	6	9	16	489	85
2	14	33	55	6	11	267	405	114
3	31	46	91	5	12	235	430	121
3A	27	35	–	9	19	318	–	84
5	37	36	440	13	57	255	–	156
6	65	65	124	12	15	434	335	121
8	2	7	35	1	2	140	150	48
9	11	48	18	6	3	475	–	94
10	15	9	16	8	8	173	245	68
11	–	–	40	2	10	154	229	87

To date, virtually all commercial collecting has been done in the upper sound, between stations 1 and 2, largely because facilities for anchoring rafts are better there than elsewhere and setting has usually been adequate. It is, however, quite feasible to hold rafts in other parts of the sound, at least during July and August, but thereafter they should be moved to safer waters.

VERTICAL DISTRIBUTION OF SPATFALL

Of interest and importance also is the vertical distribution of spatfall and the two phases of this are relevant to the positioning of both shore and floating cultch. This is partly related to the vertical distribution of larvae. (Fig. 42)

(a) *Shore cultch*

As previously indicated (p. 63), it may be said that shore cultch catches less spat than does cultch suspended from rafts; but the difference decreases with increases in the intensity of spatfall.

In years of average (100 spat per shell) to excellent (1000 spat per shell) spatting, shore cultch collects an adequate number of spat. A comparison of shore and floating cultch is shown for 1 year in Table XIV.

Table XV shows the vertical distribution of spatfall on long strings of cultch hung against a vertical cliff near station 2 in Pendrell Sound. It may be seen that actual spatting occurs to the level of the very highest tides. However, mortality of spat at higher levels occurs almost immediately owing to desiccation. At any rate spatting occurs at tide levels considerably higher than those at which significant

TABLE XIV. Comparison of spatfall collected by shore and floating cultch, Pendrell Sound, 1953.

Station	Floating cultch (mean spatfall per shell)	Shore cultch (mean spatfall per shell)
1	36	10
3	91	5
6	124	50
8	35	9
9	18	5
10	16	2
11	40	11
Total	360	92

survival occurs. At the other end of the scale spatting falls off very rapidly below zero tide level and for practical purposes the numbers spatted are inconsequential. Where no specific cultch has been exposed, spatfall below the zero tide mark has not been found. In Pendrell Sound, natural spatting and survival on the shore occurs between zero and the tide level of 12 feet. In Ladysmith Harbour, the large majority of spat are found consistently between the levels of 4 and 8 feet and much the same situation exists in Puget Sound. In Willapa Harbor, Washington, however, where there is little evidence of temperature or salinity stratification, maximum spatting occurs nearer lower tidal areas than in Puget Sound or Ladysmith Harbour.

TABLE XV. Vertical distribution of Pacific oyster spatfall on shore cultch, Pendrell Sound.

Tide level (ft)	Mean spatfall per shell per foot		Tide level (ft)	Mean spatfall per shell per foot	
	1952	1953		1952	1953
16	0.1		− 1	22.5	6.7
15	1.2		− 2	13.0	3.2
14	5.5		− 3	6.0	0.6
13	7.9		− 4	2.0	−
12	44.4	1.4	− 5	2.9	0.1
11	76.3	2.0	− 6	2.1	0.4
10	90.9	10.0	− 7	1.3	0.5
9	97.0	32.2	− 8	1.0	−
8	−	−	− 9	1.0	0
7	90.0	58.6	−10	4.0	
6	63.3	72.3	−11	1.0	
5	54.0	70.6	−15 −1	[a] 1.0	
4	42.9	−	−19 −1	1.0	
3	39.5	101.1	−20 −1	1.0	
2	36.4	56.6	−22 −3	3.0	
1	35.5	46.1	−28 −1	1.0	
0	24.4	−			

[a] Total spatfall per foot.

The lack of spatting below zero tide level in Pendrell Sound may be due to several factors. First, in waters below zero tide levels, silting is such that there is probably little or no clean, suitable setting area. Also, larvae occur in the upper 10 to 12 feet of water where suitable temperatures occur. At low tide, the shore below zero tide level is certainly exposed to larvae-bearing water but at high tide this area

is in a zone where water temperature is not conducive to either larval or spat survival. Also, experiments have indicated that maximum spatting occurs near the time of high water when tidal action is minimal and there would be few larvae in the layer of water covering the subtidal zone.

The conclusion is that shore cultch in Pendrell Sound may be exposed between the tide levels of zero and 10 feet. An advantage of shore cultch is that best hardening conditions occur between the 4 and 8 foot levels; also, the danger of attack by intertidal starfish which, particularly in summer, are concentrated closer to the zero tide level than in winter, is removed.

(b) *Floating cultch*

Similarly, long shell strings were suspended from a raft at station 2, and the results of these experiments are shown in Table XVI. In 1951, there was significant setting down to about 20 feet below the surface but, in 1952 and 1953, 9 or 10 feet

TABLE XVI. Vertical distribution of spatfall on floating cultch, Pendrell Sound.

Depth	Mean spatfall per shell per foot			
(ft)	1951	1952	1953	1956
1	46.1	160	42	500+
2	27.7	302	40	500+
3	36.9	232	50	500+
4	27.8	218	–	500+
5	34.6	129	40	500+
6	41.7	116	37	500+
7	42.4	97	22	500+
8	28.1	69	–	500+
9	24.2	53	6	500+
10	15.8	15	3	500+
11	16.1	26	3	500+
12	30.8	19	–	
13	30.8	14	2	
14	26.9	7	0.5	
15	22.3	7	0.2	
16	25.4	3	–	
17	17.7	2	0.2	
18	19.7	2	0.08	
19	7.7	–	0	
20		18		
21		12		
22		14		
23		19		
24		14		
25		[a] 5		
26		14		
27		4		
28		–		
29		1		
30		5		

[a] Total spatfall per foot.

marked the lowest level of main spatting. In 1956, the spatfall was so intense (over 500 per shell) that counting was impossible. Setting was heavy from the surface to a depth of 11 feet, where a sharp drop in numbers occurred. From the 11-foot level down to 14 feet, there were relatively few spat, and below that there were none.

The standard length of a string of shell cultch is 6 feet, so, with floating cultch, the shells lie within the zone of heaviest setting (Fig. 67), correlating with the high concentration of larvae (Fig. 68). Somewhat longer strings could be used and still be within the zone of optimum spatting, but experience has shown that strings 6 feet long are about the maximum length for efficient handling with present methods.

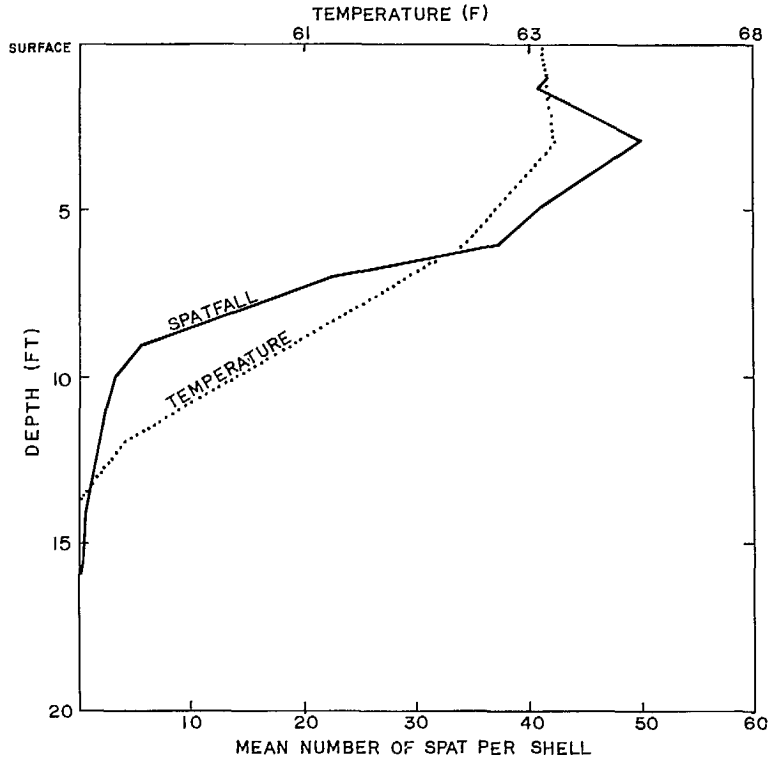


FIG. 67. Vertical distribution of spatfall on floating cultch, Pendrell Sound, 1953, as related to vertical temperature changes.

Although knowledge of the specific time of day when spatting occurs has little practical application, it has been investigated briefly, and it appears that the most intense spatting takes place during the period of minimal tidal action, which is usually associated with the high tide of the day.

Another problem related to spat collection is the relative amount of spatfall on the upper and lower surfaces of the shell cultch. Strings are made up with the rough sides of all shells uppermost so that the cups of all valves are on the underside. They are hung in this way so that if there is any silting, the silt will not collect in the cups of the shells. Table XVII gives the catch on upper and lower shells and the data show that the upper surface collects more spat than the lower.

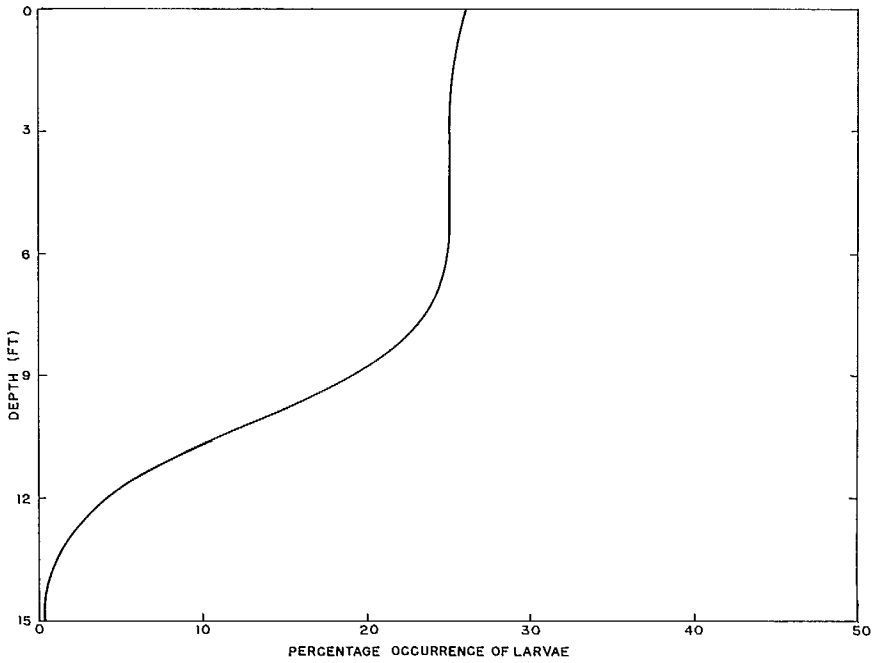


FIG. 68. Percentage occurrence of Pacific oyster larvae with depth, based on a total of 288 samples (day and night combined). Station 2, Pendrell Sound, July 25–28, 1956.

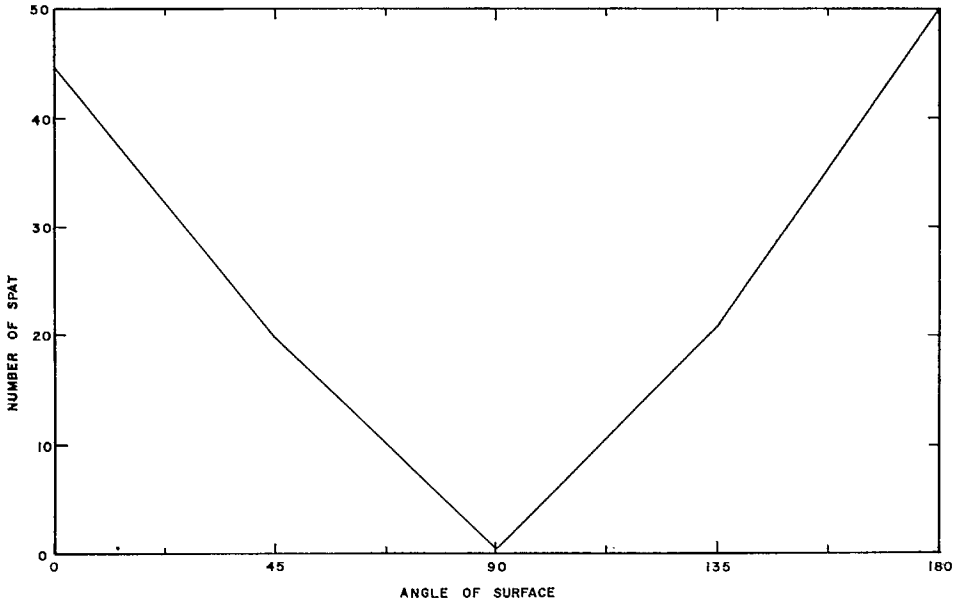


FIG. 69. Relationship between the angle of setting surface and spatfall, Pendrell Sound. (0° = lower horizontal; 180° = upper horizontal; 45° = lower diagonal; 135° = upper diagonal; 90° = vertical)

TABLE XVII. Pacific oyster spatfall on upper (rough or outer) and lower (smooth or inner) surfaces of shell clutch, Pendrell Sound, 1951–1955.

	Percentage of total catch	
	Upper surface	Lower surface
1951	36	64
1952	65	35
1953	73	27
1954	54	46
1955	66	34
Mean	59	41

In this same connection, a study was made of the setting intensity relative to the angle at which the cultch is held by placing cement coated laths at various angles. The data are shown in Table XVIII and Fig. 69.

The upper lath caught little or no spat on the vertical and upper surfaces and the lower horizontal caught three times as many as the lower diagonal. This is close to the typical pattern found for both native and Pacific oysters in most other Pacific coast areas. The lower lath caught twice as many spat on the upper horizontal as on the lower horizontal with none on the vertical and nearly equal amounts on the upper and lower diagonals. This approximates the pattern of setting on shells in Pendrell Sound. There was virtually no silting during this experiment so that this factor, which is often an important one, may be disregarded in this experiment.

TABLE XVIII. Angle of setting surface and setting intensity of Pacific oysters, Pendrell Sound, on double laths one inch apart.

Angle	Upper lath	Lower lath	Mean of both laths
0° (under horizontal)	42.5	46.5	44.5
45° (lower diagonal)	14.0	26.0	20.0
90° (vertical)	1.0	0.0	0.5
135° (upper diagonal)	3.0	38.5	20.7
180° (upper horizontal)	1.0	100.0	50.5

JAPANESE SEED

Japanese oyster seed destined for British Columbia originates entirely in the Miyagi area of Japan and is often known as Miyagi seed to distinguish it from the seed grown in other producing areas such as Hiroshima, far to the south. Miyagi Prefecture is in northeastern Japan (Fig. 4) and Matsushima Bay, the main producing bay, is separated from the open Pacific only by a chain of islands. The summer water temperature in Matsushima Bay reaches 77 F with a salinity of 27‰. The collecting material used for export seed is entirely oyster shell. Since most of Japan's production of market oysters comes from raft culture, the characteristic shell is relatively small because of the short growing period, but thin, because of rapid growth. During the winter, 70–100 of these shells are punched with a hole and strung on wires 6 feet in length. Such shell strings are known as "ren." At the appropriate time in early summer, the "ren" are taken by sampan and placed on catching racks (Fig. 70) to collect the oyster spat. At the end of summer, these

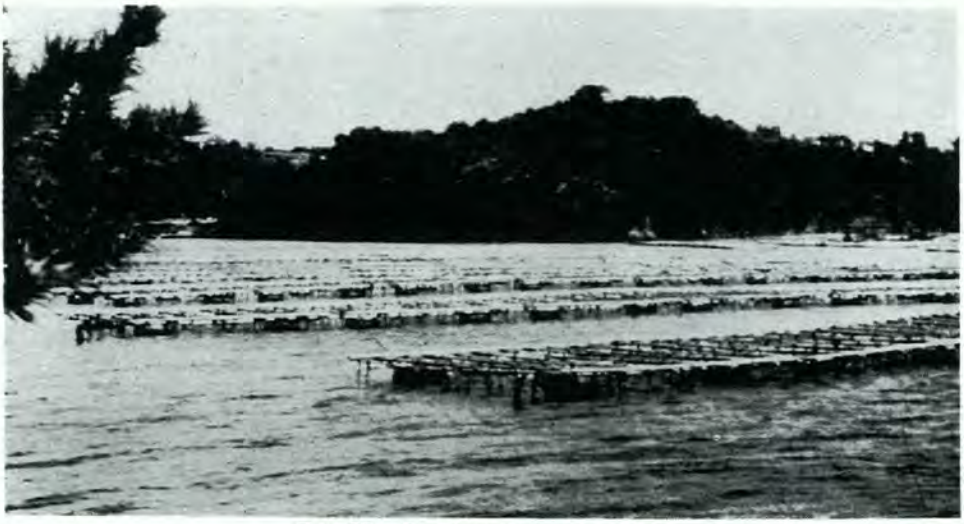


FIG. 70. Japanese seed-oyster racks.

strings are removed from the catching racks to the "holding" or "hardening" racks, which are placed at a tide level which allows the strings to be uncovered for a part of each day. The strings are most often placed horizontally on these racks. The purpose of hardening is to condition the seed for the trans-Pacific shipment to the U.S.A. and Canada. It is thought the process hardens and thickens the shell edge so that the young oyster is able to retain the fluids inside the shell, thus preventing desiccation.

PACKING

The seed is packed for export during February, March, and, rarely, into April. There is a purpose in shipping at this time of the year, when it is quite cool in the Miyagi area. The low water temperature inhibits the movement of oyster drills from the hibernation areas onto the shell strings. Secondly, the growers receiving the seed are reaching the end of winter harvesting and ground is available for seed. Also, by this time, the winter storms are over, so seed loss from this factor is eliminated. In addition, the seed reaches the ground in time for the important spring growth period.

The "ren" are removed from the holding racks to the packing sites, of which there are about eight in the Matsushima area. Each packing site has its code number and this is stamped on all seed cases from that site (Fig. 71), so that the source may be identified. The shells are taken from the wires, placed in wicker baskets, and washed well with strong jets of water to dislodge mud and debris which might harbour predators. The shells are then examined for pests, such as oyster drills, and for quality (number and size of spat). Japanese seed is available in several forms, the descriptive characteristics of each form being given in Table XIX.

To provide broken seed, the shells are cut into two or three pieces with a machine like a paper cutter, or with a circular saw. The seed, regardless of type, is all packed into wooden boxes 36 inches by 18 inches by 12 inches and 4½ cubic feet in volume.

TABLE XIX. Types of Japanese seed.

Type of seed	Average size (*mm*)	Number of spat per piece	Number of spat per case	No. of pieces
Unbroken	6–18	10 or more	12,000	700–900
Broken	6–18	5 or more	18,000	1800–2000
High count unbroken	6–18	–	40,000	5000
High count broken	6–18	–	30,000	–

FIG. 71. Case of Japanese oyster seed.

Sometimes, growers order seed in cases half the normal size so that the cases may be used as shipping containers. (Two wires are placed around each case for strength.) After packing, the boxes are placed on racks in the intertidal zone for storage until a sufficient number have accumulated to form a cargo, which may take up to 6 weeks. The seed is lightered out to the anchored ship on which it is loaded as deck cargo and covered with rice matting (Fig. 72), shipments usually consisting of between 5,000 and 10,000 cases. The trans-Pacific voyage takes 10–12 days, during which the seed is watered down at frequent intervals. Up to 40 days may elapse between the time of packing and the final planting of the seed on west coast oyster beds.

INSPECTION

A careful seed oyster inspection system has been worked out through the years, the main purpose of which is to prevent, or at least keep to a minimum, the spread of oyster pests. Japanese oyster drills obtained a firm foothold in a number of British Columbia and U.S.A. oyster beds before the introduction of the inspection system.

The major inspection is done at the packing sites in Japan, by a biologist from the Washington State Department of Fisheries, the regulations of which state require this type of inspection to prevent the importation of pests. The State of California also sends a biologist to Japan to examine seed to be imported into that state. Seed

FIG. 72. Deck cargo of Pacific oyster seed newly arrived from Japan with the rice-matting cover removed.

destined for British Columbia is inspected by the Washington State authorities, for it is obtained through the Pacific Oyster Growers Association which negotiates the purchase of large blocks of seed on behalf of its members. In addition, it is often examined on arrival from Japan. Some large U.S. oyster growers purchase their seed directly rather than through the association. The cost of inspection is borne by the purchaser and amounts to about 6¢ per case. Various factors contributing to the cost of Japanese oyster seed are shown in Table XX.

TABLE XX. Percentage cost breakdown of Japanese oyster seed.

	Percentage cost
Seed	60
Freight	28
Insurance	1
Handling	2
Inspection	2
Advertising	4
Association	1
Overhead	2
Total	100

In addition to the biologists who inspect the seed, the Oyster Growers Association usually has a representative in Japan, and his main task is to handle general liaison and look after shipping schedules and seed quality. Various Japanese governmental agencies also have inspectors on hand so that, theoretically at least, North American growers should be assured of high quality seed. It should be noted that the onus for ensuring that seed is of acceptable quality, particularly in respect to pests, is on the seed purchaser.

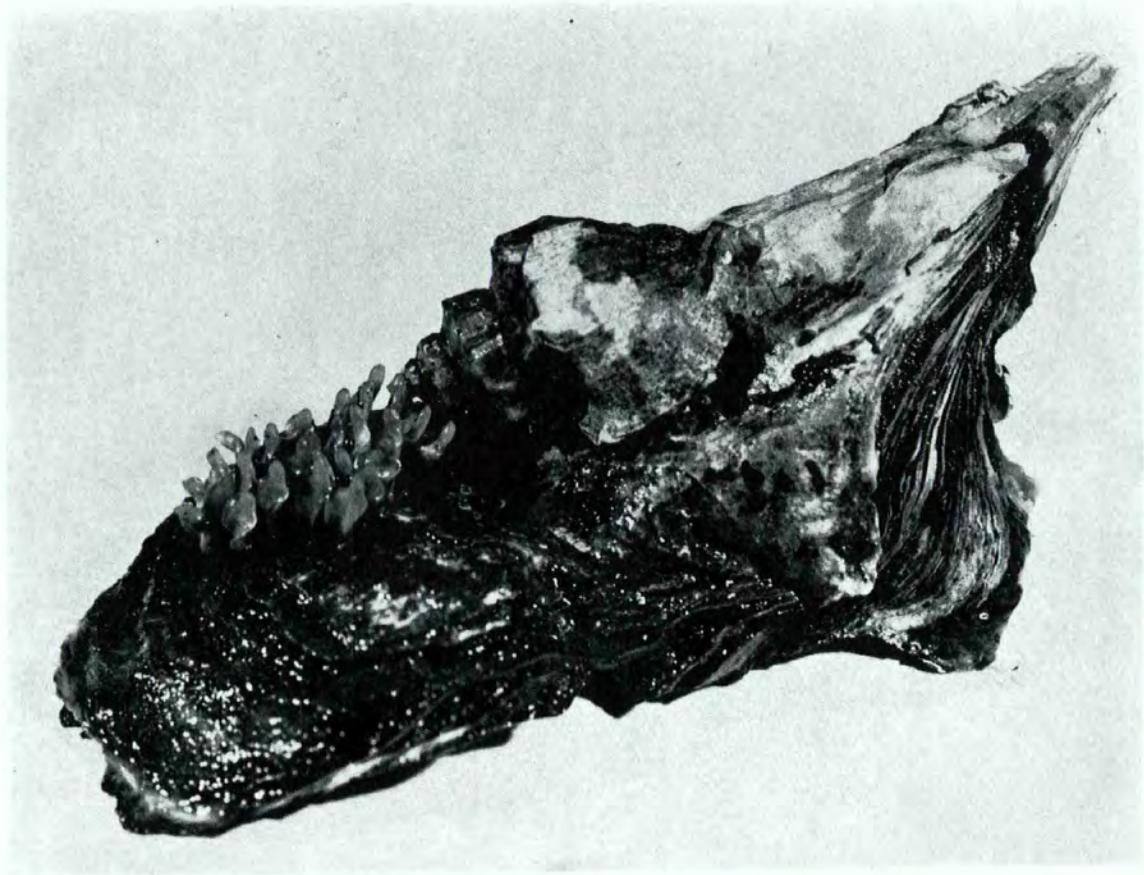


FIG. 73. Photograph of Japanese oyster drill *(Ocenebra japonica)* with egg capsules on a Pacific oyster. The drill lies to the right and above the capsules. × 1.5.

There are two main periods of oyster setting in Japan: one in early summer and one in late summer. The early set is destined mainly for domestic use and the second for export. North American growers have come to prefer very small seed for they believe that it stands a better chance of survival than larger seed. The latter may possess certain advantages but more research is required on this point.

Spatfalls in Japan occur with regularity, although there are annual variations in intensity and in degree of survival to time of packing. Each year, about 3 million "ren" are used to collect seed, and to make up one case of export seed between 20 and 35 "ren" are required, so it can be seen that there is a considerable amount of handling involved. All of this involves manual labour and, with the rise in the standard of living in Japan, the cost of labour, and therefore the cost of seed, must inevitably continue to rise as it has done since the resumption of the oyster seed business after World War II. Recently, however, low seed production due to poor sets has made it difficult for Japanese producers to fill orders from the U.S.A.

Pests

The danger of introducing pests with oyster seed has been noted. There are several species of potentially dangerous oyster drills, but the main problem occurs with the Japanese oyster drill, *Ocenebra japonica* (Fig. 73), which has unfortunately already gained a strong foothold in some areas of both British Columbia and the State of Washington. The grower who imports Japanese seed should know this drill well so that he can recognize it.

In addition to drills, another serious pest is the flatworm, *Pseudostylochus ostreophagus*, which, though often very destructive in parts of Puget Sound, has not been observed to do damage in British Columbia. This rather small and inconspicuous worm, wafer-thin, is able to drill a tiny, key-hole shaped hole in the shell of small oyster spat.

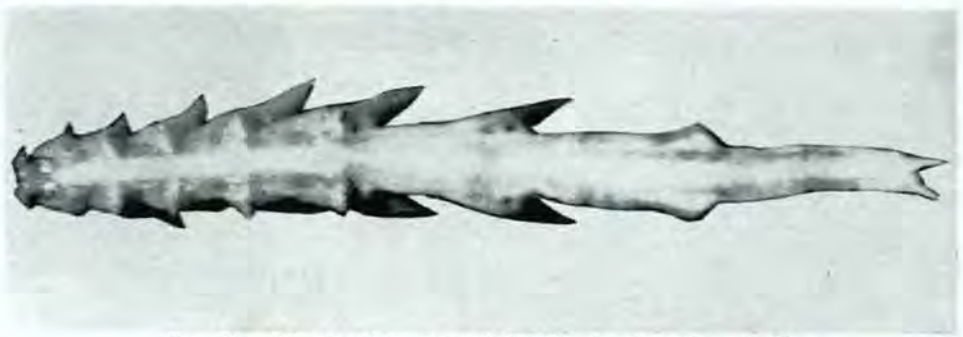


Fig. 74. The parasitic copepod (*Mytilicola orientalis*). × 22.

Mytilicola orientalis, a parasitic copepod (Fig. 74) which occurs in the lower intestine of oysters and mussels, also originated in Japan. In British Columbia it is more prevalent in mussels than in oysters, and appears, so far, to have caused no observable damage to either mussels or oysters. Several years ago in Europe another species of *Mytilicola* nearly destroyed the large and valuable Dutch mussel industry through mortality and poor condition.

FIG. 75. The Japanese seaweed *(Sargassum muticum)* introduced into British Columbia waters with oyster seed. Whole plant with holdfast on pebble. × 0.1.

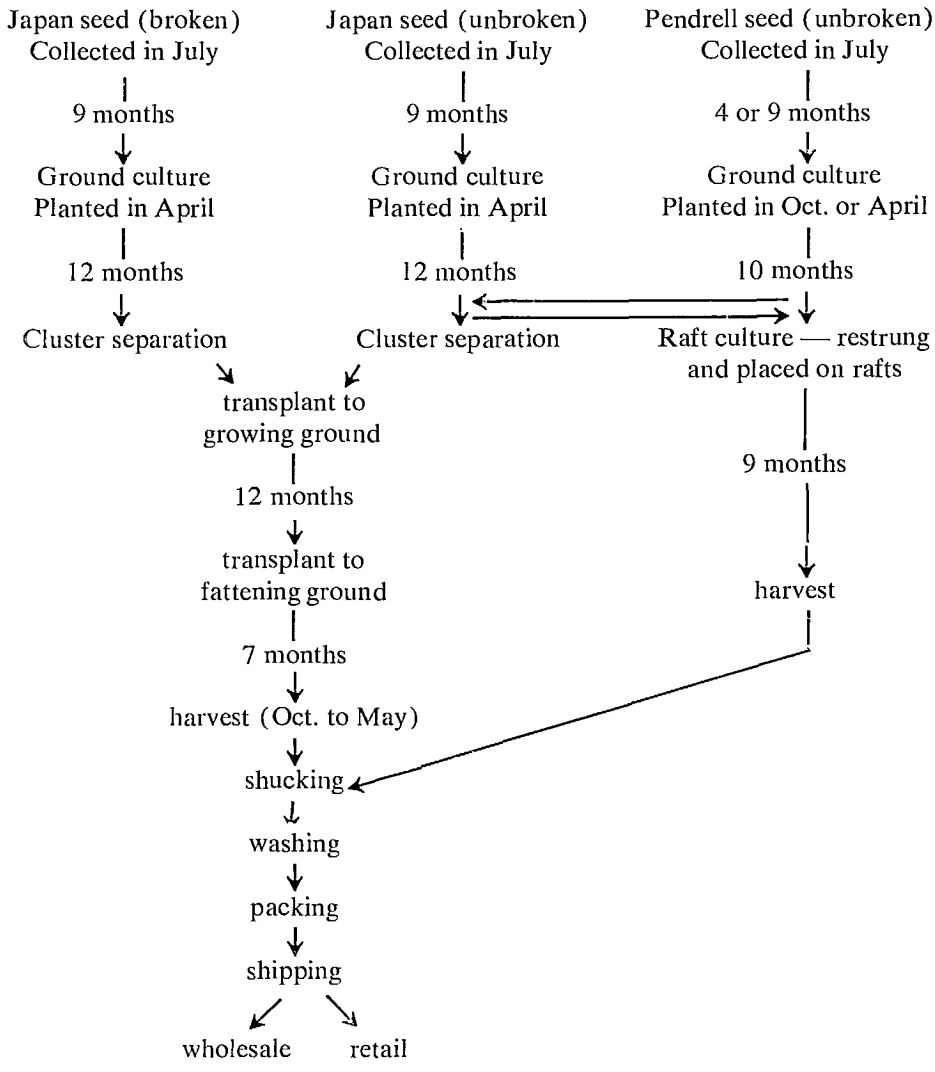
FIG. 76. Enlarged section of the Japanese seaweed *(S. muticum)*. × 7.

Along with the pests mentioned above, several other species of organism have been introduced into British Columbia through the medium of oyster seed. Among these is the Japanese littleneck or Manila clam, sometimes called the "baby" clam, which is a useful addition to British Columbia fauna. Looked upon not quite so favourably is the Japanese weed *Sargassum muticum* (Fig. 75, 76) and the woodborer *Limnoria tripunctata*, one of the gribbles or pinworms.

OYSTER CULTURE

To establish and simplify the relationships between the various cultural operations the following flow diagram may be referred to as the text is read.

PACIFIC OYSTER CULTURE — FLOW DIAGRAM OF MAIN OPERATIONS



HANDLING SEED

In British Columbia after exposure for the set, cultch is usually allowed to remain in situ at least until October, whether it be on the bottom, on racks, or on rafts. This permits the spat to attain near maximum growth for that year, for by the end of October growth will normally have ceased. In addition, the air temperatures in October are low, but with little danger of freezing and fairly high humidity so that exposure to air does not seriously affect the spat when being transported as would be the case when the weather is warm and dry. Seed is normally transported

directly from rafts in the seed area (Pendrell Sound) to seed ground, so that raft-caught seed, in particular, suffers a drastic change in being moved from a condition of continuous submergence to one of intermittent exposure to air.

Unless the cultch, either shell strings or bags, is to be placed on a rocky bottom, the shells should be removed from the wires or from the bags. If left on the wire the strings will sink, in time, even into very firm bottom and there will be mortality.

Seed is nearly always shipped as deck cargo, either on a scow or vessel, but it may be carried in the hold providing the air temperature is low enough. If at all possible, raft-caught seed should not be moved during periods of freezing temperatures since this will cause some mortality. The transportation period, although it can be as long as four or five days, should be kept as short as possible and this also applies to Japanese seed. Handling should not be unnecessarily rough, for this will cause shell breakage leading to mortality, particularly with seed about ½ inch or more in diameter.

Spreading

Seed may be spread from the case or the string at low tide after being dropped overboard at the appropriate spot at high tide. To reduce labour the high tide drop should be carefully arranged. The alternative and superior method is to open the cases or remove the shells from the string and place the shells in a pile on a top float or scow, from where they are spread by shovel or other means as the scow is moved slowly over the seed bed. Mechanical spreaders have been developed, but since this is usually a once-a-year operation, the expense is not warranted unless large quantities of seed are being planted. A relatively inexpensive means of spreading seed is to wash it overboard by means of water pressure from a hose which can also be used for unloading any type or size of oyster. The shovel method of spreading seed, while seeming primitive, is very effective and if done carefully gives a spread of uniform density.

If Japanese seed is being planted, each case should be examined, as it is opened, even briefly, for the presence of oyster drills, which are usually found in the corners of the boxes.

Planting Density

Of importance in the spreading operation is the question of the correct density or amount of seed to be planted per acre. There are no strict rules or limits; instances are known of plantings as light as 10 cases per acre and as heavy as 100 cases per acre (Fig. 77). However, the density may be varied with the amount of seed ground available and according to whether or not the seed ground is to be used for further growth. If the ground is to be used only for seed which is to be transplanted later, a fairly dense planting is advisable for it is more economical to transplant a heavy seeding than a light one because of picking-up costs. In spite of the costs involved in transplanting, it should be done as frequently as possible for a change in environment nearly always gives an oyster renewed energy and the growth rate usually increases, at least for a time.

Seed is normally planted at a density which is equivalent to 25 cases of Japanese seed per acre. It may be less, but preferably should be somewhat more. A density of 25 cases of unbroken seed per acre means that 20,000 pieces of shell are placed on

FIG. 77. Heavily planted seed bed of Pacific oysters, Comox Harbour.

4840 square yards of ground (5000 square yards is usually used to make calculation simpler) or four pieces of shell per square yard. If there is full survival there should be a minimum of 60 oysters per square yard, but, in fact, on the average, only about 20 oysters per square yard survive. On an acreage basis, this is equivalent to 100,000 oysters weighing about 25 tons. Thus, a case of seed, on the average, produces 1 ton or about 4000 oysters, and if they are of such a size as to give 150 oysters per gallon the ton of oysters is roughly equivalent to 27 gallons.

If oysters are planted too thinly harvesting is difficult and there is a tendency for movement if there is the slightest wave action. If the oysters are planted fairly densely (not less than 2–3 per square foot), they assist each other in preventing movement, and harvesting is made more efficient whatever the method used. Moderately dense planting does not seem to materially affect growth or fattening.

In the utilization of seed ground there are three alternatives:

(1) Plant at a low density such that when clusters are separated on the spot the seed will represent the number of oysters that may be matured in the area without transplanting.

(2) Plant at a high density and transplant all of the oysters to other growing ground.

(3) Plant at a high density and transplant only some of the oysters, leaving the remainder to mature on the spot.

SEED GROUND

While most types of oyster ground may be used for seed, some are more suitable than others. Apart from predators, the two main sources of mortality in seed

are competition for space on the cultch and silting, the latter being a function of the type of seed ground. Silting mortality is directly proportional to the amount of silt on the seed ground. The obvious requirement, then, is for a firm bottom, and this is usually associated with gravelly ground. Gravel and similar firm ground most often occur at higher tide levels, where lapping of the waves as the tide rises and falls prevents deposition of fine silt which nearly always occurs near low tide levels, unless there is strong current action. While growth rates are usually lower at higher tide levels, the differences in the growth rate of seed at various levels up to the 7- or 8-foot tide mark are not very great. Since high ground is of little value for any other purpose, its use as seed ground is advocated, provided it has adequate protection from strong wave action, an area which has been used in this way being Comox Harbour.

Indeed, in British Columbia, there are many intertidal areas at a level too high for normal oyster culture, which could well be utilized for seed growing alone. In time, because of the small amount of oyster ground available in this Province, it is nearly inevitable that there will emerge growers whose sole occupation would be growing seed up to a length of about 2 inches for sale to other growers with normal growing and fattening ground.

The following is a summary of the factors which influence the planting and growing of seed. Each factor must be assessed in the light of local conditions and the method of culture in use.

(1) The amount of suitable ground at various tide levels in proportion to the amount of seed being planted.

(2) Firmness of the bottom; this affects the shape and survival of seed. Firm ground increases survival and induces the growth of a round, deeply cupped oyster.

(3) Unbroken seed is more readily moved by tidal and wave action than is broken seed, but broken seed is more readily silted than unbroken seed.

(4) Seed at lower levels is more susceptible to attack by predators such as crabs, sea stars, and oyster drills, for these species normally occur there rather than on higher ground.

(5) The time available to work on seed at low tide levels is less than at high levels.

(6) The desirability of transplanting.

(7) The natural habitat (where survival of natural set is highest) in most British Columbia areas is between the 5- and 8-foot tide levels and it is here that survival is maximal.

Separating Clusters

Cluster separation should be practised for there are many advantages such as the development of better shape, growth, and fattening, along with greater ease and efficiency in opening.

Cluster separation or breaking, as it is often called, is the process of breaking up clusters of oysters (Fig. 78) developed from a single cultch unit into as many individual oysters as possible. This is normally done in spring and summer of the year following planting. It would be preferable to do this in late winter before spring growth adds new and fragile shell edges. Handling breaks these off and they must be

FIG. 78. Cluster of Pacific oyster seed spatted in Pendrell Sound in July 1965 and photographed in December 1966.

replaced. It is said that the Atlantic oyster compensates for the loss of shell edges by relatively speedier growth, but this has not been demonstrated for the Pacific oyster. Usually, however, the period of breaking is regulated by the time available to the grower and this occurs most often during summer after the harvesting season.

Some mortality during the breaking process is inevitable, and it may reach as much as 25%, depending on the degree of separation required, as well as on the amount of care taken. The extent of mortality will also depend on the type of bottom on which the seed has been grown, for soft-bottom seed is usually easier to break than hard-bottom seed. The size of the oyster is also a factor, and there is an ideal size where seed have grown away from the mother shell but have not yet grown too much together. This point can be determined only by experience. Consistency of the mother shell is also an important factor, and one reason why many growers prefer Japanese seed is because they believe the thin soft mother shell makes easier breaking as compared with the thick hard shell of local seed. This is true only to a certain extent for, at the right time, seed will peel off a hard shell quite easily. Of course, the importance of skill and care on the part of the breaker cannot be overestimated.

Briefly, excessive mortality may be due to:

(1) Breaking too finely
(2) Carelessness
(3) Seed too small or too large relative to the hardness of the shell.

Corrective measures for the first two factors are obvious. In the case of the third it may be necessary to delay breaking for a time to allow further shell growth on small seed. If the seed is too large there is little that can be done except to accept the mortality or to allow the seed to grow to maturity without breaking.

The simplest way to break is to pick up the cluster and pull the oysters apart by hand, possibly aided by prying with a breaking iron which is a pointed steel bar about 12 inches by 1½ inches by ¼ inch. Other types of tools are used according to individual preference. After pulling or prying the loose oysters apart, a sharp blow on the mother shell is usually sufficient to separate those remaining. Breaking to obtain single oysters only is the ideal, but impossible to attain without excessive mortality. Clusters of two or three oysters (doubles or triples) are satisfactory.

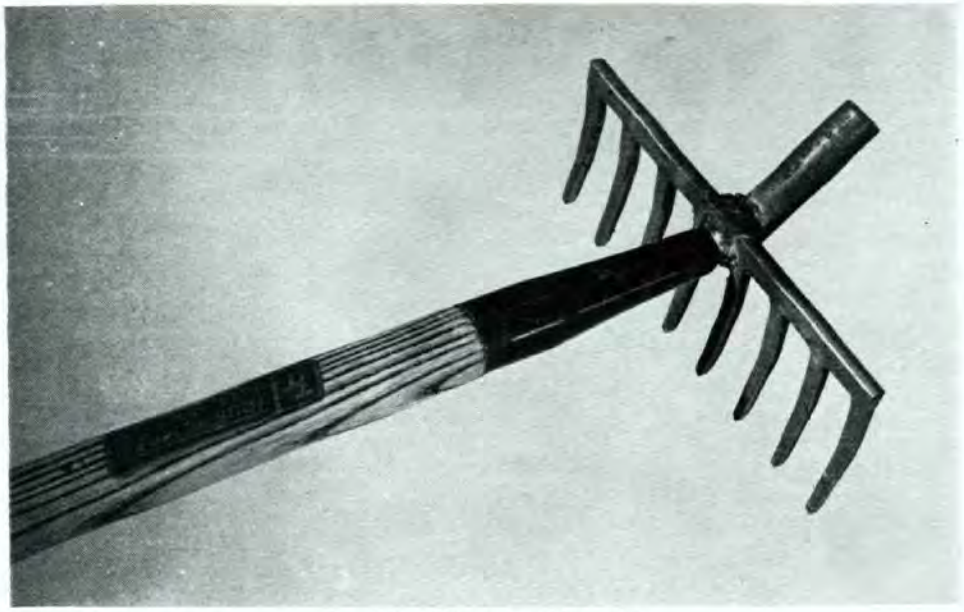


FIG. 79. Cluster-breaking rake.

A small rake, about 6–8 inches wide, to the back of which has been welded a hammer made of a short piece of round iron about ¾ inch in diameter and 1½ to 3 inches in length, is also used for breaking (Fig. 79). The rake is used to pull the cluster out of the mud if necessary and to turn the cluster over to permit a blow on the bottom of the mother shell by the hammer. This method is not so efficient as hand breaking but it is fairly rapid and less laborious, as it is not necessary to pick up each cluster.

A third method of separating clusters has only recently come into prominence and this is the towing of a spring-toothed English harrow over the seed bed at high

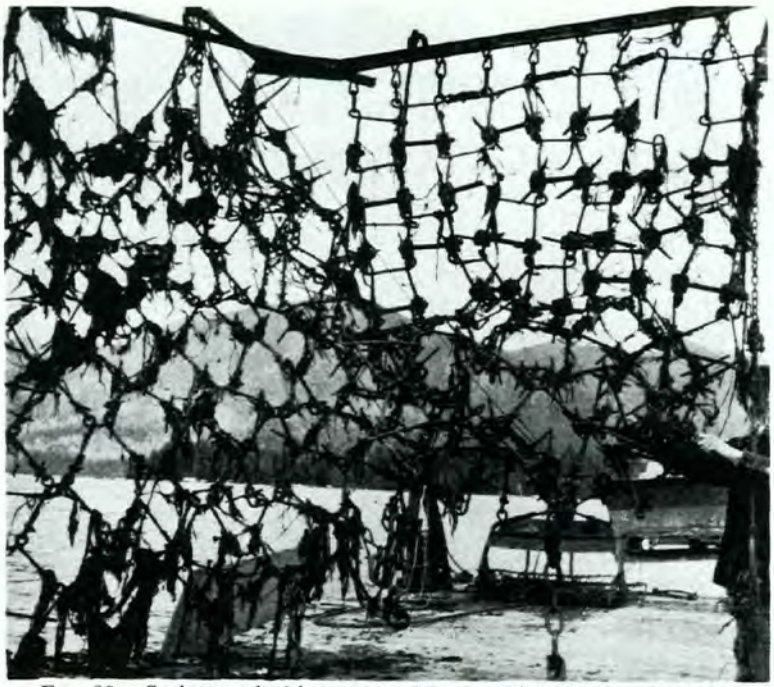


FIG. 80. Spring-toothed harrow used for breaking clusters of oysters.

tide (Fig. 80), which lifts the clusters out of muddy ground and performs a reasonable job of breaking. Its main advantages are speed, low cost, and independence of low tides, and it apparently does not cause excessive mortality.

The cost of breaking is variable, depending on the method used and the extent to which separation is carried out. Minimum time of breaking by hand can be placed at about 2 hours per case of seed, and it requires as long to separate broken seed as it does unbroken seed. A case of broken seed contains about 3000 pieces of cultch and nearly 1000 of them have enough spat to require some breaking if there has been good survival. Of course, all of the 800–900 pieces of cultch in a case of unbroken seed require breaking.

The separation of seed on cemented veneer rings may be done in two ways. One is to cut the circles into small pieces before planting, but this is feasible only if good unsilted seed ground is available. Otherwise it is imperative that the circles be removed from the wires because they will sink, in spite of light weight, into every type of bottom except solid rock. The single circles are then spread on the bottom quite densely. Breaking is done in the usual way, as described for shell. Local seed may be crushed or broken in some manner prior to planting, and in this way it comes to resemble Japanese broken seed. Several types of crushers have been used; in one such machine loosely meshing gears are placed at the bottom of a hopper into which are fed loose shells. Another method is to have the cultch shells carried on a rubber belt under a rotating gear wheel which presses down on the shells and crushes them as they pass under it. Shells can also be cut into pieces by circular saws and this method has been used in Japan. While some mortality is caused by such

methods, it is less than breaking mortality and increases total survival by reducing competition for space on the shell.

The inevitable mortality due to breaking, silting, and competition for space is compensated for by purchasing excess seed equivalent to the amount of expected mortality from these causes. For example, if all of the spat in a case of Japanese unbroken seed (guaranteed 12,000) were to survive a production of about 100 gallons would result. However, a production of about 25 gallons per case is the normal yield, so for a production of 100 gallons, four cases of seed are required instead of one. While not all mortality can be prevented, a good proportion of it can be, if all of the causes are examined critically with this end in view.

Oyster Ground

Selection of an area where oysters might be grown commercially depends on finding a locality where water with the necessary characteristics and the required type of bottom occur together.

Water Quality

Pacific oysters are extremely hardy, being able to withstand wide variations of temperature and salinity. The species occurs over a wide range of latitude in the Japanese Islands (30°N to 45°N) and has been successfully introduced into Australia. It has also been grown experimentally both in Scotland and on the Atlantic coast of North America. On the Pacific coast, it has been grown commercially between Morro Bay in southern California (35°N) and Ketchikan, Alaska (55°N), and, experimentally, north of there.

In British Columbia, this oyster lives and grows in waters with a temperature range between 40 F and 75 F, and is able to withstand freezing air temperatures (25 F) when uncovered by the tide. It grows in water with salinities as high as 33‰ and in river-mouth areas it may be in fresh water for up to 8 hours a day. Water with the necessary temperature and salinity range is not difficult to locate; the main problem is to find fertile water in which oysters will grow rapidly and fatten well. The capacity of water to produce oyster food is variable and wide extremes occur within short distances. This type of water cannot be easily recognized and is generally located only by trial and error, using the oysters themselves. In addition, the water must be free of industrial and sewage pollutants.

Type of Bottom

The selection of ground suitable for oyster culture is based mainly on three factors: Tide level, bottom consistency, and protection from wave action.

TIDE LEVEL

The Pacific oyster is a species which flourishes in the intertidal zone which is that area between the low and high tide marks. In British Columbia, in areas where breeding has occurred, the position of greatest abundance is found to be between the 5- and 8-foot tide levels (the Strait of Georgia). Although this is the area of greatest survival, maximum growth does not occur here but, instead, is normally greatest at the levels closest to zero tide level. Most oysters are grown in the 2- to 5-foot zone as measured in the Strait of Georgia, where the average tidal range is 14.7 feet. Satisfactory growth may occur throughout the lower third of a tidal zone

of this magnitude. Therefore, most of the ground selected should be between the zero and the 5- or 6-foot tide levels. Some good ground may be found above this and can be used for storage and, possibly, for growing seed.

In Table X and Fig. 35 are shown the average number of hours per day an oyster above a given tide level would be exposed during the year. These data are for the areas covered by four reference ports in 1964, and for 1965 for Fulford Harbour where the average daily exposure during each month of the year is given in Table IX. It may be noted that the length of exposure for each foot of tide after the 6-foot level increases markedly; thus, after an average exposure of 5 hours per day, growth rate drops markedly. With the same type of information for other reference ports it is possible to make comparisons of tide levels and exposure times, as for example between the Strait of Georgia and Prince Rupert. In the latter area the average tidal range of 22.8 feet is nearly twice that in the Strait of Georgia (12.1 feet) and with a somewhat different tidal pattern. For example, at the 5-foot tide level at Point Atkinson there is an average exposure of 4 hours while at the same level at Tofino there is an average exposure of 6.1 hours.

BOTTOM CONSISTENCY

Bottom consistency is the second factor to be considered. It is possible to grow oysters on almost any type of bottom, from solid rock to extremely soft mud. However, on solid rock it is difficult to prevent oysters from moving for the slightest wave action will disturb them. There are very few areas of rocky bottom at the correct tide level where there is not excessive wave action. At the other end of the scale, in very soft mud, oysters tend to grow long and thin and to sink, which makes them difficult to work with. A firm bottom of fine gravel, sand, mud, or any combination of these three, provides optimum conditions, for mortality is low, shape is good, the oysters tend to hold, and are easily worked. Riffled sand bottom is unsuitable for the riffling indicates instability which would cause the oysters to be buried.

WAVE ACTION

The third factor to be considered in selecting oyster ground is the degree of protection from wave action. If there is an excessive amount of wave action, the oysters are tumbled about and usually washed up or along the beach into piles or windrows, which then have to be moved. Tumbling knocks off fragile shell edges, especially during the growing season, and even at high tide excessive wave action can cause turbidity by stirring up the bottom sediments. This causes oysters either to stop feeding entirely or to expend considerable energy in separating mud and sand from edible particles. It is difficult to state in specific terms the maximum amount of wave action that would permit oyster culture, for this would have to be decided on the basis of experience.

It is not often possible to find optimum levels of the three factors together in the same ground and usually it is necessary to compromise on at least one of them. Since most of the potentially good oyster ground is already under lease, assessment of new ground should not be too difficult. Oysters may be grown, after a fashion, almost anywhere but when considered from the commercial point of view every condition less than optimum makes it that much more difficult to produce them economically and competitively.

Eelgrass

In addition to the desirable characteristics of oyster bottom described above there are other situations that may be considered. At the lower tide levels, on ground that is otherwise suitable, eelgrass very often grows in profusion. Oysters will grow satisfactorily among eelgrass which, however, can interfere with working them. Eelgrass has a seasonal cycle, growing rapidly and extensively during the summer and dying down to a considerable extent during the winter. In most areas, if work on the oysters can be confined to the winter months, there is normally little difficulty, otherwise it may be necessary to cut the grass as is done in parts of the State of Washington where a long cutting blade is dragged over the bed at high tide by a tugboat, the cut grass being carried away by water currents. So far, in British Columbia, little use has been made of eelgrass ground, probably because there has been sufficient ground of other kind available.

Ice

In certain areas there is the problem of ice, which, fortunately, arises only during severe winters at infrequent intervals. Freezing on the British Columbia coast is often associated with periods of little or no wind, and if this succeeds a heavy rainfall a layer of fresh water develops on the water surface and ice can then form. As the tide falls the ice rests on the bottom and if it is soft the oysters are forced into the mud; if the bottom is firm oysters may become frozen into the ice and when the tide rises they are lifted off the bottom. When the ice breaks up considerable numbers may be carried away and finally dropped onto other beds or into deep water, as has been observed at both Ladysmith Harbour and Boundary Bay.

Efficient Use of Ground

Once ground with the necessary characteristics is selected, there arises the question of its most efficient use. It is not often that any piece of oyster ground over a few acres in extent shows uniformity in tide level, bottom consistency, or the reaction of oysters with respect to survival, growth, or fattening. In general, it has been found that the survival of spat is greatest at higher tide levels, chiefly because there is less silting there. This is shown by an experiment in Ladysmith Harbour: the survival of spat held at four different positions between the zero and 6-foot tide levels is shown in Table XXI. This decline in survival rate with lower tide level coincided with a gradient in bottom softness which is typical of most intertidal areas.

Table XXI. Survival of Pacific oyster seed at various tide levels, Ladysmith.

Tide level (feet above zero):	0	2	4	6
Survival (%):	22.2	29.4	35.7	61.1

Therefore, the general conclusion is that seed should be planted relatively high, possibly up to the 7- or 8-foot level. Since maximum growth is not attained at high levels, seed grown here is transplanted at the end of 1 year to an area of maximum growth which is generally near zero tide level. At this time the seed is generally large enough to withstand to a considerable extent attacks of mobile predators such as crabs and drills, which are more abundant at this level. Along with the desirability

of attaining market size as rapidly as possible, development of a high degree of meat yield or fatness is necessary. Ground on which oysters grow rapidly is not always conducive to good fattening. As a general rule, fattening is best at about the 3- or 4-foot mark. If the oysters are moved to this level, there is also the advantage of making the oysters more accessible during the harvesting season.

The rule for moving oysters from high to low to medium ground in successive years, though sound, is only a general one, and is subject to many variations in practice. Under certain circumstances, very firm, low ground may be the spot to plant seed and leave it until ready for transplanting to higher ground for fattening. In some cases, it may be possible to grow and fatten in one area. This may be done at the cost of high seed mortality or poor fattening or poor growth or any combination of these. This situation must be weighed against the availability of alternative superior ground and the cost of transplanting. It may be realized by now that the suggested basic plan of culture is only a guide that must be modified with experiment and with experience. It cannot be emphasized enough that no two pieces of oyster ground are exactly alike and each one presents a different situation that must be dealt with on its own merits.

One of the challenges of oyster culture is to produce maximum meat yield per unit of seed from the available ground. Only rarely is a particular area capable of furnishing optimum conditions. The oyster culturist must fit a thorough knowledge of the biology of the oyster into the jigsaw of the capabilities and limitations of the available ground. While some of the salient factors may be predetermined, others can be discovered only by trial and error.

Improving Ground

It has been emphasized that it is seldom possible to find oyster ground with all the necessary requirements; one or more of them is usually lacking in some degree.

Mention has been made of the difficulties in growing oysters on very soft ground. Hardening soft ground can be, and is being, done. Most of it is done on a long-term basis, most often by utilization of shell from the shucking house. The actual method of treatment varies with the softness of the bottom, but the general principle is the use of a primary layer or layers of whole shell followed by a covering coat of crushed shell. If available at a reasonable cost, gravel may also be used.

It is also possible to layer the ground with veneer cuttings or thin plastic sheeting before applying the top coat of crushed shell or gravel.

Soft sandy ground may be hardened by ploughing and rolling at low tide, but this is fairly costly and is used only in special cases such as on ground softened by mud shrimps.

Another method of hardening ground is by means of drainage ditches but this is not often used.

In certain circumstances it may be necessary to destroy eelgrass. This may be accomplished by covering it with plastic or roofing until the plants die.

Problems of wave action may be overcome by the use of breakwaters. Stone is often used if it is immediately available; anchored boom sticks help to arrest the main force of breaking waves.

While many of the above suggestions are feasible on a practical basis, the economics must be carefully considered before embarking on major efforts along these lines, and small-scale pilot experiments should precede extensive programs.

At present, it may not be economical, but it is possible that in the forseeable future tide levels on oyster ground will be adjusted by lowering the level of high ground and by filling in low ground. By lowering high ground, especially, considerable acreage can be brought into use.

Attempts to improve the productivity of oyster ground have been made in Australia by sinking containers of fertilizing material in various parts of the bottom. Linseed oil meal with superphosphate has been used although any nitrogenous manure will serve. Some oyster bottoms are normally rich in nitrogen and do not require more. It is said, however, that all bottoms are improved by the addition of phosphate. The purpose of adding these nutrients to the water is to induce plankton production. Assessments of the efficacy of such fertilizer additions are difficult to make.

HARVESTING

Hand Picking

There are many ways of harvesting oysters and the method chosen depends on the type of ground, the size of the operation, and the availability of labour.

In British Columbia the most widely used method is probably picking by hand. Oysters may be picked into baskets of various sizes, directly onto a scow that has been spotted near the centre of the harvesting operation, or into a wheelbarrow (Fig. 81). Hand picking allows a certain amount of selection if the oysters are not all of

Fig. 81. Harvesting wild oysters. This method is also widely used for harvesting cultivated oysters.

market size. Specially manufactured galvanized-wire baskets are available which are light to carry, the wide mesh permitting mud to be washed off the oysters easily. Rubber-covered-wire egg baskets are also suitable and available from poultry dealers. Loaded baskets are carried to a scow, raft, or boat which has been anchored near the harvesting area at high tide. Sometimes the baskets used are too large to

be lifted by hand; in this case, they are buoyed and, on the next high tide, a boat or scow with a derrick lifts the baskets on board. If the ground is firm enough a fork-lift truck may be used. Small farm tractors pulling carts have also been used.

Many oyster growers use rakes to pile the oysters into windrows. Forks are then used to transfer the oysters in the windrows to baskets, wheelbarrows, or directly onto the floating equipment spotted nearby. When a new area is to be harvested it is necessary to previously clear space of oysters for spotting the floating equipment in which the oysters are to be transported. The space is usually marked at low tide by means of stakes.

These are the picking methods that are used for low-tide operations.

Tonging

The high tide methods are mainly mechanical but one, seldom used in British Columbia, is tonging. Oyster tongs (Fig. 82) are made up of a pair of flat poles hinged about three quarters of the distance along from the handles. At the working

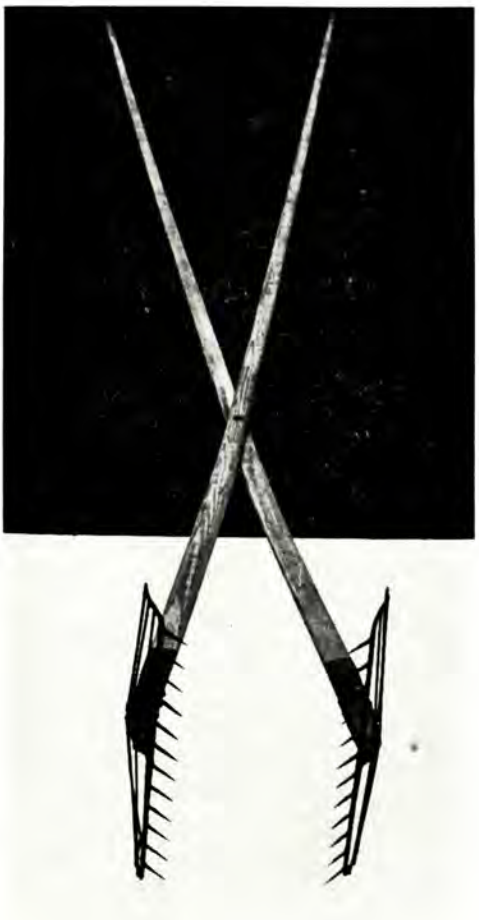


Fig. 82. Pair of oyster tongs.

end of each pole is a half-basket arranged so that when the handles are drawn together the two half-baskets join to make an enclosure. The bottom edges of the half-baskets are studded with teeth. To operate, the tongs are lowered to the bottom and spread. The handles are then drawn together with an alternate lifting and drawing motion. In this way oysters between the jaws are lifted out of the mud and either rolled ahead of the rakes or rolled into the half-basket. When the handles are together again the tongs are drawn to the surface and emptied. Tongs might be used on occasions when tidal conditions make it difficult or impossible to harvest by picking.

Drag Dredging

Standard high-tide harvesting equipment is the drag dredge as shown in Fig. 83. The size, shape, and construction of the dredge will vary according to preference, size of operation, and type of bottom. The vessel carrying the dredge equipment may be self-propelled or towed, but it must have some power in order to operate the winches and booms. Hydraulic power is widely used. Drag dredges, as the name implies, are dragged over the bottom and the mouths are so fitted that the oysters are scooped into the dredge bag, which may be of rope or chain mesh. At the end of the drag, the dredge is hoisted out of the water, swung over the deck, and the bottom of the bag is opened by tripping or lifting up a locking bar. Either a single dredge, or two, one on each side, may be operated from a single vessel.

The drag dredge is not a highly efficient harvester for tests have shown that at best it is able to collect little more than 25% of the oysters in its path. Further, there is a tendency for it to break oysters rather badly under some circumstances. On the soft ground, it is often advisable to use a harrow or raking device to lift the oysters out of the mud before using the dredge. For family-type operations the dredge is not an economical method of harvesting.

Hydraulic Dredging

For very large harvesting operations, the Bailey dredge has been developed. This is based on a hydraulic principle by which water pressure is used to create a flowing mixture of sand and oysters under a hood which rests on and makes a seal with the bottom. The moving oysters are deposited on a conveyor belt which carries them to the surface, leaving the sand and small particles behind. The Bailey dredge is anchored, and is towed about its anchor in ever widening circles by a tugboat. There is very little effect on the bottom, and the oysters are generally quite clean, but there is a tendency at times for the meats to be badly sanded. This is quite an efficient machine, capable of handling a large volume of oysters but only economical on this account.

A more recent development for oyster operations is the modification—by the Atlantic Biological Station—of the Chesapeake Bay escalator-type clam harvester (Fig. 84). The principle employed is also hydraulic and, in this case, water jets lift the oysters off the bottom directly onto a conveyor belt which carries them to the surface. The escalator is usually about 25 feet in length and can operate in depths up to 6 feet. This is a very efficient gear and does no damage to the bottom. Three of these machines have been built in British Columbia. The cost would probably be

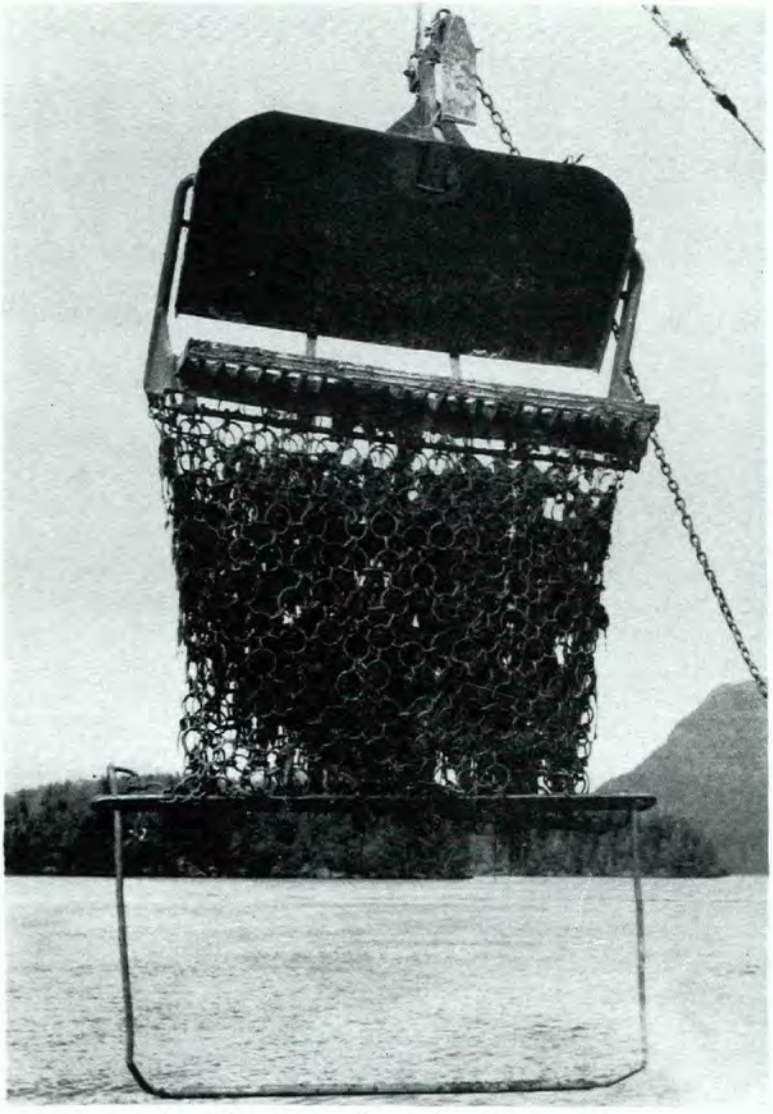


FIG. 83. Drag dredge for harvesting oysters.

uneconomical for the family-sized operation but several adjacent growers could profitably use a machine on a cooperative basis.

TRANSPORTATION

There are no hard and fast rules governing the type of vessel used to transport oysters either from the bed to the shucking house or from one part of a bed to another. In British Columbia these vessels range from small skiffs to 60-ton-capacity scows. The size of vessel normally depends on the size of the operation. The average small grower uses a sink float, top float, or small scow. The latter is the handiest,

FIG. 84. Escalator-type oyster harvester.

for it can be easily poled, towed, or powered with an outboard motor; it has good carrying capacity and draws little water, which is an important advantage. Log-top floats are fairly expensive to build and are also costly in terms of the effort needed to move them. Moreover, they do not last so long as lightly built plywood scows. Where wet storage is possible, sink floats (log float with the floor attached to the bottom of the logs so it is submerged) are used and are most useful. However, plywood pontoons instead of logs would, in the long run, be less expensive and more versatile.

GEAR

Normal hand operations require D-handled grain shovels (usually aluminum), garden rakes, and vegetable scoop forks. These will vary according to the harvesting needs and personal preference.

Many methods of harvesting oysters have been tried and it is likely that as long as oysters are harvested new gear will be developed. Each grower must adapt gear to the needs of his own operation.

PROCESSING

HAND SHUCKING

As indicated previously, practically all Pacific oysters are marketed in the shucked or opened state so that the art of removing an oyster from its shell is of some importance.

Shucking skill comes only with practice and each opener develops his own individual opening technique. However, there are some basic points that are fairly standard practice for a right-handed shucker.

First, the shucking table should be quite high but, again, this depends on the individual; tall people usually have additional platforms placed on the normally used table. Shucking knives having a fairly long blade are now the standard type used for Pacific oysters (Fig. 85). Gloves and finger stalls or cots (short rubber

FIG. 85. Oyster knife typical of those used for shucking Pacific oysters.

coverings for the finger tips, much like long sewing thimbles) are needed, for the shell edges are very sharp. Each opener has his own shucking container which is most often a stainless steel vessel, usually with a capacity of one gallon for ease of tallying, for shuckers are paid on a gallonage basis. The shucking container may or may not be perforated.

The opening process begins by placing the oyster on the table with the cupped or left valve down and with the hinge pointed toward the opener's left. With the oyster in this position the single adductor muscle, which must be cut to allow the shell to open, is located—about two thirds of the distance from the hinge toward the right. The point of the knife is inserted between the valves at this point with a slight twisting motion of the knife. Usually the handle of the knife is elevated slightly for most often the upper flat valve is slightly inside the lower valve. After the knife point has entered, the blade is forced into the oyster to about 1½ inches, when a movement of the knife to the right and to the left will sever the muscle. The knife

is then turned until the blade is vertical and a prying motion will break the hold of the hinge and the two shells will separate. The cutting of the adductor muscle by a right–left motion must be done against either the upper or the lower valve. This should be decided before the knife is forced into the shells so that the knife blade will be against either one valve or the other, so as not to injure the oyster meat and also to ensure that the adductor muscle is cut right against the shell. The valve with the oyster still attached to it is then picked up, held at the outside edge of the shucking container and the remaining attachment of the adductor muscle is cut flush with the valve surface and the oyster flipped into the pail.

In an alternative method of inserting the shucking knife, used in the United States, the knife is driven through the shell like a dagger an inch or so from the posterior or "bill" end of the shell. After entry, which may require more than one stab, the knife is worked forward to sever the adductor muscle.

It can be seen that up to this point the oyster has come into contact only with the oyster knife, and this is the way it should be. Also it can be recognized that if the oyster shell is well washed and clean, there will be little opportunity for mud to get into the shucking pail or to touch the oyster meat.

Mechanical Shucking

Many attempts have been made to develop a mechanical method for shucking oysters. Unfortunately, the lack of uniformity in size and shape of oysters makes a purely mechanical system difficult and so far no suitable method has been devised.

Chemicals can be used to cause the adductor muscle to relax and so enable the shucking knife to be introduced more easily; but from then on essentially all the operations used in normal opening must be carried out. There is also the necessity of providing tanks and chemicals; and, moreover, the time required for anaesthesia can be fairly long. Thus there is little advantage in using this method.

Oysters may be opened by heat and this is the method generally used when oysters are to be canned for they have to be cooked eventually.

More recently, there has been developed what is called the "heat shock" method for opening clustered and irregularly-shaped South Carolina oysters. Here, oysters are given a brief dip of 2–3 minutes in water at a temperature of 145–150 F. This causes relaxation of the adductor muscle without actually cooking the oyster meat, and is followed by an immediate chill. Again, all of the normal shucking motions still have to be carried out.

An interesting discovery unlikely to be of practical benefit is that oysters will open quietly when subjected to a pressure of 700 atmospheres or 11,000 lb per square inch, equivalent to a water depth of 23,000 feet.

It may be that, in the future, most oysters will be sold fresh in the blanched condition. The blanching process consists simply of a brief dip of the oyster meat in boiling water to solidify the outer layers of tissue. This prevents slime formation during storage and it firms the oyster just enough to make it more attractive to handle. The blanching process is essential prior to freezing oysters.

Shell Disposal

Disposal of the shell is a problem and some oyster shucking houses have holes in the table leading to chutes which carry the shells to a suitable collecting point.

Small operators usually have a tub or wheelbarrow beside each shucker. The shells are taken to a shell pile for storage (Fig. 86). They may be used for oyster cultch or sold to shell processors who grind them up for chicken scratch. It is also possible to use them for building or firming up oyster bottom. More soft oyster ground could be reclaimed in this way and it is a more profitable use of the shell than disposing of it to shell processors.

FIG. 86. Shell pile adjacent to a shucking house.

Flies are often attracted to shell piles, particularly during warm weather, and this leads to difficulty in keeping them out of the shucking house. Insecticide sprays should therefore be used on the shell pile when necessary.

WASHING

After the shucking pail is full it is taken to the delivery window since, according to regulation, the shucking and packing rooms must be separate. The next process is washing, the ideal way being to blow the oysters. The blower is a stainless steel tank with air pipes in the bottom; the tank is filled with water, the oysters placed in it, and the air turned on. The air bubbles churn the water and oysters, providing a cleansing action without damaging the meats. Smaller operators, however, normally use stainless steel deep sinks with a colander insert and stir the oysters gently by hand or with paddles. Rubber gloves are to be worn during washing and packing, according to regulations.

After washing, the oysters are poured onto a shallow perforated stainless steel tray called a skimmer. Here the oysters receive a final wash from an overhead hand-held spray. The bits of shell as well as any reject oysters such as those which are badly cut or of poor colour or condition are removed. Here, too, the oysters may be graded. The skimmer usually has several pour lips under which the final containers are placed.

The sanitary regulations state that all shucked stock shall be thoroughly washed with cold water for a period not exceeding 3 minutes. Also, the Canada Food and Drug Act states (B.23.017) that "No person shall sell shucked oysters that contain more than 10 per cent of fluid separable by draining for 5 minutes through a 10-mesh sieve."

The reason for these regulations is to prevent adulteration, for when a shucked oyster is placed in fresh water there is an exchange of fluids, with fresh water entering the cells of the body of the oyster and salts and minerals leaving those cells. In this way the fluid content of the oyster is increased as is the whole volume and weight of the oyster and the process is known as "plumping" or "floating." In this way volume yield can be unjustifiably increased in favour of the oyster producer while, at the same time, the quality of the oyster is impaired for the consumer is then purchasing more water and less of the minerals and salts that contribute to the flavour and nutritive value of the oyster.

The problem of oyster standards based on the fluid content is a controversial one, for when an oyster is opened some blood vessels are usually severed and bleeding may occur. The amount and time of bleeding and indeed the amount of mineral salts–water exchange is very variable from area to area and, very likely, from species to species as well as from season to season.

At any rate, to comply with the present regulations and to provide a quality product, washing and holding in fresh water should be kept to an absolute minimum. A 3-minute wash may increase the weight of an oyster by 1–12%.

Packaging

The basic sanitation regulation regarding packaging states: "Shucked shellfish shall be shipped and sold, retail or otherwise, either in single service containers made of clean impervious materials positively sealed or in such containers so sealed that tampering with the container can be detected. After sealing, the container must be water tight."

The purpose in using nonreturnable containers is to ensure a minimum amount of handling for each additional step increases the hazard of contamination. In this way, the grower is assured that the consumer is receiving a product in the same sanitary condition as it left the plant. Further, the containers must be marked by the packer's certificate number, and it is thus possible to trace the source of any shipment. This is important for the producer, the governmental agency concerned, and the industry as a whole, for any problem such as contaminated oysters will reflect on every producer. In this way the source of contaminated oysters can be pinpointed immediately and steps taken to correct the difficulty.

The actual containers are many and varied in size, shape, and material. Gallon containers are usually of metal. There are 32-ounce quarts and 42-ounce quarts, 16-ounce pints and 20-ounce pints, ¾ pints with 12 ounces and ½ pints with 8 ounces. Many containers are of United States manufacture and consequently arranged in American measurements rather than Imperial.

The containers may also be of waxed paper, plastic, or both. The relative numbers of each size of container used varies with sales, but the following gives an approximate idea of the manner in which oysters are marketed in British Columbia: half pints, 75%; pints, 5%; quarts, 11%; gallons, 9%.

STORAGE

Storage is a most important facet of producing oysters, and there are a number of problems. First, there is shell stock storage, where oysters are held in the shell until ready for shucking. Since there are tidal cycles to consider, there must be a stock on hand during periods when oysters cannot be readily obtained from the beds. The second problem is to hold shucked oysters until, and during the time of shipping.

Shell Stock

Because of the alternation of spring and neap tides, there will be periods of 7 or 8 days when the oyster beds are not exposed and harvesting by picking or raking cannot be carried on. To compensate for this, it is necessary to obtain a supply of shell stock during the spring tide period adequate to carry over until the next spring series.

These oysters may be stored either wet or dry but attention must be paid to the pertinent section of the sanitary regulations (Sections e and f of part 7, page 5). Wet storage is the term given to the method of holding oysters in water during the period between harvesting and shucking.

"e. Floating and wet storage. Floating and wet storage shall not be practised unless written approval is given each year by the Deputy Minister of Health. A sketch drawn to scale shall be shown on the reverse side of the certificate indicating the fixed location of the float or structures and all the potential hazards to which shellfish in the designated areas may be exposed. The presence of usable sink floats in the water shall be deemed to be evidence that floating is practised.

"f. Dry storage. Shell stock in dry storage shall be adequately protected from contamination at all times."

Wet Storage

The problem with wet storage is that oyster shucking houses are often close to concentrations of population, which may give rise to pollution. If the shucking house is adjacent to an approved area, and many shucking houses in British Columbia are so placed, it is permissible, as stated in the regulation, to practise wet storage. This may be done simply by placing shell stock in a receiving area which should be beach floored with clean firm gravel, or a cement platform relatively high in the tidal zone. The oysters should be accessible, at least to waders, during the neap tide period. The fact that they will be uncovered for much longer periods than at the lower tide levels from which they came will have no significant effect over a short period of time of up to 2 or 3 weeks. An alternative is to use a sink float

(which is merely a floating platform with the floor submerged to a depth of 12 or 16 inches). This is anchored near the shucking house so that oysters are available at all times, whether the float is floating or is dry on the beach. In either sink floats or beach storage, oysters may be piled to a depth of 12 inches or more without harm. A clean beach storage area or float storage area also allows oysters to cleanse themselves of any accumulated mud within the shell and the movement in and out of the water enables much of the mud adhering to the outside of the shell to be cleaned off. The cleaner an oyster is when it reaches the shucking table the cleaner will be the end product. Shuckers always tend to do a better job with clean oysters.

Dry Storage

This must be used when there is pollution or possible pollution of wet storage areas in the neighbourhood of the shucking house. The obvious disadvantage is that the oysters are out of water completely and storage life then depends on air temperature and humidity, as well as on how badly the shell edges have been broken during handling. Shell edges are more fragile and more easily broken in spring and summer than during winter. The lower the air temperature and the higher the humidity, the less oyster meats will be desiccated. It is difficult to place exact time limits on dry storage, because of these variables, but, during most of the winter, they should hold quite easily for a week or more. Freezing should be avoided, although, under certain conditions, oysters may be frozen and yet live, if carefully thawed without jarring. This often occurs on the beach. Ice is often used to keep dry-stored oysters cool during warm weather.

On the Atlantic coast of Canada, where oyster grounds freeze over during winter, the supply of oysters for that period must be harvested during the fall, so a good deal of storage space is required. Dry storage is always used in this case, and it has been found that well-shaped oysters with fat meats store best. Optimum storage temperature appears to be about 34 F or just above freezing, but some storage is carried on as high as 40 F. Storage life at these low temperatures may be 4 months or longer.

Storage of Shucked Oysters

There are specific points in the sanitary regulations of British Columbia to cover this aspect of processing oysters.

SANITARY REGULATIONS

"Part 10 (page 7). Refrigeration Rooms or Ice-boxes. Where a refrigerator or ice-box is used for the retention of shellfish, it shall be so constructed as to permit easy and thorough cleaning and have adequate capacity to store all stock which may be shucked or packed in the plant in any one day. The refrigerator or ice-box shall be well insulated and have an impervious lining; the floor shall be graded to drain quickly; and an accurate thermometer shall be kept in each refrigerator at a point predetermined to have the highest temperature. No drain from a refrigerator or ice-box shall be connected directly to a sewer or other waste disposal system.

"Part 11 (page 7). Ice. Any ice used shall be obtained from an approved source and shall be stored and handled in a clean manner. No ice or other foreign substances shall be allowed to come into contact with shucked stock.

"Part 13(b) (page 9). Refrigeration. Shucked shellfish shall be cooled to a temperature of 45 F or less within 5 hours after the shellfish are shucked, and kept at or below 45 F until subjected to a cooking process or delivered to a consumer. If shucked shellfish are frozen, they shall be kept in a frozen condition until delivered to the consumer. If subjected to a quick freezing process, the temperature of shucked shellfish shall be held at 10 F or lower until delivered to the consumer."

REFRIGERATION

Two factors involved in the storage of freshly shucked oysters are the speed of cooling after shucking, and storage temperature. Even though an oyster originates in nonpolluted water, it still harbours, as most animals do, quite large quantities of bacteria which, in normal numbers, cause no harm. Under suitable conditions, however, they can multiply rapidly in the body of the oyster, or in the container, and so cause spoilage. The purpose of refrigeration then is to hold numbers of bacteria in the oyster, or any other food, at as low a level as possible. There are several methods of measuring spoilage and one of these is by bacterial counts, where samples of oysters are incubated in suitable chemicals for certain periods of time. Another method utilizes the *p*H or acidity of the oyster after a period of time but this has limited use, for the initial *p*H of oysters varies according to area of origin. A third is the chromate method which is a colour test. Here potassium dichromate and sulphuric acid (1 ml of each) are added to liquor (2 ml) from the oyster sample. In the oyster liquor are organic substances capable of reducing the chromate ion to chromium (111), the concentration of which may be determined either by spectrophotometry or by comparison of its colour with visual standards. The reducing substances have been shown to increase with time and temperature, and by applying the concentrations of chromium (111) found to standard curves, the temperature or age of storage may be found and acceptability limits established. Finally there is the organoleptic or taste and smell test and, of course, this is an important one. Usually a panel of tasters is used, and quite consistent results may be obtained.

The speed of cooling of oysters in containers of various sizes has been measured as indicated by the temperature in the centre of the container and these results are shown in Table XXII.

It may be seen from this table that it requires a considerable time to cool oysters, particularly in the larger containers, and that dry cooling requires more time than cooling with crushed ice. The greater the delay, after shucking, washing, and packing, in beginning the cooling process, the greater the opportunity for spoilage to set in and the shorter the "shelf life." This is the term used to describe the length of time the oyster can remain on display by the retailer and still be a good product. The longer the shelf life, the greater is the opportunity for a sale.

After the oyster has been cooled as rapidly as possible, it should be held constantly at as low a temperature as possible without freezing. Permitting the temperature to rise for appreciable periods will destroy the effect of rapid cooling. Tests

TABLE XXII. Rates of cooling of oysters in containers.

Container size	Initial temperature (F)	Final temperature (F)	Time (min)
	Cooling in crushed ice (31–32 F)		
1 gallon	63	42	285
1 gallon	79	45	345
½ gallon	66	39	200
½ gallon	85	40	275
1 pint	65	40	100
1 pint	81	40	125
12 ounces	65	40	92
12 ounces	80	40	105
½ pint	67	40	60
½ pint	83	40	80
	Cooling in dry refrigeration (31–32 F)		
1 gallon	81	43	400
1 gallon	62	39	400
½ gallon	83	41	350
½ gallon	66	40	350
1 pint	85	40	190
1 pint	66	40	170
12 ounces	85	40	160
12 ounces	65	40	100
½ pint	84	40	110
½ pint	64	40	90

have shown that oysters held at 53 F were unacceptable after 3 to 5 days, while those held at 46 F were unacceptable after 7 to 8 days and those held at 35 F on ice were still satisfactory after 16 days. These are, of course, very approximate figures, for they will vary depending on the origin of the oysters, how well they were handled prior to storing, and, particularly, on the cooling rate.

TABLE XXIII. Temperature and number of bacteria in stored oysters.

Original number of bacteria per gram	Final number of bacteria per gram	Temperature (F)	Time (days)
1600	1,800	23	24
1600	8,900	32	24
1600	1,600,000	41	24

The importance of good refrigeration cannot be over-emphasized. An example of what happens to naturally occurring bacteria in oysters at different temperatures is given in Table XXIII. This is very convincing evidence of the need for adequate refrigeration.

PRODUCTIVITY

Productivity of the Pacific oyster may be defined as meat production in relation to amount (number) of seed planted. It is the result of the interaction of such factors as mortality, growth rate, and condition or fatness of the oyster. These factors are

dependent on the type and quality of seed, and the particular oyster bottom used, as well as on seasonal and annual variations. If productivity is known or can be estimated, potential production may be calculated by multiplying productivity by the number of units of seed per acre and by the number of acres used. As an example, it may have been found that a certain 10-acre bed has a productivity of 25 gallons per case of seed, on the average, from plantings of 30 cases per acre. The estimated potential production will be $10 \times 30 \times 25$ gallons or 7500 gallons at the end of the 3- or 4-year growth period.

It would be of value for the oyster grower to understand something of the factors that control productivity.

MORTALITY

There are four main causes of death in Pacific oysters.

(1) Natural mortality
  (a) Age
  (b) Predators
  (c) Disease
  (d) Exceptional circumstances
(2) Competition for space
(3) Silting
(4) Cluster separation

NATURAL MORTALITY

This may be due to factors such as old age which, in normal cultural procedures, does not constitute a problem since Pacific oysters have been known to attain an age of 20 years and the usual age for harvesting is, at the most, 5 years but more commonly about 3 years.

Predators such as sea stars, oyster drills, and crabs, may contribute materially to mortality rates, but some measure of control is possible as discussed on page 98.

Disease can be a very serious mortality factor but, so far, British Columbia waters have been relatively disease-free. Disease is not easily controlled, especially when it first strikes, but often culture methods can be modified to materially reduce the effects.

Other types of mortality which may be considered in the "natural" category are loss by ice and movement by wave action from freak winds; in two instances in British Columbia, tidal waves caused destruction of oysters in Clayoquot Sound on the west coast of Vancouver Island, the first wave on May 22, 1960, from an earthquake in Chile and the second from one in Alaska on March 28, 1964.

COMPETITION FOR SPACE

Competition for space (crowding) on cultch is a most important source of mortality in the present system of oyster culture. This means that only a certain number of oysters of a given size can be attached to a given area of cultch; the larger the oysters the fewer per unit of cultch. Experiments to determine the effects of crowding started with spat of approximately equal size but with different numbers

per unit of cultch. These spat were grown by the raft culture technique, so that types of mortality, other than that due to competition for space, had no opportunity to operate, or had minimal effects. With 14 spat per shell, 10 oysters survived to a length of 4.5 inches, with 34 spat per shell 14 oysters survived, and with 87 spat per shell only 20 oysters survived. Thus, to double survival rate a six-fold increase in the original number of spat was required.

If one of these units had been cut into several pieces before the start of the test, the sum of the oysters on the pieces would have been greater than the number surviving on the larger unit of equal area. The reason is that the length of the perimeter relative to the surface area as well as the actual surface area itself affects survival. This is because additional perimeter permits the oysters to spread further away from each other and from the ones in the centre, and is one reason for separating clusters at the end of the first year, although by this time competition for space has already had considerable effect.

The time when small pieces of cultch are most advantageous is at the initial planting. However, reducing the size of cultch is a method of reducing competition for space only, and other types of mortality may have greater effect on smaller pieces of cultch than on larger pieces.

Still another way in which the grower may reduce mortality due to competition for space is to purchase larger spat, where mortality due to this factor has already taken place to a considerable extent. But the economics of the situation has an important bearing, for any advantage depends on whether seed is purchased on the basis of number of spat, or volume of cultch, or both, and on the price range of the different types of seed.

SILTING MORTALITY

The considerable difference between the number of seed planted and the number of oysters harvested led to experiments to determine the cause or causes of this discrepancy. Japanese seed with known numbers of spat were grown under conditions as close as possible to commercial conditions. Counts of surviving oysters were made annually and on comparable lots of seed; mortality during the first year averaged 91% whereas during the second and third years after planting there was only a 2% increase in mortality as shown in Table XXIV. This particular seed lot had a very high count (up to 100,000 spat per case).

One way in which to increase the number of spat in a case of seed is to increase the spat count per piece, and another is to decrease the size of the pieces so there will be more of them in the case. But the smaller the piece of cultch, the greater will

TABLE XXIV. Survival and mean length of Japanese seed oysters, Ladysmith Harbour, 1952–1955.

Date of count	Survival *(%)*	Mean length *(cm)*
April, 1952	100	0.6
April, 1953	9	6.6
June, 1954	7	9.4
June, 1955	7	10.3

be the mortality due to silting, so the advantage of using small pieces to reduce competition for space is lost unless the seed is given special treatment by placing it on very firm ground with little silt.

Even in this experiment, where the cultch pieces were very small, there was probably some mortality from competition for space, but it would have been minimal. There was no evident predation or sign of disease, so silting was indicated as the main source of this very significant mortality during the first year after planting. It is likely that the majority of deaths occurred within the first few months.

Further experiments were conducted to compare spat survival under various silting conditions. To eliminate the effect of silting entirely, wire-mesh trays held off the bottom were used. Varying levels of silting were obtained by arranging the experiment down the slope of the beach, the lower levels having deeper silt than the upper ones.

Average survival on the bottom was 37% as compared with 64% on the trays. The tray mortality of 36% could be attributed mainly to competition for space, for there was no apparent sign of any other type of mortality. The bottom mortality of 63% could be attributed to a combination of competition for space and silting. It is likely, however, that a considerable part of the silting mortality occurred prior to the time when sufficient growth had taken place to initiate competition. On the softest (lower) bottom, mortality reached 78%, while on the hardest (higher), it was only 48%. This then is an indication that seed ground should be hard ground which is generally found at higher tide levels, where wave wash keeps silting to a minimum.

CLUSTER SEPARATION

Mortality from this cause has already been discussed on page 93. That it may reach a level of 25% is of importance, and every effort is required to reduce it. Smaller pieces of cultch and careful breaking are means of reducing the loss. New types of cultch that will reduce breaking loss are required. Breaking is discussed in detail on page 94.

CONDITION

Size of meat, either by weight or by volume, between two oysters of equal shell dimensions may be very different. The seasonal cycle of change from glycogen (animal starch) to spawn has already been described, and the plumpness or the extent to which the oyster fills its shell cavity may be due to the presence of either glycogen or spawn, or a mixture of both. Strictly speaking, a "fat" oyster is one which is plump with glycogen. However, the oyster industry describes a plump oyster, whatever the cause, as a "fat" oyster. The word "condition" would be much more apt to describe the plumpness of an oyster.

In late summer, usually August, after an oyster has spawned, it is quite thin and watery, with a glassy appearance. This is because in prespawning oysters a large part of the body is filled with spawn (eggs or sperms), and when this is discharged there is little material left.

Almost immediately after spawning, if food is available (and this is not always so) the oysters begin to build up their depleted bodies by converting food to an animal starch called glycogen, which, in sufficient quantity, gives oysters in winter a plump, creamy appearance. By the end of November, there is little food left in

the water and, as low temperatures decrease feeding rates, the degree of fatness of an oyster during the winter is mainly decided by then. Because oysters enter a near-hibernating state in winter, little, if any, of the "fatness" that was recovered by fall is used up. If for some reason the fall feeding season has been poor, then oysters may go through the winter relatively thin.

Another situation may exist when, as occasionally happens in British Columbia waters, oysters fail to spawn. In this case spawn is carried throughout winter and, although they may be plump, they are not "fat" in the true sense of the word, for the plumpness is caused mainly by spawn and not by glycogen. However, spawn may also be converted to glycogen in varying amounts. This, too, is generally completed by the end of November, so conversion of spawn to glycogen appears to be associated with success of fall feeding.

The degree of fatness attained by November changes little during the winter until about March. At that time, increasing temperature and light create conditions in which oyster food can flourish, and there is normally a rapid increase in fatness during spring. This is when Pacific oysters are nearly always in prime condition and fill their shell cavities with bodies composed largely of creamy, succulent, glycogen-filled meats.

When water temperatures rise still higher, in May, oysters begin to develop spawn and the glycogen-filled tissues are replaced by either sperm or eggs, according to sex. The fatter the oyster, the greater is the amount of spawn developed. Spawning condition is maintained throughout summer until spawning occurs and the cycle begins again.

While oyster growers know of this seasonal fatness cycle and observe it throughout the years in a subjective way, a quantitative measure is necessary for recording and comparative purposes.

There are several ways of measuring quantitatively the condition or fatness of oysters, although, in most instances, plumpness, or the degree to which oyster meats fill the shell cavities, is measured, rather than true fatness; for, as mentioned before, most methods do not distinguish between glycogen and spawn.

The industry, particularly in the United States, uses a gallon to bushel ratio in percentage terms. That is, if 75 gallons of oyster meat are produced from 100 bushels of oysters, then the return is "75%," and increase in this percentage value indicates an increase in condition. The number of oysters per gallon compared with the number of oysters per net bushel (oysters less trash) may also be used for it stems from the following relationship.

Total number of bushels $\times$ number of oysters per bushel = total number of gallons $\times$ number of oysters per gallon

or

$$\frac{\text{Total gallons}}{\text{Total bushels}} \times \frac{\text{Number per bushel}}{\text{Number per gallon}} = \text{fractional return} \times 100 = \text{percentage return}$$

In this way meat production is related to the size of the oyster for the measure of volume (bushel) is in reality doing this (number of oysters $\times$ size of oysters). It should be remembered that the unit of volume, whether it be bushels, cubic feet,

or some other measure, should represent net volume, i.e., excluding trash and including only shucking oysters.

Growers often mistakenly refer to number of oysters per gallon as a measure of condition. This is of no value for this purpose unless reference is made to the size of the oysters, for the gallon could be composed of 100 large oysters in a poor condition or 100 small oysters in good condition.

It has been the tendency in British Columbia to use gallons per unit of weight (tons) rather than volume (bushels) as a measure of condition. In most cases, this is a fair approximation, although the weight–volume relationship in Pacific oysters is not strictly regular. However, quite a regular relationship exists between the total volume of whole oysters and the volume of the shell cavity (Fig. 87). This is used for a more precise measure of condition in oysters, known as the "condition factor."

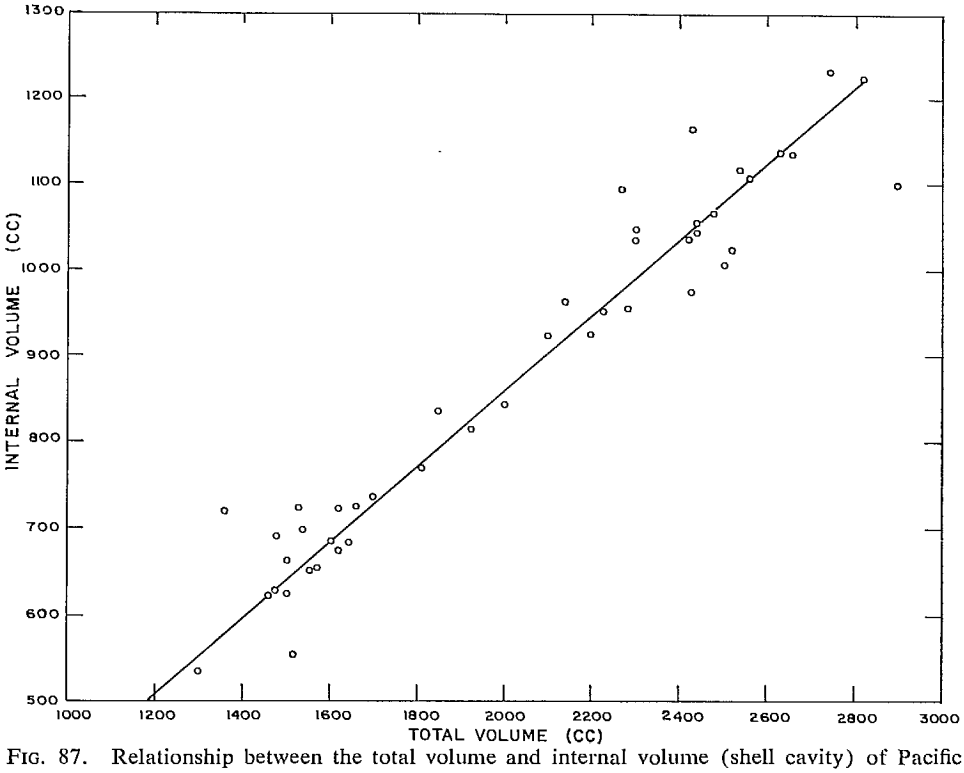


FIG. 87. Relationship between the total volume and internal volume (shell cavity) of Pacific oysters *(C. gigas)*.

Shell-cavity volume is the difference between the volume of a whole, closed, intact oyster and the volume of the two shells after the oyster has been shucked. Volumes are determined by displacement, or else by weighing in air and water, the difference between these two values being volume in the metric system. After weighing, the meats are dried until all moisture is lost. Condition factor is obtained from the fraction,

$$\frac{\text{Weight of dry meat}}{\text{Volume of shell cavity}} \times 1000.$$

This gives a value that ranges from about 40 (very thin oysters) to about 150 (very plump oysters). Multiplication by 1000 merely converts the ratio from a fraction to values that are more readily comparable. The assumption is that a solid, meaty oyster fills the shell cavity, while a thin one does not. Meat production, whether it be in gallons or pounds, is related to shell volume, whether it be in bushels or cubic feet.

This condition factor is a somewhat artificial ratio. It is possible to use volume of the oyster meat and this has been done. However, the water content is variable and an oyster may be plump with water which is usually lost soon after the meat is removed from the shell. The rapid change of volume when much water is present does not provide comparable results so, to evade the problem of water, the dry weight of meat after water has been removed was adopted. Consequently, the greater the dry weight of meat relative to the size of the cavity that contained it, the better the condition of the oyster and the larger the numerical ratio.

A further specific method for measuring true fatness is determination of the glycogen content of oysters. This is a different type of measure for it does not determine plumpness. As a rule it is used only for basic scientific studies. Still another measure is the percentage of solids present, which is, in reality, a measure of the moisture content, but does not refer to size.

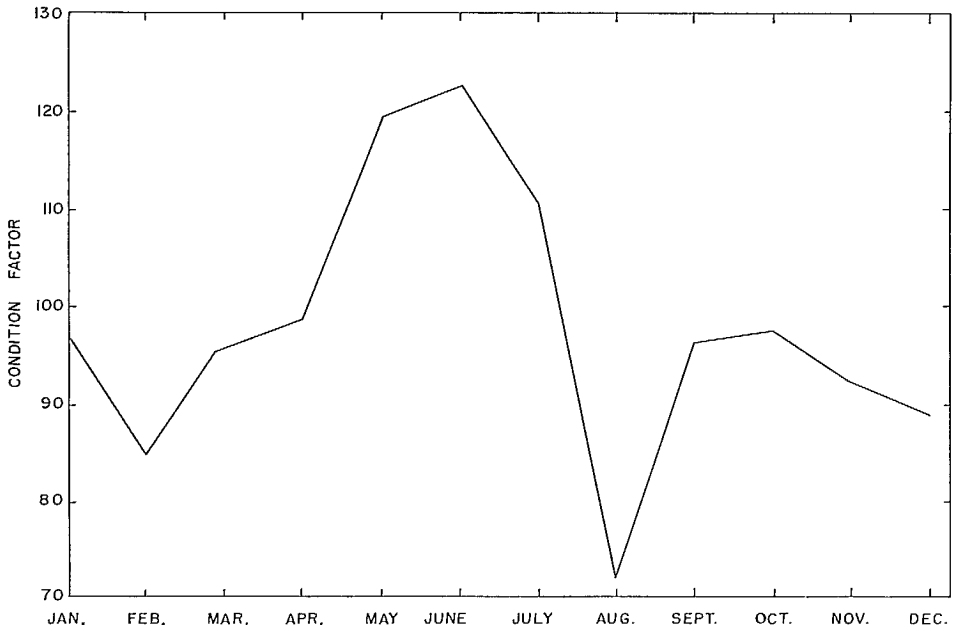


FIG. 88. Seasonal variation of the condition factor of Pacific oysters in Ladysmith Harbour. Mean of 148 samples, 1952–1956.

Studies at Ladysmith Harbour over a period of years have demonstrated the seasonal cycle of condition as measured by the condition factor (Fig. 88). As described above, there is little change from November to March, a sharp rise to May, a levelling off until spawning when a sharp dramatic drop occurs, followed

by a slow rise to November when the winter level is again reached. The stages vary in level, as well as in timing, from year to year. In some years, the winter level may be quite high, in others, relatively low. Recovery to a reasonable level may occur rapidly after spawning or it may take several months. Just as land farmers experience good and bad growing seasons, so do oyster farmers.

Table XXV records the data condensed from condition factor samples taken at various stations in the Ladysmith area and shows the variation from year to year, and from month to month. This picture of season change is well known to oyster growers and it does indicate that the condition factor is a fairly adequate quantitative measure of these changes.

TABLE XXV. Average monthly condition factor.

	1952	1953	1954	1955	1956	Average
January	105.7	68.5	94.6	92.0	99.1	91.9
February	99.8	–	62.7	90.9	–	84.4
March	91.4	–	77.2	93.1	90.7	88.1
April	128.2	–	73.3	–	75.1	92.2
May	160.3	98.9	109.8	118.9	91.7	115.9
June	149.1	103.4	99.2	134.4	108.4	118.9
July	156.7	92.9	114.1	140.0	73.6	115.4
August	90.4	55.8	83.4	91.1	107.2	85.5
September	96.5	–	114.1	92.0	–	100.8
October	109.5	76.3	128.0	98.2	81.9	98.7
November	101.6	78.5	96.2	70.4	91.4	87.5
December	109.0	62.2	92.8	96.0	76.7	87.3
Average	116.5	79.5	95.4	101.5	89.5	

Total number of samples — 210

A quantitative measure of condition permits growers to analyse accurately variations in productivity of the whole or parts of their ground, and gives an indication of whether or not they are utilizing all parts of their oyster farms to best advantage. It gives an accurate check on whether or not variations in production are due to seasonal and annual changes in condition, or to other factors. If there are drastic changes in condition, they may be pinpointed accurately as to time, and possibly correlated with causes. It is impossible to rely on memory or on impressions in such instances. This leads to the question of what information may most usefully be recorded by the grower.

Some consistent volumetric measure of shell stock passing through the plant should be maintained: bushels, baskets, or tubs. Weight is satisfactory but, usually, volume is more easily determined. In addition, origin (i.e., part of bed) of shell stock should be recorded. Growers are already required to report production in gallons to the Department of Fisheries so only the number of oysters per gallon need be determined. This may be obtained from check counts of the number in a volumetric measure, or from counts of actual gallon measures. If this were done on a daily basis, and it should take only a few minutes; growers would be sure to find the information most valuable. Further, at the end of the season it would be possible to calculate the actual number of oysters harvested. By comparing this with the

number of seed planted, an estimate of survival and of the efficiency of the operation may be obtained.

MEAT YIELD

Since, in the calculation of the condition factor, the whole volume of the oyster is known, it has been possible, by statistical procedures, to establish the average quantitative relationship among size (i.e., volume), condition factor, and meat weight.

Statistics are not required to show the oyster grower that there is, indeed, this relationship between oyster size and meat yield, and between meat yield and condition, for he knows it and operates his business on these principles. But the definite quantitative relationship may be of interest and for the Ladysmith area data (Table XXVI) this may be expressed by the equation:

$$E = 0.346\,X_1 + 0.112\,X_2 - 26$$

where E = weight; X_1 = volume; X_2 = condition factor.
This means that with an increase of 1 cubic centimetre in volume (size) there is an average increase of 0.346 grams of meat and with each unit increase in condition factor there is an average increase of 0.112 grams in weight of meat.

TABLE XXVI. Condition factor data, Ladysmith area, 1952–1956.

Condition factor	Total whole volume *(cc)*	Weight drained oyster *(g)*	Average weight oysters *(g)*	Average volume *(cc)*	Number of oysters
50–59	29758.8	4812.0	17.1	106.2	280
60–69	40798.2	7693.7	22.2	110.7	346
70–79	50514.0	9114.6	19.1	106.3	475
80–89	73936.3	14068.7	22.3	117.3	630
90–99	103892.4	20792.4	24.5	122.5	848
100–109	79421.0	17907.8	28.0	120.4	639
110–119	23859.5	5110.0	23.0	109.4	218
120–129	36363.0	9262.8	27.8	109.2	333
130–139	28885.7	7934.2	34.8	126.6	228
140–149	19014.0	5279.2	31.0	111.8	170
150–159	11511.0	3008.0	27.3	104.6	110
160–169	4869.0	1438.0	41.1	139.1	35
170–179	—	—	—	—	—
180–189	4081.0	1041.5	29.7	116.6	35
190–199	5450.0	1709.7	35.0	111.2	49
200–209	3024.0	102.7	4.1	120.9	25
	214 samples				4421 oysters

Thus, an oyster of a given size would yield an average of 2.8 grams or $\frac{1}{10}$ ounce more meat with an increase of 25 C.F. (condition factor) units in condition. In terms of the usual number of oysters in a gallon this increase would be between ¾ pound and 1 pound. It can be seen that in terms of hundreds or thousands of gallons this adds up to a considerable weight of oyster meat. The oyster grower, however, must continue to produce oysters and cannot avoid seasonal fluctuations in condition factor. But, it *is* necessary for him to examine his beds carefully to ensure that he knows and takes advantage of areas that produce oysters with the

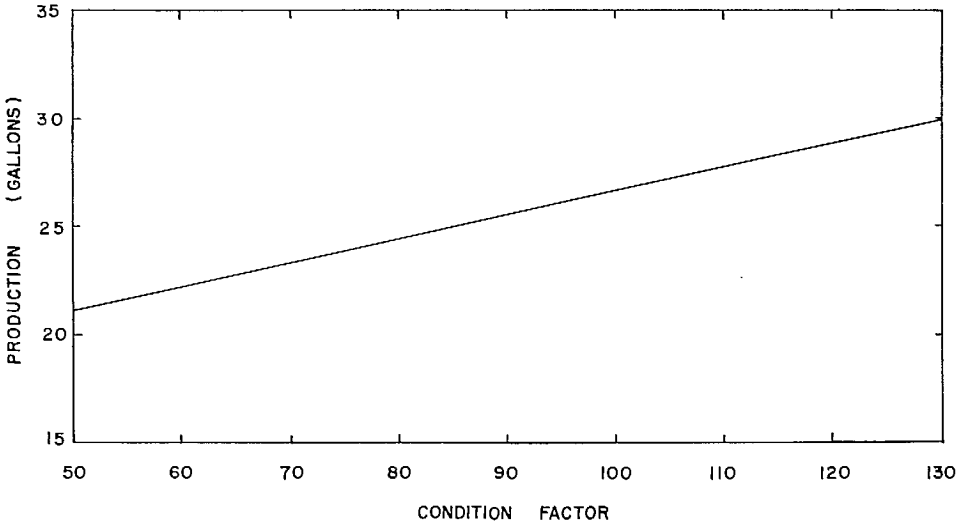


FIG. 89. Relationship between condition factor and oyster production in gallons per case of seed, for oysters approximately 5 inches long (120-cc volume), Ladysmith Harbour.

highest condition factor, not only on the average throughout the year, but at specific times.

Another way in which the importance of condition factor is shown is indicated in Fig. 89, which illustrates the relationship between condition factor and the production per case of seed in gallons. This is based on a return of 4000 oysters per case with 8.75 pounds of meat per gallon. An increase in condition factor of 25 points increases production per case by nearly 3 gallons. The vertical position of the line on the graph is determined by the size (volume) of the oyster which, in this case, was 120 cc, very roughly equivalent to an oyster 5 inches in length. This measurement is very approximate, for the relationship between length and volume is, of course, not very constant, for both width and thickness affect volume. It might be expected that larger oysters would show a relatively greater increase in meat weight with increase in condition factor, and the data does tend to show this when individual regressions are calculated for each size group. The maximum increase was calculated to be about 4.0 gallons for each 25-point increase in condition factor for oysters in the 150–159 cc volume group.

It may be realized, then, that the condition of oysters is of great importance in terms of production, particularly in the case of the Pacific oyster whose value is in terms of meat yield as compared with some other oyster industries where the number of individual oysters is the criterion of production.

In addition, the appearance of the oyster, which is related to its condition, is an important factor for it is critical in consumer acceptance. Oysters in prime condition have a good appearance with a smooth, cream-coloured, rounded body and with thick, crinkly, creamy mantles. Thin, transparent, flabby mantles, or a body blotched or dark in colour or with the dark digestive gland showing, indicates oysters in poor condition. Although the grower soon learns to recognize large

differences in condition, small differences are difficult to estimate on a quantitative basis. It is most important to have adequately written records for memories are short and subjective judgements not always reliable. Records of some consistent quantitative measurement of condition should be maintained along the lines suggested above.

If the effect of interaction of mortality, growth rate, and condition as described are properly understood and adequate records maintained in order that the effect of each factor be estimated, the grower will be in an excellent position to make adjustments to his methods of culture in order to get the best out of his oyster ground and from the seed he plants on it.

It cannot be emphasized enough that oyster production is the result of what happens on the oyster beds and not in the shucking house. It is on the oyster beds that effort and study will pay greatest dividends.

OYSTER PRODUCTION

The earliest official record for oyster production in British Columbia goes back to 1884 when 220 barrels with a landed value of $1250 were produced. These

TABLE XXVII(A). Pacific oyster production in British Columbia.

	Production (landed) *(gallons)*	Landed value *($)*
1940	21,700	36,784
1941	36,489	80,100
1942	37,450	56,749
1943	37,740	76,514
1944	49,710	129,644
1945	37,700	99,835
1946	66,650	231,523
1947	60,700	197,600
1948	46,158	187,600
1949	59,753	233,900
1950	62,710	287,800
1951	58,951	233,500
1952	81,185	368,600
1953	66,476	276,000
1954	85,870	307,000
1955	84,814	316,000
1956	89,983	340,000
1957	67,366	265,000
1958	62,746	334,000
1959	74,667	407,000
1960	78,384	339,000
1961	85,164	369,000
1962	101,165	466,000
1963	170,375	635,000
1964	153,449	444,503
1965	150,676	337,643
1966	134,336	672,627
1967	128,345	870,981

Data from Fisheries Statistics of Canada, 1940–1967.

TABLE XXVII(B). Oyster[a] production in British Columbia without species differentiation.

	Production (1000 lb)	Value ($)		Production (1000 lb)	Value ($)		Production (1000 lb)	Value ($)
1884	44	1,250	1912–13	556	11,282	1940	1,736	36,784
1885	50	1,250	1913–14	536	9,380	1941	2,819	80,100
1886	60	2,100	1914–15	354	13,840	1942	2,996	56,749
1887	–	3,500	1915–16	218	14,337	1943	3,019	76,514
1888	240	2,400	1916–17	312	20,788	1944	3,977	129,644
1889	300	5,250	1917	358	32,202	1945	2,818	99,835
1890	150	7,000	1918	290	26,926	1946	5,316	231,523
1891	200	3,000	1919	476	38,659	1947	4,860	197,600
1892	320	4,000	1920	344	36,830	1948	3,693	187,600
1893	320	8,000	1921	316	21,136	1949	4,780	233,900
1894	320	8,000	1922	409	30,406	1950	5,077	287,800
1895	320	4,800	1923	515	23,625	1951	4,716	233,500
1896	240	8,000	1924	333	26,492	1952	6,494	368,600
1897	320	4,800	1925	294	22,905	1953	4,986	276,000
1898	480	8,000	1926	470	34,122	1954	6,440	307,000
1899	480	12,000	1927	438	30,792	1955	6,361	316,000
1900	600	12,000	1928	482	40,334	1956	8,999	340,000
1901	600	15,000	1929	845	49,952	1957	2,230	265,000
1902	600	16,000	1930	639	56,825	1958	3,900	334,000
1903	–	18,000	1931	711	61,247	1959	6,952	407,000
1904	800	13,000	1932	402	28,638	1960	5,879	339,000
1905	500	7,190	1933	446	25,670	1961	6,387	369,000
1906	290	5,075	1934	659	33,886	1962	7,587	466,000
1907–08	–	10,000	1935	671	43,173	1963	13,630	635,000
1908–09	320	7,263	1936	1,239	51,978	1964	11,509	588,000
1909–10	800	30,935	1937	466	36,199	1965	11,301	612,000
1910–11	544	22,362	1938	596	36,258	1966	12,416	802,000
1911–12	1,076	39,053	1939	2,262	48,719	1967	10,268	871,000

Data from Fisheries Statistics of Canada, 1884–1967.

Conversion: shell oysters — 1 barrel = 200 lb = 2.5 gallons Pacific oysters.

[a]1884–1910 — mainly native oysters; 1906–1925 — native oysters and eastern oysters; 1925–1935 — natives, easterns, and Pacifics; 1936–1967 — mainly Pacifics.

were, of course, native oysters. By the turn of the century production had reached 625,000 pounds (in the shell) and was valued at $15,000. Production fluctuated widely (Table XXVII A and B) and analysis is made difficult because the published statistics did not differentiate between species. However, it was not until 1930, just about the time when Pacific oysters were first marketed, that the landed value reached the $50,000 mark, and it was not until 1944 that production was valued over $100,000 (Fig. 90, 91). It is remarkable that production was maintained as high as it was during the later years of World War II, for there was no importation of Japanese seed from 1942 to 1947. The 1941 Japanese seed reached market size in 1944 and the 1947 seed in 1950 so there was a period of 6 years of production during which seed requirements were filled by local seed fortuitously produced in 1942 by general breeding in all the Strait of Georgia growing areas.

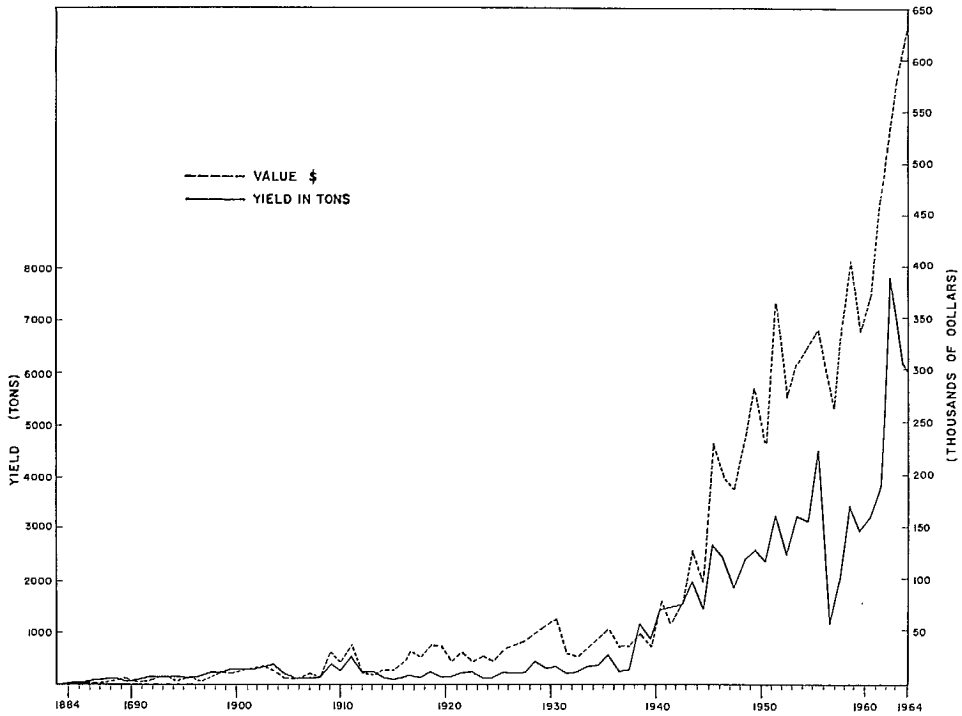


FIG. 90. Oyster production in British Columbia, 1884–1964.

During the postwar period there was a gradual year-by-year increase in production with minor fluctuations until 1962 and 1963, when two very significant increases placed the landed value at a figure of $635,000 in 1963. This was due largely to the availability of large quantities of wild seed and oysters from the extensive and widespread breeding in the Strait of Georgia in 1958. Oysters resulting from this breeding were available to the industry in fairly significant quantities until 1965 and in reduced numbers until 1969. Between 1939 and 1961, inclusive, 54,000 cases of Japanese seed were planted on British Columbia oyster beds. At an estimated yield of 25 gallons per case this should have produced 1,350,000 gallons during that period. The actual production was approximately 1,750,000 gallons, giving an estimated 400,000 gallons from local seed or the equivalent of 16,000 cases of Japanese seed. As described elsewhere, British Columbia is now virtually independent of Japan for the supply of seed oysters due to the consistent production in Pendrell Sound. The plantings of seed are given in Table XXVIII.

During the 10-year period from 1951 to 1960, average annual production was approximately 75,000 gallons. During the period 1948 to 1957, inclusive, the period during which seed which produced oysters between 1951 and 1960 was on the beds, approximately 33,000 cases were planted. This shows a return of 23 gallons per case.

In 1963 there were 3,500 acres with about 160 lots under lease, including both Provincial government, and Esquimalt and Nanaimo Railway leases, held by 78 leaseholders. The total return for that year was 173,375 gallons and on the basis

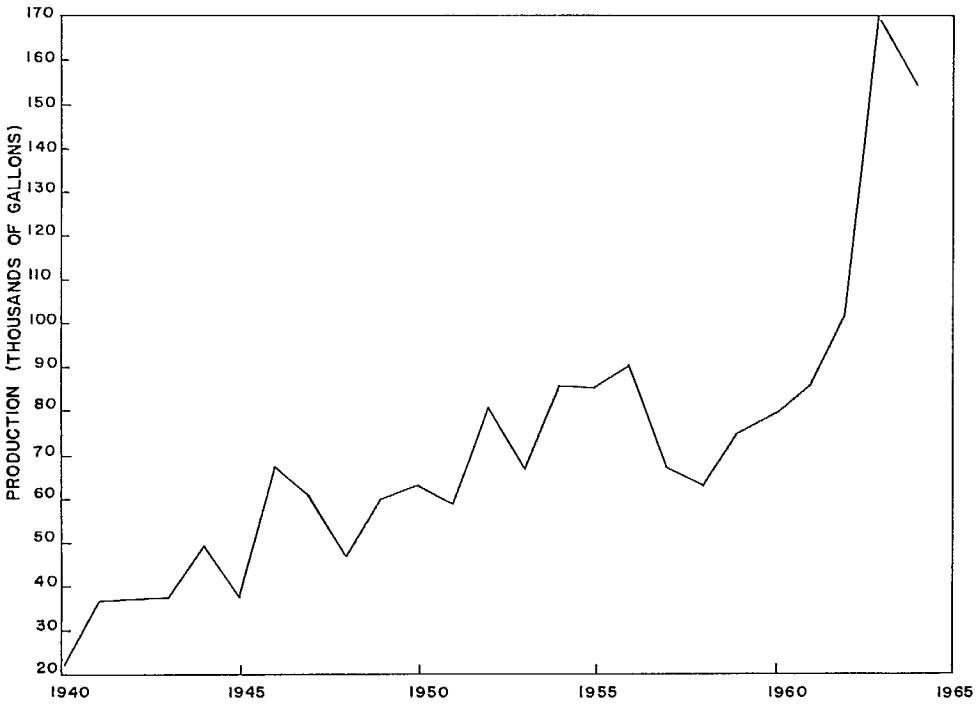


FIG. 91. Pacific oyster production in British Columbia (in gallons), 1940–65.

of an area of 2400 acres held by the 38 growers who produced oysters in that year, the average return was 72 gallons per acre. When it is considered that an acre of oyster ground should produce between 200 and 300 gallons per acre annually, it is evident that British Columbia oyster ground is not producing near to its full potential.

In mid-1966 there was a total of 80 leaseholders with 2748 acres of which 537 acres (20 leaseholders) were granted by the Esquimalt and Nanaimo Railway on

TABLE XXVIII. British Columbia imports of Pacific oyster seed from Japan in cases.

	Number of cases		Number of cases		Number of cases
1925	20	1940	602	1957	3342
1928	40	1941	3065	1958	3348
1929	300	1947	2192	1959	1290
1930	43	1948	2675	1960	909
1931	127	1949	4804	1961	1000
1932	189	1950	5204	1962	1000
1933	589	1951	5400	1963	nil
1934	625	1952	3584	1964	nil
1935	79	1953	1425	1965	25
1936	207	1954	1516	1966	nil
1937	221	1955	1609	1967	90
1938	912	1956	3240	1968	300
1939	1060				

its Crown-grant foreshore in Baynes Sound. The remaining 2211 (60 leaseholders) were granted by the Provincial Department of Lands. Some leaseholders may have a number of separate leases. The average leasehold is 35 acres and the size distribution of leaseholds is shown in Table XXIX. This shows that more than half the leases were less than 20 acres, and 40% were less than 10 acres, indicating either that a considerable proportion of the leaseholders do not use their leases or that oystering is a part-time occupation.

TABLE XXIX. Size frequency of oyster leaseholds in British Columbia as of July, 1966.

Average *(acres)*	Frequency
1–5	16
5–10	16
10–20	20
20–50	15
50–100	6
100–200	2
200–300	3
300–400	1

It is estimated that probably not more than 85% of oyster ground under lease is actually usable, for often a proportion of unusable or marginal ground is included to simplify survey. On this basis, the total potential yielding area at the moment (1966) is 2700 acres less 15%, or 2300. A 3-year cycle may produce 750 gallons per acre or 250 gallons per acre per year, so the estimated potential annual production should approximate 575,000 gallons. However, this potential cannot now be realized unless some means can be found to bring the restricted polluted areas back into production.

In 1953, only 1425 cases of seed were planted to produce the 1956 crop. In other words, the available ground, a minimum of 500 acres, was planted at the rate of 3 cases per acre when a minimum of 25 cases per acre or 12,500 cases should have been used. In 1952, however, 3524 cases were planted and 5400 cases were planted in 1951. In the 2 years following 1953 only 3125 cases were planted and the relatively low production around 1958 was the result of this low level of seeding. The higher seeding in 1950 and 1951 must have assisted in the 1956 production, for the basic seeding in the cycle year would have been insufficient to provide the production reached in the year. The point that cannot be too strongly emphasized in growing Pacific oysters is "as ye sow so shall ye reap."

It may be seen that the British Columbia oyster industry can expand its production very considerably. There is a natural desire to expand as the potential market increases. There is an automatic expansion in markets due simply to population increase but rate of expansion could be accelerated considerably by advertising. Whether or not advertising is economically feasible is problematical considering the size of the industry. Also, most growers are single-family producers who are content to maintain a production sufficient to provide a modest income. Expansion would occur if the government decided that greater utilization of the oyster ground it leases

is necessary, and legislated to bring this about. There is little doubt that if the present growers do not wish to utilize all of the ground they now hold under lease, there are many who would do so, for virtually all potentially useful oyster ground in the Strait of Georgia and the west coast of Vancouver Island is now under lease. There is relatively little ground north of this area, and the slower growth of oysters and marketing difficulties will make the utilization of that ground uneconomical for many years to come.

In other words, potential oyster production in British Columbia, using the cultural practices of today, has a very definite limit, which may be still further reduced by pollution problems.

Production Factors

There are, however, other techniques that will permit expansion of oyster production. One of these is raft culture which is described in another section. Also, at the present time there is a modest amount of what may be termed marginal oyster ground. This type of ground lacks one or more of the three basic requisites of oyster ground: (a) correct tidal height, (b) correct bottom consistency, (c) adequate protection from wave action. As oyster ground becomes more valuable, as it is nearly bound to do, it will become economically feasible to change the level of ground that lacks the correct tidal cover either by excavation if it is too high, or by filling if it is too low. Bottom consistency can be changed by filling with appropriate material such as gravel or shell on soft ground. Unprotected ground may be guarded by appropriately designed breakwaters. However, even now, some marginal ground could be integrated in a system of oyster culture as outlined on page 92.

As may be gathered in reading this section, production statistics are necessary for the authorities, as well as industry itself, to analyse what is going on in the industry. At the present time, all registered growers are required to file an annual production return with the Commercial Fisheries Branch of the Provincial Department of Recreation and Conservation and a monthly return with the Department of Fisheries of Canada on the form shown below.

In addition, as mentioned previously, for his own use the grower should maintain careful records of everything he does with his oysters from the time, place, and density of planting of seed to the time it is marketed. Source of the seed should be noted as well as an average spat count and the average size of the spat. Average size of every planting of seed at the end of each year should be noted, as well as the estimated mortality. Every transplant should be recorded.

When oysters are harvested, some record of the volume of oysters harvested, and their condition or fatness, should be maintained as suggested on page 119. Only in this way can the grower make an intelligent appraisal of what he is doing and whether he is doing it correctly. The expert can only suggest broad principles on how to grow oysters, for every oyster bed is different from every other oyster bed and there can be considerable variation within a single bed. It is up to the oysterman himself to be aware of the details of his own ground, details that can mean the difference between only adequate production and excellent production.

An example of a typical record form is shown below. The individual grower can easily devise a form to suit his own needs.

PRODUCTION REPORT

Oysters transplanted to or harvested from: _____ Date _____, 19____
(Bed name)

Oysters transplanted to _____ Date _____, 19____
(Bed name)

Year:					
Type:	Japanese Seed	Pendrell Seed	Wild Seed	Wild Oysters	Other

Harvesting method _____

Gross Bushels	Av. No. Oysters per Gross Bushel	Gross No. of Oysters

Mortality: Estimated % _____ Reason _____

Comments: _____

_____

Economics of Oyster Production

The average cost of producing a gallon of oysters is difficult to determine because of the wide range in oyster cultural methods and efficiency. The following estimates must be understood to be quite crude and only very approximate but because the economics of oystering are so important, this guide is provided. The estimates are based on a 3-year cycle for 1 acre, with the planting density set at 25 cases of seed per acre and a production of 600 gallons, no account being taken of the capital investment involved, or a number of smaller items.

Lease fees and taxes	$ 40.00
Seed	450.00
Spreading seed	50.00
Breaking seed	200.00
Transplanting	100.00
Harvesting	200.00
Shucking	800.00
Containers (gallon)	300.00
Packing	200.00
Plant overhead	100.00
	$2440.00

Cost per gallon $\frac{\$2440}{600} = \$4.07$

Market value of table oysters (1969) — $6.00

RAFT CULTURE

Culture of oysters by suspending them from rafts or racks has been practiced for many years in several countries, such as Norway, France, and Japan. The amount of oyster ground in British Columbia is relatively small owing to the precipitous nature of the coastline; but there are numerous sheltered coves and bays that might be suitable for raft culture.

In Japan, particularly, raft culture has been used extensively since about 1923, and at the present time this is the major oyster growing method. There, each raft holds between 6,000 and 10,000 shells on wires or ropes about 10 feet in length with bamboo or other spacers to hold the mother shells apart. The time taken to produce a marketable oyster by the raft culture method in Japan varies from 1 to 2 years. Each 10-foot string produces about ¾ gallon of marketable oysters. Production is said to exceed 8000 bushels per acre per year. Utilization of the dimension of depth, rapid growth, better quality, and freedom from pests are advocated as advantages by the Japanese.

Experiments with the raft culture method have been carried on in Ladysmith Harbour and the essential details and adaptations for British Columbia conditions have been worked out.

Shells holding Pacific oyster spat are strung on No. 12 galvanized wire and held about 6–8 inches apart by twists in the wire (Fig. 92). The shells are separated to allow the spat to grow freely in all directions. A small tool has been developed for making the twist in the wire (Fig. 93). Various separators, such as lengths of bamboo and rubber hose, have been used but the cost of labour and of these materials indicates that the wire twist is the most suitable method for separating the shells. Various gauges and types of wire, including stainless steel, as well as hemp cord, have been used but No. 12 gauge galvanized wire has proved to be most satisfactory for it has the necessary strength and lasting qualities and is cheap enough to be expendable, thus facilitating the removal of oysters from the strings. This is done simply by cutting the wire between each group of oysters.

The strings may be made up either as "singles" where 15 shells are placed on the wire and hung from a nail on the raft, or as "doubles" where 30 shells are placed on a single string, each group of 15 shells being separated by 2–3 feet of blank wire. These double strings are draped 12–18 inches apart over the logs of the raft so that 15 shells hang from each side. In this method, nails are unnecessary, thus reducing both string losses and handling costs.

There are no definite standards of raft construction, but almost any type strong enough to withstand the buffeting of wave action would be suitable. Two-log rafts of discarded fir boomsticks held together by drift-bolted 6-inch × 6-inch cross members were used in the Ladysmith experiments and found quite suitable (Fig. 94). Logs held together end-to-end by boom chains would no doubt prove to be the most efficient type of raft since no cross pieces would be required and little labour is involved in chaining the logs together. Cement or rock anchors with chain were used and this combination is probably the most economical holding gear because of long life and safety.

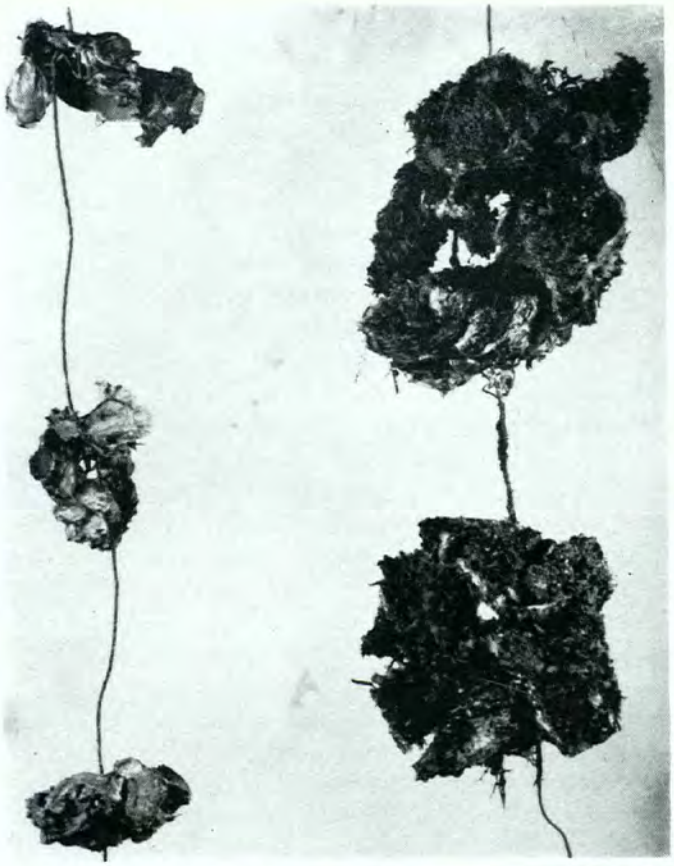


FIG. 92. *(above)* Section of raft culture strings. × 0.2. Left—before placing on raft in February 1967. Right—growth to October 1967.

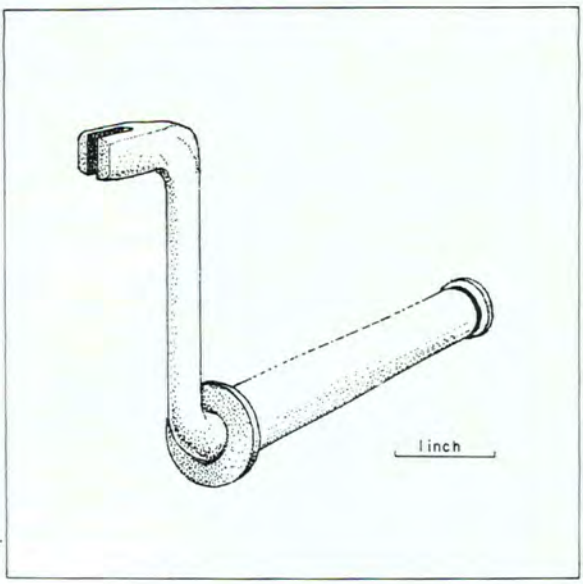


FIG. 93. *(right)* Wire-twisting tool for separating raft culture shells.

FIG. 94. Two-log raft culture float, Ladysmith Harbour, 1967.

The rafts are placed in water where the water depth at the lowest tide exceeds the length of the string, so that the ends of the strings do not touch bottom. Maximum depth is limited only by the cost of the mooring cables. Strings longer than 8–10 feet are too unwieldy to handle easily. Relatively sheltered water is required, both for the safety of the raft, particularly if this is of solid construction, and to keep the weight and cost of mooring gear to a minimum. Compliance with the terms of the "Navigable Waters Act" is necessary, and deep-water foreshore leases should be obtained. Under normal circumstances, the strings are placed on rafts in February or early March and no further care is necessary until harvesting, which may begin in mid-November or December.

Either local or Japanese seed may be used and the initial cost is about the same. Local seed has the advantage that the shells are larger and harder, allowing more space and security for attachment of the growing oysters. Seed should have a minimum diameter of about an inch before it may be expected to attain market size in the March to November growing period. Unless the local set has occurred very early in the summer, the above condition is seldom met and the only way in which the minimum size may be obtained is to hold the seed on the beach for a year before using it for raft culture. If seed less than about one inch in diameter is used, too low a proportion of marketable oysters is yielded in one growing season. Two growing seasons are not considered advisable since there is relatively little additional growth in the second year, and fouling becomes a significant problem; therefore, valuable float space is used with little gain. As a general rule it is advisable to use one-year-old seed which has not quite been allowed to attain its maximum growth. If larger seed is used one season of raft growth may yield oysters that are too large. The cost of Japanese or local seed is about ½¢ per shell and one-year-old seed may be purchased for a bit more than 2¢ per shell.

Fouling during the March to November period is not a major problem, although some does occur in the form of hydroids, barnacles, and mussels. It is important that the strings be hung from the raft before the main barnacle settlement of the year, which occurs each year within a week or so of April 1. Barnacles grow rapidly and this tends to inhibit settlement of other organisms. By November most of the barnacles have died and fallen off, carrying with them much of the fouling that has been able to attach. Those barnacles that have not fallen off are very easily removed. The mussel is the main fouling organism.

There are two methods of harvesting. One is to move the whole raft into the intertidal area at high tide where the strings are dropped off so they may be picked up at low tide. The other method is to lift the strings directly from the culture raft with a derrick or hinged "A" frame to another raft or scow.

When the individual groups of oysters have been separated by cutting the wire, clusters are broken up into single or double oysters by forcing the oysters apart or by breaking the mother shell. At the same time any adhering mussels may be removed. After washing, the oysters are ready for shucking.

The objective should be to obtain about a gallon of oysters per string, which represents 100 to 150 oysters of market size. This is purely an arbitrary objective and will be seldom attained. In addition to seed size, an important factor in governing yield per string is the initial number of spat and the ideal number appears to lie between 10 and 20 spat per shell. If there are less than this, mortality losses, in addition to undersized oysters, reduce the number below that required to yield 1 gallon per string. If there are more than about 20 spat per shell, there is competition for space and for food, and with resulting mortality and slow growth, survival will be less than the number required to yield one gallon per string.

A rough breakdown of cost has been made on the basis of a single string from a 300-string operation in 1953, but these estimates are only approximate, particularly those concerned with rafts and loading. By now costs have likely more than doubled.

COST PER STRING OF 15 CULTCH SHELLS

Wire	$0.04
Labour (stringing)	0.13
Labour costs are calculated at the rate of $1.50 per hour.	
Cultch at 2¢ per shell	0.30
Loading	0.03
Unloading	0.05
Separating clusters	0.20
Float (per string per year)	0.10
	$0.85

This cost of 85¢ per string (1953) is an approximate cost of producing one gallon of oysters ready for shucking. Equipment, such as the culture raft and loading raft, will vary very widely in cost according to the individual case. It seems that the cost of the culture raft may be the critical factor in the economics of the raft culture method. The discarded boomsticks that have been found suitable for rafts are generally available from booming ground operations or from log salvors at a minimum

cost, since they are of no value as saw logs. An estimate of $90.00 has been made for a raft able to carry 300 strings and with a life of about 3 years.

The raft method of oyster culture has been shown to have a number of important advantages over beach culture. First, the time taken to reach marketable size is reduced from 3 years to 2 years and, in some cases, to slightly over 1 year. The appearance of the oyster meat is generally good for the mantle is not as dark as in those oysters grown on the beach. At all times of the year they are fatter than those grown on the shore only a few hundred yards away. Raft culture oysters in Ladysmith Harbour consistently had a condition or "fatness" factor of about 130 as compared with 80–90 for those grown on the nearby shore.

Since the oysters are held off the bottom, mortality does not occur from silting or from predators such as starfish or drills. Further, the operations do not depend on low tides.

Rack Culture

Another method of growing Pacific oysters which is little used as yet is by means of racks (Fig. 95). This method permits utilization of very soft oyster bottom and is a means of extending oyster bottom for a short distance into the subtidal area.

Fig. 95. Rack culture of Pacific oysters, Ladysmith Harbour.

Racks of 2-inch × 4-inch lumber are usually stout enough but they should be creosoted for long life. The posts are driven into the ground and joined by caps both lengthwise and crosswise. The actual dimension and shape is not fixed and may vary according to the bottom available and to the extent of the rack system. Enough space should be left between individual racks to allow easy handling of the shell strings. The shells are strung on wire as for raft culture but usually they are not longer than about 4 feet. The top of the racks in the intertidal area should not be above the 5- or 6-foot tide level.

To utilize the subtidal margin of an oyster bed by racks the posts are driven so that the top of the racks are about 1–2 feet above the zero tide level. This limits the working time, but the strings are only handled and harvested when exposed, so this is not too important a consideration.

The growth rate on intertidal racks is on the average midway between those for bottom and raft cultures.

Stick Culture

This is a method that has been used in a slightly different form in Australia and to a limited extent in Washington and California. It consists simply of a stick of wood usually about 1 inch in diameter and about 18 inches in length with a 2-inch nail driven part way at one end (Fig. 96, 97). The other end is pushed down into

Fig. 96. *(left)* Stick culture of Pacific oysters, Ladysmith Harbour, showing cluster of oysters on 1-inch by 1-inch stake.

Fig. 97. *(below)* Stick culture of Pacific oysters, Tofino, 1967.

the bottom nearly a foot and a single seeded oyster cultch shell is placed on the nail through the hole in the shell. If the shell is the left valve the cup side should be placed downward to prevent being filled with silt. The sticks are placed about a foot apart with lanes every few feet to allow planting and harvesting. The sticks should be creosoted for long life. Seed of any size may be used. The growth and survival rates are superior to those for bottom culture.

At first glance the method may appear uneconomical but when it is considered that about 10 oysters may be grown to market size on a single stick, the system has merit under certain conditions such as on very soft ground.

NUTRITIVE VALUE AND CHEMICAL COMPOSITION

The seasonal change in chemical composition of oysters in British Columbia has been studied and the results are given in Table XXX.

TABLE XXX. Chemical composition of Pacific oysters in British Columbia.

	Average weight (g)	Moisture (%)	Solids calculated on moisture-free flesh				
			Protein (%)	Glycogen (%)	Fat (%)	Ash (%)	Balance
Feb. 9	18.90	78.20	47.80	20.50	10.68	8.66	12.36
April 12	18.30	79.84	46.65	24.95	12.94	7.62	7.84
May 30	16.72	77.50	47.70	23.80	13.31	6.87	10.32
Aug. 3	11.07	81.41	54.60	11.85	15.75	7.80	10.00
Oct. 3	17.40	80.00	52.20	14.25	11.72	5.78	16.05
Dec. 7	20.10	83.37	49.90	20.05	13.08	8.42	9.45
Feb. 6	20.00	79.89	49.60	19.00	15.27	6.81	9.32

The balance represents material not accounted for, and is probably the result of destruction of some of the carbohydrate by chemical action in the analytical procedure. As previously observed, oysters are usually in best condition during spring, and this is reflected in this table with high values for glycogen which gives a prime oyster its characteristic colour and flavour. In early summer, as spawn is developed, apparently at the expense of glycogen, the value for this material drops but there is a corresponding increase in the value for protein. Presumably in this experiment few, if any, of the oysters spawned. After the August low, glycogen content began to rise and the December value is indicative of the winter condition with a value somewhat lower than the high level in spring.

In Table XXXI are given the data from a similar study in Japan with Pacific oysters which spawned in July and August. In this case the sharp drop in glycogen may be noted as spawn is being formed in April, May, and June, as well as the marked reduction in meat weight as a result of spawning in July and August.

In addition to the organic chemicals just mentioned, oyster meats also contain most of the numerous inorganic elements that occur in sea water such as sodium, potassium, calcium, magnesium, iodine, and phosphorus in small concentrations, and the following in very low concentrations: iron, copper, zinc, aluminum, silicon, strontium, lithium, rubidium, nickel, silver, titanium, vanadium, gold, zirconium,

platinum, and manganese. An analysis of Pacific oyster meats and shells was made by the Washington Pollution Control Commission in 1959 and the results are given in Table XXXII.

TABLE XXXI. Chemical composition of Pacific oysters in Japan.

	Weight of meat (*g*)	Moisture (% of fresh meat)	Dry matter (*g*)	Dry matter (%)			
				Protein	Glycogen	Fat	Ash
Jan.	13.5	74.0	3.457	35.5	4.6	9.4	7.3
Feb.	14.1	74.4	3.566	32.5	5.7	10.4	6.3
March	17.2	79.0	3.591	30.5	5.5	9.6	5.9
April	15.4	74.6	3.854	36.9	4.0	10.1	5.7
May	12.7	76.3	2.990	43.2	2.4	9.6	7.0
June	12.4	79.8	2.533	43.5	0.8	9.6	9.7
July	6.8	76.4	1.621	38.8	0.9	3.5	8.4
Aug.	7.2	84.6	1.144	51.7	0.4	6.0	10.8
Sept.	9.2	84.7	1.415	43.3	0.7	5.8	9.3
Oct.	15.5	80.6	3.017	40.4	1.8	6.0	9.6
Nov.	15.41	68.1	5.582	23.0	4.2	5.1	3.7
Dec.	20.2	79.6	4.098	31.7	3.7	9.3	5.7

Heavy metals such as copper, iron, zinc, and manganese can be concentrated and stored by oysters through direct absorption if there is a concentration of these metals in the sea water in which they are growing. Oysters stored in galvanized containers or on galvanized trays will concentrate relatively large amounts of zinc.

TABLE XXXII. Metallic element content of Pacific oysters, 1959 — Mean of 8 samples.

	Shell	Meat
Total solids		11.36g
Ignition residue (% by weight)	93.66	–
Calcium — % ash	10+	–
Sodium — % ash	1+	–
Elements in ash (*ppm*)		
Aluminum	1490	7762
Silicon	4562	9500
Iron	1024	1070
Strontium	300	412
Zinc	–	250
Titanium	69	381
Copper	34	89
Manganese	–	128
Chromium	9	49
Vanadium	–	62
Boron	40	84
Silver	–	8
Lead	180	150
Nickel	–	72
Magnesium	4162	–

Data condensed from: "On Oysters and Sulphite Waste Liquor" by G. Gunter and J. McKee. 1960. Washington Pollution Control Commission.

Strangely enough, arsenic is one of the heavy metals that is stored only in modest amounts.

Copper is picked up readily, as is shown by the bright green oysters that grow near slag piles from former copper smelters in Ladysmith Harbour and in Howe Sound. Heavy metal analyses of British Columbia oysters from various areas are shown in Table XXXIII. The highest concentrations, as would be expected, were in

TABLE XXXIII. Heavy metal analysis of Pacific oysters in parts per million.

Area	Zinc *(ppm)*	Copper *(ppm)*	Lead *(ppm)*
Crofton	11,000	590	10
Ladysmith 1	13,000	700	10
Ladysmith 2	13,000	1,200	10
Ladysmith 3	21,000	940	10
Slagpile			
Ladysmith 1	28,000	9,600	10
Slagpile			
Ladysmith 2	34,000	20,000	10
Porteau	2,300–5,000	50–1,600	–
Commercial	330–480	5–27	–

oysters from near the slag pile of the former copper smelter in Ladysmith Harbour and from Howe Sound near Britannia Beach. In the case of copper, the colour is diffused throughout the body, especially where there is an ample supply of blood. Such oysters should not be eaten. This should not be confused with the green-coloured gills which result from the oyster feeding on certain coloured organisms. A well-known practice at Marennes, France, is to place oysters in ponds or claires in which a particular diatom flourishes in order to colour the gills, thus producing an oyster which fetches a premium price.

Oysters have been shown to be a good source of vitamins A, B, and D, as well as niacin, riboflavin, and thiamine. Recent studies have shown that some molluscs such as the eastern oyster and abalones contain antibacterial and antiviral substances.

FOOD VALUE

Dr J. P. Tully has calculated the food value of Pacific oysters and his data are shown in Table XXXIV. The indication here, also, is that oysters are in the best condition during the winter and early spring.

TABLE XXXIV. Energy content of Pacific oysters.

Date	Calories per 100 grams (3.5 oz.)			
	Protein	Glycogen	Fat	Total
Feb.	42.7	18.3	23.4	84.4
April 12	38.4	20.6	24.2	83.2
May 30	42.0	21.8	27.9	91.7
Aug. 3	41.6	9.0	27.2	77.8
Oct. 3	42.9	11.6	21.8	76.3
Dec. 7	33.4	14.9	20.2	68.5
Feb. 6	40.9	15.7	28.8	85.4

MARKETING

Oysters are marketed in a number of ways. These are (a) direct to the consumer (at the plant, to the public, or to restaurants); (b) to retailers (fish markets and supermarkets); (c) to wholesale fish dealers; (d) to other oyster producers; (e) to processors (canners).

The method depends partly on the type of oyster available. For instance, if there is a supply of very large oysters these will almost invariably go to canners for soup, but these bring a lower price. Smaller producers tend to develop their own direct markets such as restaurants and supermarkets, but this is difficult for large-volume producers.

Until recently, oyster marketing could only have been described as a "free-for-all" with considerable price-cutting and exchange of markets. For a number of years, the price of oysters increased very little in proportion to the relatively large increase in production costs. However, on December 17, 1964, the British Columbia Oyster Marketing Board came into being and virtual chaos was changed into order. A plan was instituted, voted for by a majority of oyster growers, for the effective promotion, control, and regulation, within the province, of the transporting, packing, storing, and marketing of oysters.

The Board consists of three oyster growers who are elected by the British Columbia Oyster Growers Association at its annual convention. The Board licenses and collects fees from all persons handling oysters and fixes both maximum and minimum prices at which the regulated product may be bought or sold in the province. The Board is also required to promote the oyster industry by advertising and other means.

PROCESSED OYSTER PRODUCTS

In addition to standard fresh and half-shell oysters, there are several ways of processing oysters; these include smoking, canning whole oysters, canning oyster stew, and freezing. Only brief outlines will be given here, for anyone considering these processes will require a considerable amount of detail beyond the scope of this bulletin. So far in British Columbia, the main processed pack of oysters has been the smoked variety, with lesser amounts of the others. Assistance may be obtained from the manufacturers of cans and canning equipment and from the Vancouver Laboratory of the Fisheries Research Board of Canada.

Canned Smoked Oysters

This method requires oysters that have been steamed open or which have been shucked fresh and then partially cooked. They are rinsed for 5 minutes in a 2.5% brine solution to salt the product slightly and to wash off bits of grit. They are then spread in a single layer on a ½-inch-mesh galvanized-wire tray which has been previously oiled with cooking oil to prevent adherence of the oysters to the wire. At this time the oysters should be left in the open air as briefly as possible otherwise oxidation will cause them to become dark. For this reason, the smokehouse should also be ready at the smoking temperature of 120 F. Smoking time is variable but about 4 hours at this temperature gives a light brown colour without causing the

meat to become shrivelled or tough. Birch sawdust gives a sweeter flavour than alder, and does not darken the oyster as much; crabapple is also often used. The wood used, and time and temperature of smoking are largely a matter of individual taste and opinion.

Smoked oysters are usually packed in ½-pound flat cans filled with 1—¼ fluid ounces of salad oil and exhausted for 15 minutes at 10—12 pounds pressure in the retort. After double-seaming, the cans are then processed in a retort at 240 F for 60 minutes and immediately cooled.

Canned Oysters

This is the pack in which oysters are canned whole in brine. Either cold (fresh) shucked oysters or steam-opened oysters are used but in any event they are at least blanched before being placed in the can. Thereafter, standard canning procedures are used.

Oyster Stew

This product forms an outlet for oysters which are too large for the fresh oyster trade; however, such oysters bring a lower price to the oyster grower. As with canned oysters, they are usually precooked, and chopped into small pieces. Milk, spices, and finally a pat of butter are added followed by standard canning techniques.

Frozen Oysters

This method of preserving oysters is relatively new and as yet an ideal process has not been perfected. Just freezing a container of oysters results in a product that leaves much to be desired because of so-called "drip," a slimy secretion produced when they are thawed. Attempts have been made to overcome this by freezing individual oysters or by preliminary blanching.

Precooked, breaded, frozen oysters have also been marketed with some success.

Half Shell

On the west coast of North America, in both the United States and Canada, virtually all oysters are marketed in the shucked state and, except for a small proportion used in oyster or seafood cocktails, they are consumed in a cooked state.

This is completely different from Europe where practically all oysters are consumed raw or, as it is often described, "on the half shell." There, oysters are sold to restaurants in the shell and they are opened on the premises when ordered by customers. They are served in the cupped shell, usually six on a plate.

Almost all oysters produced in the Canadian Maritime provinces are eaten raw on the half shell, and the cultural practices are designed almost entirely for this particular market. Nearly all shucked oysters consumed in eastern Canada are imported from the U.S.A., and this has amounted to 80,000 gallons in some years.

A very small number of British Columbia oysters are used for the half-shell trade but there is no reason why this could not be expanded considerably. Two problems are involved; the first is to make the oyster consumer aware that such a product could be made available and the second is to have it available. This is not

difficult, for it merely involves culling out small-sized oysters which should not be more than 3 inches in length and of good shape, nearly circular in outline and with a deep cup. Indeed, it would be possible to grow nearly perfect half-shell oysters by growing single seed on hard gravel bottom. Raft-culture oysters would also make ideal half-shell oysters because of the very short mantle and attractive colour. The value of half-shell oysters is, of course, considerably more than that of shucked oysters. The value of the Canadian Maritime half-shell oyster is at least five times that of the shucked British Columbia oyster.

POLLUTION

This is probably the most serious of the problems of the shellfish industry today, not only in British Columbia, but throughout the world. In the Canadian Maritime provinces of Nova Scotia, New Brunswick, and Prince Edward Island, there are about 150 shellfish growing areas which are unproductive because of pollution. British Columbia is relatively newly settled, with a small population and it would be expected there would be few, if any, shellfish pollution problems as yet. However, sewage pollution has already closed or limited a significant proportion of oyster producing ground, and industrial pollution is a problem in at least one oystering area.

The two major types of pollution which may affect oysters are industrial and sewage.

Industrial Pollution

As the name implies, this type of pollution emanates largely from industrial wastes. In addition to manufacturing plants, such as pulp mills, oyster grounds may be polluted by washings from ore dumps or by adjacent log booming grounds. A single pollutant may not create significant harm, but often the single source provides a nucleus around which further industrial development takes place and the resultant combination of pollutant sources may be sufficient to cause difficulty.

So far, the main industrial pollutant that is of concern to the oyster industry is waste liquor from pulp mills. The two types of pulp mills are sulphite and sulphate (kraft), the difference being in the process used. In British Columbia, most mills are of the latter type, whose effluent as a whole is considered to be less toxic than that of the sulphite type. In pulp processing large quantities of water and a variety of chemicals are used. After the water has been used, it contains some of these chemicals and it must be discharged somewhere as effluent. The obvious place to discharge waste water is into a body of water such as a river or the sea. Naturally, mills attempt to recover as much as possible of the material in waste water as a matter of economics. However, some chemical waste and some wood fibre are lost in the effluent, which may amount to more than 25 million gallons per day or the equivalent of a small stream. Mill effluent is termed sulphite waste liquor or spent sulphite waste liquor (S.W.L. or S.S.L.), and kraft mill effluent (K.M.E.).

These effluents, when discharged into a body of water, either salt or fresh, have certain characteristics which are able to affect the living organisms there. These characteristics are (1) Toxicity, (2) Oxygen demand, and (3) Particulate material.

Toxicity. The source of toxicity in effluent is some of its chemical constituents. These are generally more toxic in kraft mill effluent than in sulphite effluent, although their total effect is less because of the very low concentration. Two types of effect may result from poisons in the effluent. A direct effect is the immediate toxic action on the oyster, whose tissues may be harmed or whose physiological activities may be affected. Indirect effects influence the environment of the oyster, particularly the food organisms on which it depends.

Oxygen demand. Pulp mill wastes contain quantities of organic materials which, upon decomposition, require large amounts of oxygen. This oxygen requirement is called biochemical oxygen demand (B.O.D.) and can denude surrounding waters of this material upon which most living organisms depend. If the oxygen concentration of water surrounding an organism is lowered sufficiently, the animal will virtually suffocate.

Particulate material. This consists of wood fibres, bark, and chips which are often sufficiently heavy and concentrated to sink and form a mat on the bottom. This prevents circulation of water to the bottom and animals living in or on the bottom will perish. In time, these begin to decompose and an oxygen demand is set up with attendant production of hydrogen sulphide gas. This can often be seen bubbling to the surface near log dumps. This again is an indirect effect. A direct effect of suspended material, such as fibre, results when there is enough present to clog up the gills of filter-feeding organisms such as oysters.

The effect of these factors on oysters in the vicinity of a pulp mill effluent may be felt in several ways:

(1) Mortality
(2) Reduced growth rate
(3) Reduced fatness
(4) Effect on breeding.

However, the measurement of these factors, while not particularly difficult in itself, becomes a complex problem when effects of the effluent have to be separated from the wide variations that occur normally where there is no pollution. Of these, mortality, because it is definite, is the simplest of the factors to measure, but only rarely are effluent concentrations high enough to cause significant mortality in the hardy Pacific oyster.

Through the years, particularly in the United States, a considerable amount of research effort has failed to produce conclusive results regarding the effect of pulp mill pollution or the generally acceptable tolerance limits above or below which there will be or will not be significant effects.

The effects of pollution on oysters pose a particular set of problems. The immobility of the animal makes it necessary for it to accept whatever environmental stresses are placed on it. Its ability to close its valves and the sensitivity of the mantle edge to chemical changes make it possible for the oyster to exclude the external environment for relatively long periods.

Further, the Pacific oyster is an extremely hardy and adaptable animal. The marine environment of oysters, usually an estuarine one, is highly dynamic and the

temperature, salinity, currents, and other water characteristics are continually undergoing large daily, seasonal, and annual changes. Detailed measurement of any one or all of these characteristics relative to its total effect on the oyster is difficult. As the environment is in continual flux, so are the various physiological activities of the oysters in response to these changes, so the total effect of physiological activity is difficult to measure.

An obvious solution to these difficulties appears to lie in the laboratory where the environment can be controlled. Much laboratory work has been done, measuring mortality, growth, and various physiological activities of oysters, sometimes for quite long periods, against various "set" concentrations of mill effluent. Interesting results and correlations of value have been derived, but parallel conditions do not exist in nature and it is virtually impossible to duplicate in the laboratory the dynamic aspect of the natural environment.

It is then necessary to turn to field studies. What is required is some single measurable factor which integrates or combines the various physiological activities of the animal. The condition factor nearly fits this requirement. Most activities of the oyster such as heartbeat, ciliary motion, adductor muscles action, mantle movements, and sensitivity as well as others are directly or indirectly involved in the fattening process since they control the intake of food. Fatness is, together with growth and mortality, a major factor in determining whether or not an oyster-growing operation is profitable. Every grower can observe and appreciate changes in fatness, while this is not so for such a thing as rate of ciliary action. Fatness can also be readily measured by the grower (page 116) and he should do so regularly, particularly if there is the slightest possibility his beds may be affected by industrial pollution, now or in the foreseeable future.

Kraft Pulp Mill Pollution

A kraft pulp mill located at Crofton which began operations in 1958 has created a problem for the oyster industry there. The mill is located directly above the oyster leases and the effluent line passes over the oyster beds to be discharged in Stuart Channel in a depth of 10 fathoms just off the edge of the tidal flat drop-off. In connection with this situation a number of studies of condition factor, growth, and spat survival were made but with inconclusive results. However, to demonstrate the effect of kraft mill effluent on oysters, an experiment was conducted at the Harmac kraft pulp mill near Nanaimo.

Experimental Design

The experiment was designed to test the effect of varying concentrations of kraft mill effluent (K.M.E.) on the condition of oysters. The assumption made was that the concentration of the effluent affecting the oysters would decrease with distance from the outfall discharge.

A randomized block design of three blocks with six replicates at each station (block) was selected. Each replicate group of experimental oysters was held on 3-ft × 3-ft × 6-inch galvanized wire trays coated with neoprene. The trays in this instance were held on floats and suspended 3 feet below the surface. Station F was located on a float about 50 yards from the outfall which is located just above the

high tide level from where it simply pours down the beach. At this station there was very little marine life except for slime algae on the float logs and the barnacle *(Balanus glandula)* on the adjacent rocky shore. Because of the discolouration of the water by the effluent, it was not possible to see the trays at any time.

Station G was located on the end of a standing boom in the log pond about 300 yards from the outfall. The fauna and flora on the float logs at this point were similar to that in the general area. Station H, as a control, was located at the Biological Station in Departure Bay, about 6 miles from Harmac, and where K.M.E. was presumably absent.

The distribution of oysters, obtained from Seal Island near Comox, was randomized in the trays with 150 oysters per tray. Samples of 15 oysters from each tray were used for the condition factor determinations.

The experiment was begun in May 1962 and completed in May 1963 with samples being taken at intervals of about 2 months.

RESULTS

Condition factor. The condition-factor data for this experiment are shown in Tables XXXV, XXXVI, and XXXVII. Statistical analysis (analysis of variance) of the July data shows the treatment effects to be highly significant at the 1% level.

TABLE XXXV. Harmac tray experiment — mean condition factor and corresponding concentration of K.M.E., 1962–1963.

	Station H (Biological Station)		Station F (Harmac Wharf)		Station G (Harmac Pond)	
	C.F.	K.M.E.	C.F.	K.M.E.	C.F.	K.M.E.
May 1962	120	–	120	–	120	–
July 1962	153	–	124	80.2	135	30.4
Sept. 1962	144	–	88	70.3	115	69.5
Nov. 1962	126	–	69	103.2	91	48.2
March 1963	124	–	60	47.5	77	34.6
May 1963	144	–	50	58.6	72	35.8
Mean	135	–	85	72.0	102	40.0

From this time on the order of differences increases making further statistical analysis unnecessary. There is little doubt that the difference in condition between station F with a C.F. of 50 and station H with a C.F. of 144 on May 29, 1963, is due to the effect of K.M.E. The difference between stations F and G is reflected in the difference between the average K.M.E. values. At station G the condition-factor values had become reduced in one year to a level considerably below that which would be acceptable by the market. It would seem that, together with other data from studies at Crofton, this experiment has defined the limits, between which there exists the point, possibly a spectrum, where K.M.E. exerts a significant effect on condition in Pacific oysters. This appears to lie somewhere between concentrations of 10 and 40 parts per million of K.M.E.

The total accumulated mortality for the year was 3% at the float (F), 2% at the pond (G) and 1% at the Biological Station (H).

TABLE XXXVI. Mean[a] condition factor of Pacific oysters on six trays at three stations, Harmac and Departure Bay.

	Station		Tray condition factor						Mean
May 14, 1962			120	120	120	120	120	120	120
July 11, 1962	Station	(H)	153	153	152	159	151	157	153
	Float	(F)	123	132	124	125	119	118	124
	Pond	(G)	127	143	142	132	129	135	135
Sept. 18, 1962	Station	(H)	136	147	149	159	141	134	144
	Float	(F)	84	99	89	88	84	85	88
	Pond	(G)	126	97	127	115	107	115	115
Nov. 22, 1962	Station	(H)	117	130	133	138	117	122	126
	Float	(F)	72	73	71	67	66	64	69
	Pond	(G)	101	91	82	97	96	93	91
March 6, 1963	Station	(H)	125	125	140	125	120	110	124
	Float	(F)	64	60	61	58	lost	55	60
	Pond	(G)	81	80	74	82	72	75	77
May 29, 1963	Station	(H)	149	152	139	147	143	134	144
	Float	(F)	45	51	51	53	lost	51	50
	Pond	(G)	79	71	lost	68	69	lost	72

[a]Mean of 15 oysters per tray.

GROWTH

The effect of K.M.E. on growth is demonstrated in Tables XXXVIII and XXXIX where the data for volume and weight of the whole oyster in water are given. The data, particularly the means for the year, show clearly a difference between the stations, although part of this may be accounted for by the lower water temperature that exists at Harmac than at Departure Bay.

TABLE XXXVII. Analysis of variance. Condition factor of Pacific oysters, Harmac experiment, July 1962.

Variation	df	Sum of squares	Mean square	F
Between blocks	2	2662.0	1331.0	$54.1 (F_{0.05}\ 2+15\ df = 3.68)$
Within blocks	15	368.9	24.6	
Total	17	3030.9		

LOG BOOMING

Sites for log booming leases are most often chosen on tidal flats and frequently occur close to oyster leases. In this case there are two main problems. The first is the deposition on the bottom of bits of bark broken from the logs. Most of it drops directly below the log booms but some pieces are just light enough to float for a time. Some of this inevitably lands on the surrounding area and in time enough collects to cause anaerobic conditions. The bottom becomes foul and hydrogen sulphide is produced causing mortality of any animals, including oysters, living there. The effect on oysters of toxins leached out of log booms is not known. Consequently log booming ground and oyster leases should be kept as far apart as possible.

TABLE XXXVIII. Mean volume of experimental tray oysters, Harmac experiment, 1962–1963.

	Station H (Biological Station)	Station F (Harmac Float)	Station G (Harmac Pond)
May 1962	135.8	135.8	135.8
July 1962	178.6	154.6	158.2
Sept. 1962	192.9	171.1	181.5
Nov. 1962	199.8	158.5	168.5
March 1963	194.7	167.4	172.1
May 1963	190.2	172.6	182.3
Mean	182.0	160.0	166.4

The second problem caused by log booms in close proximity to oyster beds occurs when booms accidentally swing over the oyster beds and in retrieving them, the wash from the propellor of the tugboat washes a deep furrow in the bottom and causes the oysters to pile in windrows on each side of it. The most practical solution in this case is to reach an accommodation with the tugboat or booming ground

TABLE XXXIX. Mean weight in water of experimental tray oysters, Harmac experiment, 1962–1963.

	Station H (Biological Station)	Station F (Harmac Float)	Station G (Harmac Pond)
May 1962	68.1	68.1	68.1
July 1962	82.6	75.6	73.3
Sept. 1962	89.2	85.0	87.3
Nov. 1962	96.6	77.6	79.3
March 1963	101.5	86.1	83.8
May 1963	110.4	79.8	84.7
Mean	92.6	78.7	79.4

operators before trouble occurs. The alternative is to properly post the boundaries of the oyster lease (which should be done in any case) and to obtain the necessary kind of evidence when a situation requiring action occurs.

HEAVY METAL POLLUTION

Shellfish are capable of removing from the water, and accumulating in fairly high concentrations, a number of heavy metals such as zinc and copper. While the animal itself is not harmed by the metal, its consumption by humans can result in illness if the concentration of the metal is high enough. High concentrations of copper in oysters results in a grass-green colour of the meats. This occurs particularly near copper slag piles in salt water such as at Ladysmith or near Britannia Beach in Howe Sound. Light tinges of green colour may also be found in other areas.

Analysis of oysters from near the site of the former copper smelter in Ladysmith Harbour has shown values of 20,000 ppm (parts per million) of copper and 36,000 ppm of zinc. Average values for oysters from other areas were 600 ppm of copper and 10,000 ppm of zinc.

In British Columbia, a solution of an arsenic salt is sometimes used to spray log booms to control shipworm attack in log booming grounds. Oysters will extract and accumulate arsenic from this water but fortunately in quite low concentrations.

Sewage Pollution

Oysters and other shellfish have no disease of their own which they can transmit to man. However, they have frequently been the agents by which such diseases as typhoid fever and infectious hepatitis have been transmitted. Since the oyster is a filter-feeding organism, it collects and concentrates the most minute particles from the water in which it is living and, among these, are bacteria and even viruses. The filtering mechanism has limited selective power, so both harmless and harmful particles are accumulated.

It has been shown that bacteria, once collected by shellfish, are able to survive for long periods even under refrigeration. In addition, under normal storage conditions they are able to multiply within the bodies of shellfish. The usual cooking methods may destroy some bacteria, but some are resistant to heat and among these are some harmful (pathogenic) types. Processing methods for fresh oysters are such that destruction of bacteria is not possible, and, indeed, they are often a means by which shellfish may be further contaminated. Therefore, it is necessary that shellfish be bacteria-free, or nearly so, before they reach the consumer.

Contamination may originate from two main sources. The first is the waters in which oysters are grown and the second is the processing procedure.

Pollution in Growing Waters

Waters where shellfish are grown may be polluted by direct discharge of trunk sewers into the area or by drainage from individual, improperly installed, or improperly functioning septic tanks. Pollution may occur indirectly, by runoff from the land through seepage after rains, or river discharge. Boats discharging raw sewage may be a significant source of pollution.

Sea water always carries a certain content of marine bacteria which is a normal part of the life of the sea. However, from sewage sources are added bacteria which normally inhabit the digestive tract of man and other nonmarine creatures such as seagulls and wild or domesticated animals. Most of these bacteria are not particularly harmful but others, such as the species causing typhoid fever or the virus causing infectious hepatitis, may also be found if there are carriers of these diseases in the area. Since harmful types are generally quite rare, it is too difficult to search for them, so bacteriologists use the commoner, harmless types originating in the colon portion of the digestive tract as indicators. These are normally divided into two main groups which may be identified by bacteriological tests. These are the coliform group and a human faecal coliform type known as *Escherischia coli.*

By appropriate tests, quantitative estimates of the occurrence of these two groups can be made, and the numbers found are assumed to represent the level of sewage contamination. In turn, this is an indication of the possibility of the occurrence of harmful organisms which cause typhoid fever and infectious hepatitis.

Shellfish growing areas are classified in three ways, partly on the basis of a bacteriological study of growing waters and partly on the basis of a sanitary survey, where a study is made of such factors as population density and distribution, sewage disposal systems, river discharge points and flow rates, geology, distribution of docks

and boats, hydrography, etc. The following sections are taken from "The Regulations for the Sanitary Control of the Shellfish Industry in British Columbia."

"1. *Approved areas* — Shellfish may be taken for market purposes from approved areas at any time provided that any rules or regulations of the Department of Fisheries concerning conservation or the regulations concerning relaying are not violated.

"2. *Restricted areas* — Shellfish shall not be taken from any restricted area except under written permission of the Deputy Minister of Health and only under any specific conditions imposed by the Deputy Minister of Health.

"3. *Closed areas* — Shellfish shall not be taken from closed areas, except for the purpose of depletion, and then only under written permission and strict control of the Deputy Minister of Health. Oyster leases shall not be granted in closed areas."

Following the granting of a lease and the classification by the Provincial Department of Health, subsequent periodic checks are made of the bacteriological quality of the growing waters and of the oysters, with observations on the general sanitation of the area. The grower should assist himself and the Health Department by keeping a careful watch on any deleterious sanitary condition that arises in the area, for the time to correct a difficult situation is in its early stages.

As already indicated, closure has been applied to growing areas and a number of leases in British Columbia have been placed in the restricted category. In other parts of the world, such as England and France, where dense populations occur close to shellfish growing areas, pollution has been a problem for many years. They have solved the problem by the use of various methods to purify oysters. Here in British Columbia, due to the recent closures attention is now being given to these methods.

Purification of Shellfish

Shellfish purification (sometimes called "depuration") is based on the knowledge that filter-feeding molluscs remove solid particles from the water around them, digest some, and pass the rest out enmeshed in the mucus of faeces and pseudofaeces. In time, it is even possible for them to remove enough bacteria from a small volume of water to make it pure enough for them to cleanse themselves in it. Naturally, cleansing action is most rapid when pure water is used initially. This system presumes adequate temperature and salinity. It is known, of course, that at low temperatures, most filter feeders do not filter as rapidly as at higher temperatures and this must be kept in mind in purification procedures, as the rate of purification will normally change with temperature.

Pure water for purification may be obtained from nonpolluted sources or slightly polluted water may be purified by treatment with small amounts of chlorine as is done in many cities with drinking water, or by treatment with ultraviolet light, which can destroy bacteria.

Chlorine has been used for many years, with apparent success, in England and France. Recently, however, investigators in the United States have shown that chlorine has an inhibiting effect on the feeding rate of oysters and, consequently,

they do not advocate it for shellfish purification. Ultraviolet light treatment, on the other hand, does not have such a deleterious effect and, since proper dosage can destroy over 99% of the bacteria, this is the treatment advocated.

The "United States Public Health Service Manual of Recommended Practices for the Sanitary Control of the Shellfish Industry" stipulates that water used for the purification of shellfish, if treated, should meet Public Health Service drinking water standards. To meet this standard the ultraviolet treatment apparatus would need to be of much greater killing power than those now in use in general.

Shellfish Purification Procedures

1. Restoration of polluted areas

Restoration of polluted waters to the former pure state is the most positive and, in the long run, possibly the most economical approach to shellfish purification. Realistically, this will not always be possible, but even a reduction in the level of pollution would be desirable. Also, the cost of restoration should not be charged entirely to shellfish purification, for there is also the aesthetic aspect, relative to the use of these waters by the public.

2. Relaying

Fortunately, in British Columbia, there are still many areas in close proximity to oyster beds now under closure because of sewage contamination, which are still free of pollution. Such areas could be used for relaying oysters from polluted beds for purification. In some spots, natural bottom would be suitable for relaying; in others, tanks or embayments may have to be used. It may also be possible to transport and hold oysters for purification in the same container which could be held either on the bottom or suspended from a raft. Such relaying sites might be governmental reserves set aside for the specific purpose.

3. Artificial purification

Artificial methods of shellfish purification are used extensively in other parts of the world, particularly in Europe. So far there has been limited use of the method in North America and this stems partly from the feeling that there is barely enough technical knowledge and partly from economic difficulties.

Apart from the capital cost of an artificial purification plant, the high level of bacteriological control necessary cannot be provided by the small operator. In British Columbia the only feasible approach to artificial purification would be a large central plant operated on a cooperative basis.

At the present time, the several suggested methods of relaying appear to hold more promise than the artificial methods described below.

Chlorination System

The classical method of cleansing bacteriologically polluted shellfish was that developed at Conway, Wales, where chlorine-treated water is provided for shellfish in storage tanks.

The essential requirements of a purification station are

(i) A pump and necessary lines to a supply of sea water.
(ii) A storage reservoir.
(iii) A chlorinating tank.
(iv) One or more shallow treatment tanks, fitted with wooden grids which can be emptied at all stages of the tide. For a daily output, two such tanks are essential. One cwt (112 pounds) of mussels requires about 16 square feet of floor space.
(v) A supply of fresh water or sea water at high pressure for hosing.

The successive steps in the purification routine are

(a) The shellfish, spread about two deep on wooden grids, are thoroughly hosed with a strong jet of water to remove external mud from the shells. This mud is then sluiced away through appropriate channels and valves.
(b) The tank is filled with purified seawater in which the shellfish remain overnight and the accumulated faeces and pseudofaeces are flushed out after the tank is drained.
(c) The tank is refilled for the second overnight bath.
(d) On the third morning (48 hours) the tank is again drained and flushed.
(e) The shellfish are then left covered for one hour in sea water freshly chlorinated with 3 ppm chlorine, in which they remain closed, to sterilize the outside of the shells.

British Ultraviolet System

While chlorine may be satisfactory where large volumes of shellfish are involved, British authorities believe the use of ultraviolet radiation has made possible the development of purification plants which are easy to run and suitable for the purposes of individual oyster producers.

Basically, the purification plant comprises one or more tanks of sea water in which oysters are placed on trays. Water is pumped from one end of the tank(s), sterilized under an ultraviolet lamp, allowed to fall a distance of 2 feet, during which it is reaerated, and finally returned by jets into the other end of the purification tank(s).

The British have developed two basic units: one will give a maximum daily output equivalent to about 20 gallons and the other an output of about 50 gallons of Pacific oysters. The larger production unit has two tanks each measuring 20 feet long by 5 feet wide with a water depth of 20 inches, thus containing approximately 1000 gallons. The choice of construction material is unimportant but undoubtedly coated cement would be best.

A cast iron or rubber circulating pump of sufficient size to circulate half the total volume of water in one hour is required. Two 30-watt ultraviolet low-pressure mercury vapour lamps with an 18-inch diameter semicircular reflector are used to purify the water. Water heaters are required to raise the water temperature during cold weather, in order to induce the shellfish to pump actively. The aerator tower is a simple box about 3 feet high and 1 foot across with a delivery pipe set in or near the bottom.

The operation schedule of a two-tank unit is as follows, when European flat oysters or Portuguese oysters are purified.

Day 1

(a) Tank filled with water and clean oysters at a density of about 50 per square foot.

(b) All water is then circulated and sterilized for 24 hours.

Day 2

(a) A second group of oysters is placed in the other tank.

(b) All the water is circulated and resterilized for 8 hours.

Day 3

(a) The first group of cleansed oysters is removed from the first tank (after a minimum of 36 hours of cleansing), hosed with fresh water to remove mud, etc., and is then ready for shipping or processing.

(b) A third group of oysters is placed in the vacant tank.

(c) The water is circulated and resterilized for 8 hours.

Day 4

(a) The second group of cleansed oysters is removed from the tank (after at least 36 hours) and is ready for shipping or processing.

(b) A fourth group of oysters is placed in the empty tank.

(c) The water is circulated and resterilized for 8 hours.

Water is changed in the tanks once per week, usually at the weekend, so the production schedule is not interrupted.

Total plant cost for a 50-gallons-of-oysters-per-day unit was about $5000 in 1961 in Great Britain and the present Canadian cost would be between $8000 and $10,000.

Purdy Ultraviolet System

As indicated, the "U.S. Public Health Service Manual of Recommended Practice for the Sanitary Control of the Shellfish Industry" requires that treated water for the purification of shellfish should meet the U.S. Public Health Service drinking water standards. To meet this requirement the treatment would have to be more efficient than that in general use.

The U.S. Public Health Shellfish Sanitation Laboratory at Purdy, Washington, has developed an ultraviolet water treatment unit that is capable of destroying between 99.94 and 99.97% of the coliform content of raw water that contains coliform mean probable numbers (MPN's) of 280–600 with a water flow of 39.6 gallons per minute. The unit consists of a trough with a single initial baffle under which the water flows, followed by six more troughs in which the water flows over a baffle and in which the depth of water is about one inch. The water is sterilized by a covering unit of a reflector and thirteen 30-watt germicidal lamps.

Experiments with Pacific oysters showed that in winter it required 3 days to clear 97.5% of the coliforms and in summer only 8 hours when no water temperature adjustment was made. During summer it required only 1 day to reduce the coliform content 99% (from 3400 MPN/100 grams to 24 MPN/100 grams).

PROCESSING AND POLLUTION

In the shucking and packing process there occur many opportunities for the contamination of oysters and, to prevent this, the Department of Health in "The Regulations for the Sanitary Control of the Shellfish Industry in British Columbia" has drawn up a series of regulations governing these operations. Oysters may be contaminated in processing by unclean hands, gloves, utensils, and tables. Basically, the two main problems in maintaining a high level of sanitation in processing plants are the health of the people handling the oysters and good housekeeping. If these are watched carefully and the shucked oysters refrigerated properly, there should be no problems.

PARALYTIC SHELLFISH POISON

During Captain George Vancouver's voyage of discovery in British Columbia waters in 1793 one of his men was reported to have died and several others became ill after eating mussels at what is now known as Poison Cove in Matheson Channel near Butedale (Fig. 98). In 1942 several Indians in Barkley Sound on the west coast of Vancouver Island died as a result of eating clams and mussels. These were local incidents in a long record of illness or death after eating molluscan shellfish on the Pacific coast of North America, from Alaska to California. However, shellfish poisoning is also known from other parts of the world.

As a result of studies in California, it became known that paralytic shellfish poisoning, as it was called because of the symptoms, was caused by *Gonyaulax catenella,* a microscopic dinoflagellate plankton organism which produces a virulent poison in its body. When filter feeders, such as clams and oysters, feed on *Gonyaulax,* the toxin from it is released in the digestive process, and accumulated and stored in the body of the shellfish where the poison apparently causes no harm.

It was also discovered that about the only means by which the poison could be detected in shellfish was by its reaction on mammals such as mice. Consequently, a bioassay technique was devised, whereby the poison is extracted from shellfish with a solution of weak acid. This solution is injected into a standard type laboratory mouse. Knowledge of the dosage and time required to kill mice made possible a quantitative determination of the amount of paralytic poison in the shellfish. For the sake of accuracy, several mice are used. Toxicity is measured in terms of the mouse unit, which is that amount of shellfish poison which, when injected into the peritoneal cavity of a 20-gram mouse, will cause death in 15 minutes. Another more appropriate scale is used whereby mouse units are converted to micrograms of toxin per 100 grams of shellfish meat. For British Columbia, 0.22 micrograms of purified toxin is equivalent to 1 mouse unit.

About 200–600 micrograms of poison may produce typical symptoms in susceptible persons, and a death has been attributed to an intake of about 480 micrograms of the poison. There is apparently wide variability in individual susceptibility to the poison, for a dose of 6000 mouse units (1320 micrograms) has caused

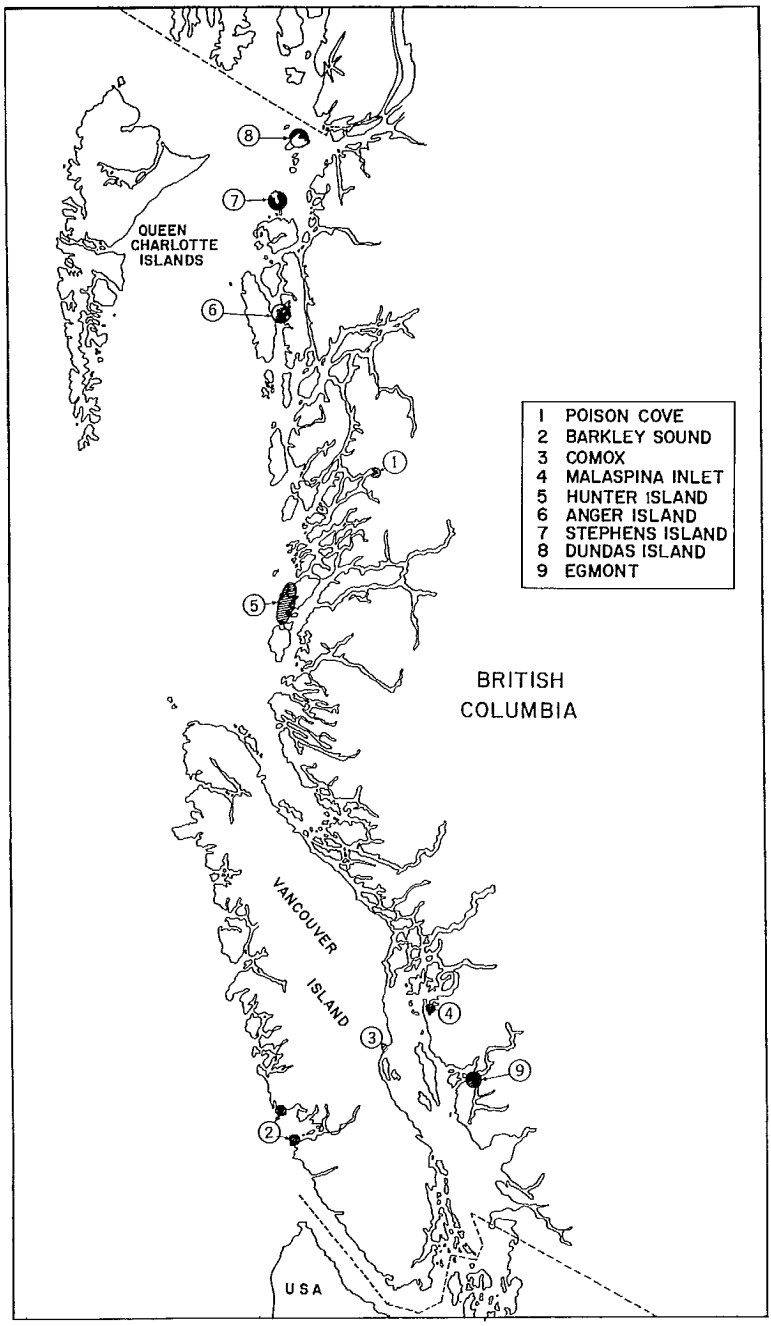


FIG. 98. Map showing areas of recent serious outbreaks of paralytic shellfish poisoning.

serious illness in a child, while one adult is recorded as having taken 10,000 mouse units (2200 micrograms) with no apparent symptoms.

Therefore, a quarantine level has been set which indicates when shellfish producing areas should be closed to the taking of affected species. This level has been set at 80 micrograms per 100 grams of meat and is equivalent to 500 mouse units. When an area shows 80 micrograms or more in several successive samples, it is closed to the taking of shellfish.

In California, and in eastern Canada, paralytic shellfish poisoning occurs mainly during the summer, whereas some species of shellfish may be toxic at any time of the year in British Columbia and Alaska. However, the initial toxification in these areas also occurs during the summer months.

A more recent occurrence of shellfish poisoning in British Columbia since 1942 occurred in October of 1957 when a number of persons became ill as a result of eating shellfish in the Courtenay area of the east coast of Vancouver Island. This was the first time that oysters were involved in a significant manner in paralytic shellfish poisoning. The next known outbreak occurred in mid-June of 1963 when high toxicity levels in butter clams were found near Namu on the central British Columbia coast. Subsequent testing showed toxic clams to occur along the whole coast between Cape Caution and the Alaskan border, including the Queen Charlotte Islands. The closure applied at that time is still in effect (1969); and, as a result, commercial production of butter clams has been seriously curtailed.

On June 1, 1965, one death occurred and four other persons became ill from eating cockles taken in a small bay in Malaspina Inlet which lies in the northeast corner of the Strait of Georgia. Several other species of shellfish including clams, mussels, and oysters were found to be quite toxic. Subsequent testing showed that all species save butter clams had lost most of the poison within 6 weeks of the peak toxicity. The causative organism in this case was found to be *Gonyaulax acatenella* (Fig. 99) rather than *Gonyaulax catenella,* the causative species in California. Oysters and mussels may lose toxicity in a few weeks and this is very rapid in comparison with butter clams, which retain toxicity very much longer, up to a year or more.

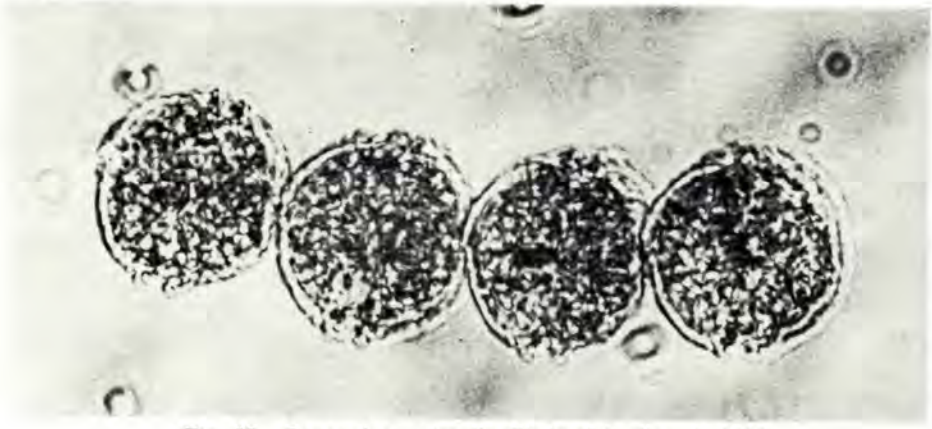


FIG. 99 *Gonyaulax acatenella.* Chain of 4 cells. × 1000.

Shellfish along the British Columbia coast are under constant surveillance for shellfish toxicity by means of sampling programs between April and November. Since the development of paralytic shellfish poison is often associated with the rapid multiplication of the causative organism into numbers sufficient to colour the water reddish or brown, such occurrences are often taken as a sign of imminent toxicity. However, there are many types of organisms, nearly all nontoxic, which can discolour sea water.

PREDATORS AND PESTS

British Columbia is singularly fortunate in having relatively few oyster predators and pests in comparison with most other oyster growing areas of the world. Nevertheless, there are several and growers must know how to recognize and to deal with them. All of them are invertebrates, and range from the one-celled Protozoa, one of which causes paralytic shellfish poisoning, to quite highly developed forms like the starfish.

Protozoa

Protozoa are one-celled animals and one of these was discussed in connection with paralytic shellfish poisoning.

There are a number of nontoxic Protozoa which can discolour sea water when they are very abundant. Oysters can feed on these and when they do the gills may become slightly pink or red and when the oyster is opened and pressure is applied to it, the red stomach contents run out of the mouth and the oyster is said to "bleed." Oysters in this condition are quite edible but not very attractive, particularly when the liquid in the container becomes pink. In addition, "bleeding" oysters do not keep well even under refrigeration, so there is a risk of premature spoilage. Growers find it to their advantage to suspend operations during periods when red water occurs, for it usually only takes 2 or 3 days for the situation to clear up.

Nevertheless, when coloured water or "bleeding" oysters occur, a check with the authorities should be made regarding the possibility of the presence of paralytic shellfish poison.

Boring Sponge

In Atlantic coast oyster growing areas, the boring sponge *(Cliona celata)* is quite a serious pest, but in British Columbia it can hardly merit that description, although it does occur here.

Boring sponges attack molluscan shells, and can riddle a shell to create a honeycomb effect to such an extent the shell becomes very weak and can easily be broken; shucking is then difficult. Also, the burrows may penetrate the nacreous interior lining of the shell forcing the oyster to expend energy in producing shell to keep these perforations covered.

The yellow-coloured sponge is readily seen in the circular holes, about $\frac{1}{16}$ inch in diameter, that perforate the surface of the shell (Fig. 100).

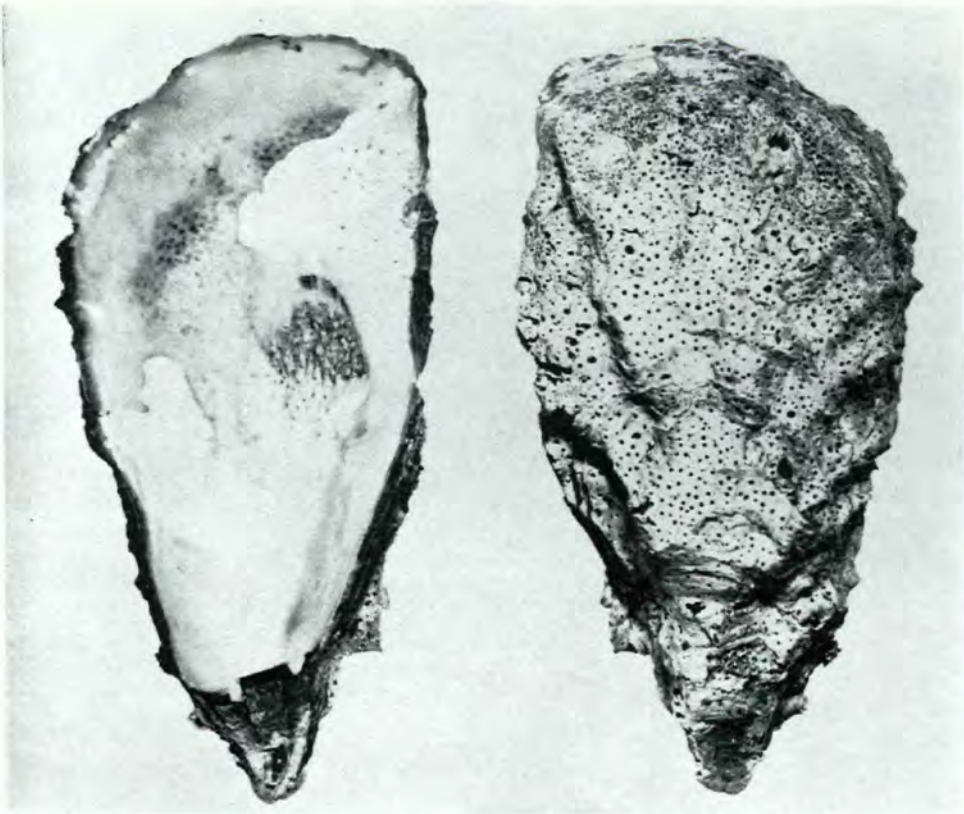


FIG. 100. Oyster shell pitted with burrows of the boring sponge *(Cliona)*. × 0.75.

As a rule, the boring sponge attacks only very old shells (10 years or older) in British Columbia, and this applies to both clams and oysters. In fact, it is difficult to find a living oyster that has been attacked by the sponge, as it is usually found in dead shells at very low tide levels. However, the oyster grower should be aware of the organism and the damage it can do.

BORING SEA WORM

Another fairly serious pest in some of the oyster growing areas in other parts of the world does occur in British Columbia but is not a problem of consequence. This is the sea worm (polychaete) of which several species occur here but *Polydora ciliata* (Fig. 101) is the only one normally associated with oysters. These worms have free-swimming larvae which settle on the outside surface of oysters and make shallow burrows near the edge of the valves, where they are readily visible. Apparently, they can make a mud burrow or can drill into the oyster shell itself and form a "U"-shaped burrow. Sometimes they may perforate the inner shell and the oyster then has to lay down a protective new shell.

FIG. 101. Burrows of the boring worm *(Polydora)*. ×2.

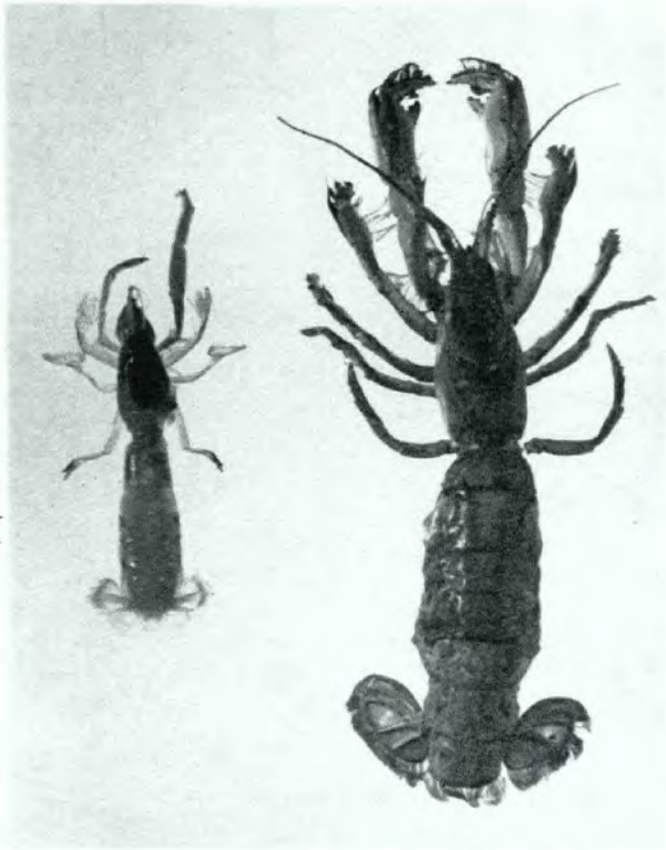


FIG. 102. Burrowing shrimps: *Callianassa californiensis* — left; *Upogebia pugettensis* — right. × 1.

BURROWING SHRIMPS

The mud shrimp *(Upogebia pugettensis)* and the ghost shrimp *(Callianassa californiensis)* (Fig. 102), are two species of crustaceans that can cause serious harm to oyster ground by making it too soft for oyster culture. *Upogebia* is generally grey-green with two clawed legs which are fairly small and equal in size. *Callianassa* is nearly transparent and the reproductive organs are coral-coloured. The two clawed legs are unequal in size.

Both species dig a "U"-shaped burrow with two openings, about ½ inch in diameter, at the surface of the bed and these are often indicated by mounds of sand. The burrows are lined with an almost impermeable lining of compacted mud so that when the tide drops the burrows remain filled with water; in many areas in some years the burrows are so numerous that the ground is virtually a quagmire at low tide.

These animals pose a serious problem to native oyster culture, where dikes are required. Shrimp burrows with an opening on either side of the dike wall form perfect siphons and at low tide the water drains out of the dike. It is therefore necessary to lay down, in the dike, under the surface layer of gravel, a floor of plywood or plastic to prevent the shrimps from burrowing.

The very warm summer of 1958 caused a burrowing shrimp "population explosion" and considerable areas were rendered unsuitable for oyster culture. Populations subsequently began to diminish slowly. Control by plowing and rolling was found to be fairly effective.

Parasitic Copepod

In the list of unwelcome introductions with oysters from Japan is the parasitic copepod *Mytilicola orientalis* (Fig. 74). This is a crustacean, distantly related to crabs and shrimps. It is a small bright red organism with the maximum length of the female not much more than ⅜ inch, and of the male ¼ inch. It occurs in the small intestine of various species of molluscs, usually near the anal opening, where the copepod holds its position by means of special hooks. There may be up to five or six *Mytilicola* in a single mollusc. Egg capsules may be found on females at any time during the year but they are most abundant during summer. The exact means of infection is not clear but it is certain that the mollusc is infected during the larval stage of the copepod.

Mytilicola has been found in British Columbia, mainly in the bay mussel *(Mytilus edulis)* but also in Pacific and native oysters. In Europe, it has caused significant damage through both mortality and reduced condition in edible mussels. So far there is no evidence that *Mytilicola* either causes mortality or has a serious effect on the condition of oysters, but the grower should be aware of the fact that it is a potential menace.

For Pacific oysters in British Columbia, the highest recorded infection rate is 20% and, for the bay mussel, 50%. There is a high correlation between areas where *Mytilicola* occurs and where Japanese oyster seed has been planted.

Crabs

Three species of crabs can cause damage by opening and feeding on oysters and oyster seed by cracking the shell edges with their powerful claws. The distinguishing features of these crabs are shown in Table XL and Fig. 103.

As a general rule crabs have not been a serious problem to the British Columbia industry, although few beds escape some damage. They can be, and on occasion have been, destructive to young seed. The solution is to keep the seed on relatively high

TABLE XL. Identification characteristics of oyster predator crabs.

Cancer magister (Dungeness Crab)	*Cancer productus* (Rock Crab)	*Cancer gracilis* (Graceful Crab)
shell with fine granulations	shell without fine granulations	shell without fine granulations
large (to 7 inches)	medium (to 6 inches)	small (to 3 inches)
–	–	shell convex
red brown	dark red	gray or tan; red spots
last tooth often on shell edge largest	5 equal teeth between eyes	–

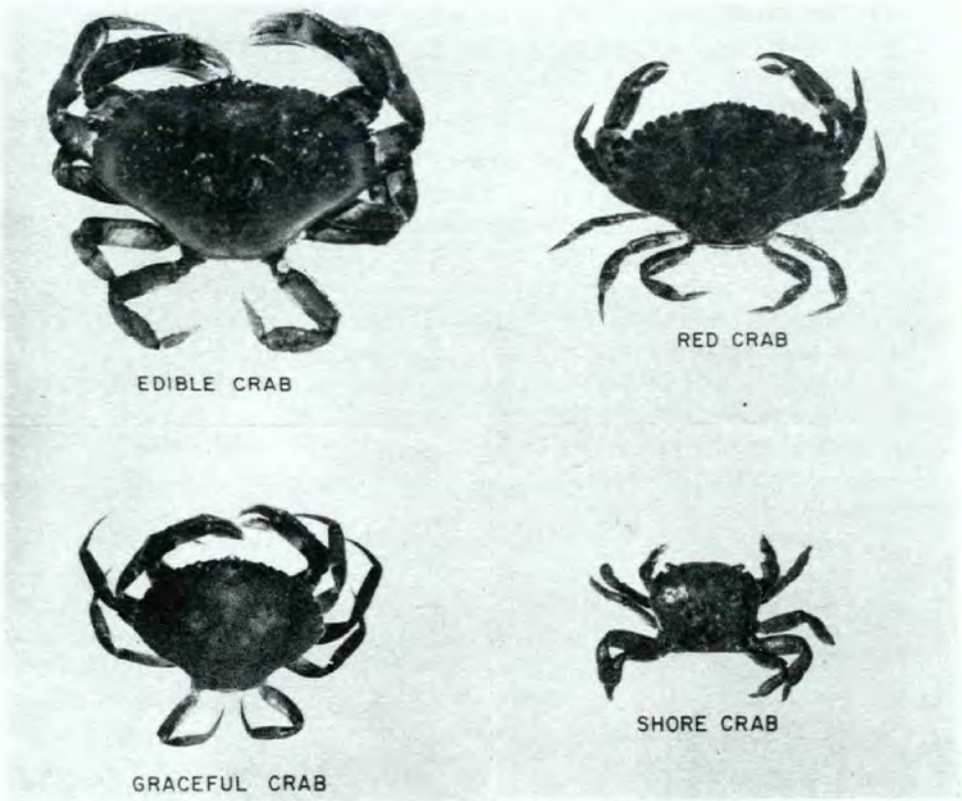


FIG. 103. Four species of crab commonly found on oyster beds. Edible crab or Dungeness crab *(Cancer magister)*, × 0.25; red or rock crab *(Cancer productus)*, × 0.25; graceful crab *(Cancer gracilis)*, × 0.3; shore crab of which there are two species *(Hemigrapsus)*, × 0.5.

ground if there is any possibility of danger from crabs. This applies specifically to the graceful crab which can be quite abundant. The only other solution to the crab problem is a trapping program. Very simple traps can be constructed quite easily and cheaply from laths.

Oyster Drills

Oyster drills are among the most damaging of the pests found on oyster beds. They are univalve snails which have, in their mouths, an extensible, toothed, rasping apparatus with which they drill in a clam or oyster shell a hole through which they can tear away the meat (Fig. 104). The most frequently observed drill hole is the

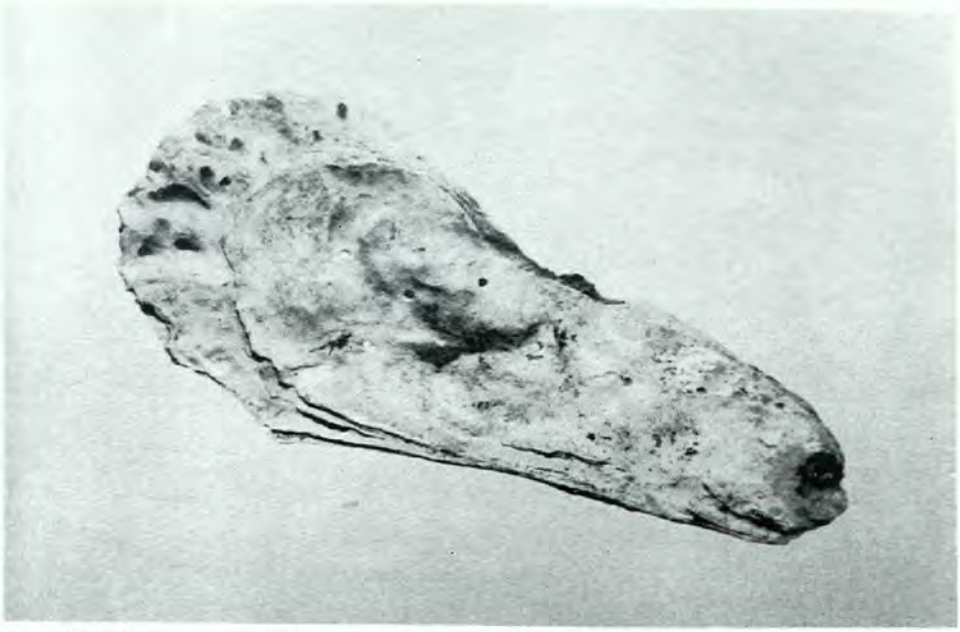


Fig. 104. Pacific oyster shell showing holes drilled by the Japanese oyster drill *(O. japonica)*. × 0.8.

countersunk circular hole often found on dead clam shells, and this is caused by the large, coiled moonsnail. Oyster drills are much smaller and, as far as is known, only two species dangerous to oysters occur in British Columbia. Both of these were introduced: *Ocenebra japonica,* the Japanese drill, from Japan, and *Urosalpinx cinerea,* the Eastern drill, from the Atlantic coast. The latter species occurs only in Boundary Bay, and its abundance has dropped markedly since the cessation of imports of eastern oysters; it is no longer of consequence as a menace to oysters. There is also what is called the native oyster drill *(Thais lamellosa)* which, however, attacks barnacles, clams, and mussels rather than oysters (Fig. 105).

Of considerable concern is the Japanese drill (Fig. 73), which is known to occur in Boundary Bay, Ladysmith Harbour, Crofton, Thetis Island, and Comox. Specimens have been found at Sooke and at Henry Bay but significant populations do not appear to have developed in these areas.

The Japanese drill breeds by copulation, after which the female deposits about 1500 eggs in about 25 yellow capsules, each about ¼ inch long, which look like grains of oats (Fig. 73 and 105). Capsules are deposited from April to November in Ladysmith Harbour and nearly always on the underside of shell clusters or debris.

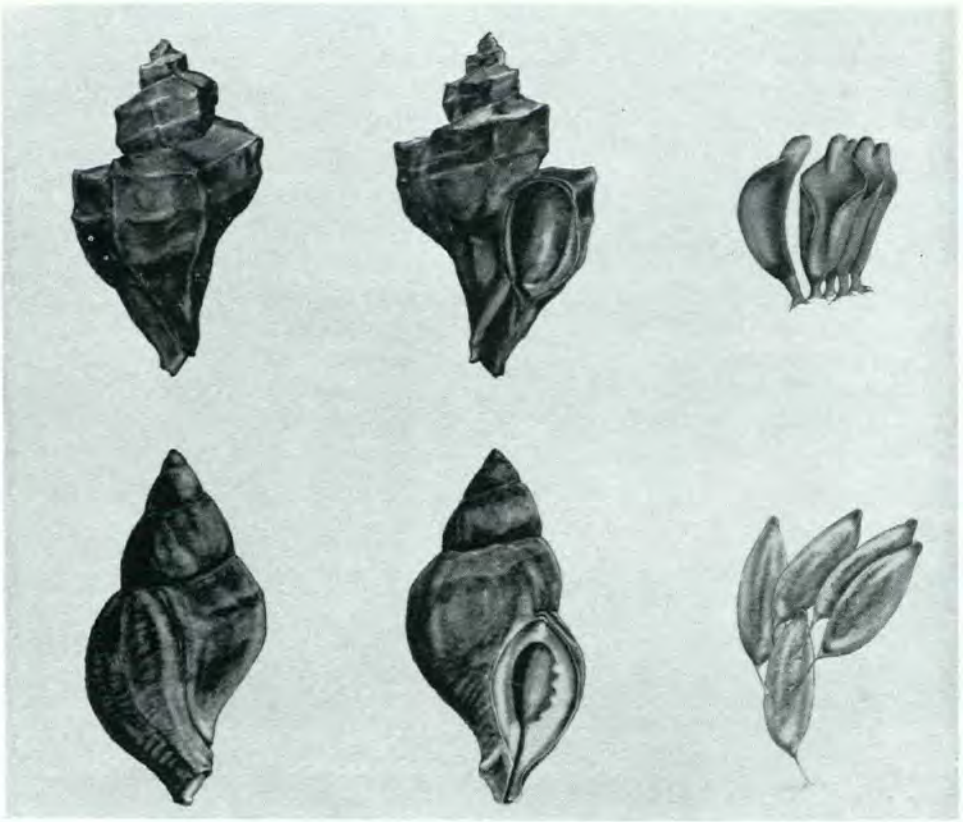


FIG. 105. Comparison of the shells (× 1.3) and egg capsules (× 3.6) of the Japanese oyster drill (top) with those of the native drill (bottom).

Often, several females will choose the same spot, so quite large clusters of capsules may be found. Development in the capsules requires approximately 2 months, after which the young drills crawl out through an aperture at the top of the capsule. Only three or four drills are hatched from each capsule, for the great majority of the eggs are nurse eggs which serve as food for the embryos that are able to develop. After crawling out of the capsule, the young drill, less than $\frac{1}{16}$ inch long, is on its own and, very likely, it subsists on plant material until large enough to drill shells. Fortunately there is no pelagic or free-swimming stage so it cannot be dispersed by water currents as is the case with oyster larvae. Little is known of its growth rate, but it probably reaches its maximum length of about 1½ inches in 3 or 4 years. It requires about 2 weeks for an adult *Ocenebra* to drill through an oyster 2 inches in length while only a day or so is required for seed oysters up to an inch in diameter.

As described previously (page 84), considerable effort is expended to ensure that Japanese seed imported at the present time is drill free. Unfortunately a large part of the damage was done before the present control system was instituted, but, even with this, there will always be the risk of accidentally introducing drills into presently drill-free areas as long as Japanese seed is imported. Also, there is the

danger of drill-free beds being infested through interlease movement of oysters within the province, by the movement of either the oysters themselves or the oystering equipment. In the State of Washington, permits are required to move oysters or oystering equipment from one area to another, and certain grounds are designated as drill areas. A similar control system has recently been instituted in British Columbia. For many years, the organization and operation of the industry did not warrant such control, for there was virtually no interbed movement of oysters and with the industry under close biological scrutiny, any potentially dangerous situation with respect to drills was placed under safeguards. For instance, in Ladysmith Harbour, where the drill had become quite abundant by 1935, its distribution remained relatively unchanged for the next 20 years.

Once an area has become drill infested, it is difficult to clean it up entirely. It is possible, by properly working the ground and by manipulating planting, to hold the drills in sufficiently close check so that their damage is kept to a minimum. For instance, drills have difficulty in attacking oysters over 2 years of age because of their relatively thick shells; so if drill-infested ground is to be used, only large oysters should be planted. Seed oysters should not be planted on drill-infested ground.

When oysters from drill-infested ground are being harvested, every effort should be made to clean off the ground as completely as possible and, if at all feasible, the ground should be raked and all debris taken ashore. Drills can also be buried *in situ* by pulling heavy drags over the ground.

Although drills do not migrate extensively, two growers working adjacent beds must cooperate in drill control activities, because the work of only one grower will likely be ineffective.

Starfish

Probably the most important oyster predator in British Columbia, other than man himself, is the starfish, sometimes called the seastar. There are about a dozen common shore or shallow-water species in these waters but only about four of these can be classed as serious oyster predators. These are the ochre star *(Pisaster ochraceus),* the pink star *(Pisaster brevispinus),* the mottled star *(Evasterias troschelii),* and the sun star *(Pycnopodia helianthoides),* which are shown in Fig. 106.

They all open the oyster in much the same manner. The initial step by the starfish is to clasp the oyster with its suction-tipped tube feet with which it is able to apply pressure in excess of 10 pounds against the oyster's adductor muscle, which is sometimes torn. However, it is thought that this pressure is not entirely necessary for the starfish has an evertible stomach which can penetrate the narrowest of apertures. Preliminary digestion takes place in this evertible stomach and when the adductor muscle of the oyster is reached the shells gape, allowing the starfish to finish its meal easily. This is a point to be borne in mind for, as a result of this ability, a starfish on the outside of a mesh basket or container can feed on the oysters inside. It requires less than 24 hours for a starfish to devour an oyster.

Opinions are not unanimous as to whether or not starfish are attracted to any extent to molluscs. An attempt to grow oysters in a water depth of about 15 feet below zero tide level, in Departure Bay, failed owing to starfish predation. About 225

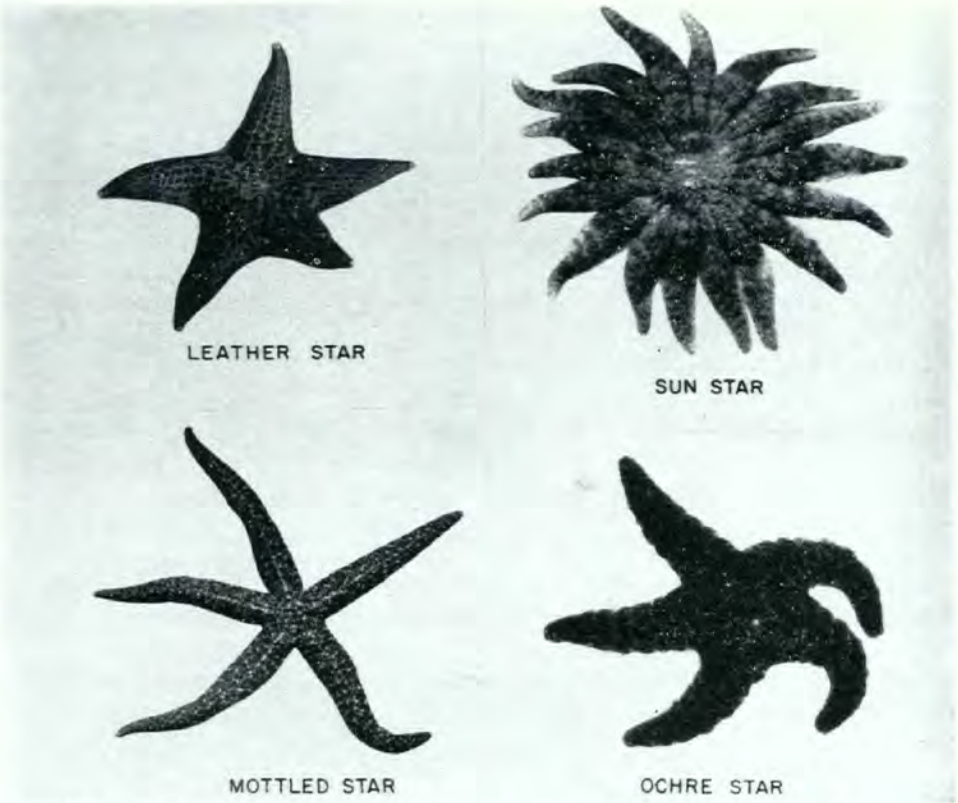


FIG. 106. The four common sea stars found on or near oyster beds. Leather star *(Dermasterias imbricata)* × 0.2; sun star *(Pycnopodia helianthoides)* × 0.1; mottled star *(Evasterias troschellii)* × 0.1; ochre star *(Pisaster ochraceus)* × 0.2.

bushels of 3-inch oysters and 150 strings of 1961 Pendrell Sound seed were planted at this depth on an area about 75 yards by 75 yards on September 1, 1961. About once a week, starfish were cleared from the planting area and from some 10 yards around it by scuba divers. This was done quite regularly for 8 months and during this period, an average of 10 starfish per week were removed. These were mainly *Pycnopodia* followed, in number, by *Evasterias,* and then *Pisaster*. Between September 1, 1961, and January 23, 1962, about 200 starfish weighing 400 pounds were removed from the bed. The diving program had to be suspended during the second 8-month period and examination at the end of that time showed the oysters had suffered a mortality of 70% and the seed practically 100%.

Whether the incursion of starfish into the oyster area was the result of direct stimulation or due to accidentally running into it during random movements is not known, but the practical conclusion is that if there are oysters present, starfish will find them.

Starfish breed in spring and summer in much the same manner as oysters and have free-swimming larvae which allows them to become dispersed, so that after an oyster bed has been cleared of starfish it may be reinfested by larvae, as well as

by adults, from distant concentrations of starfish. Young starfish, up to 2 or 3 inches in diameter, appear to be light-shy and are seldom seen except on the underside of rocks or clusters of oysters. Breaking oyster clusters as soon as possible is an excellent way in which to help in the control of starfish by making living areas unavailable to them.

Growth of the ochre star *(Pisaster ochraceus)* has been studied in Ladysmith Harbour. Starfish set in August had reached a diameter (ray tip to ray tip) of ½ inch by October and by then were already attacking small oyster spat. By the following June, the length of a single arm was nearly 1 inch, and by the end of a year, 1½ inches. In May of the following year, the length of a single ray was 2½ inches, making a total diameter of 5 inches, by which time the starfish were capable of attacking oysters of any size.

The ochre star has been found to travel up to 50 yards in a 24-hour period during the summer, but it cannot move nearly as rapidly as the sun star. There is a general tendency for all these starfish to carry out small migrations for, as a general rule, they are found at lower tide levels in summer than they are during the winter, and this is probably a response to heat and desiccation.

In British Columbia, where oyster culture is intertidal, oysters and starfish can be reached at low tide so that control of this pest is relatively simple. Starfish may be removed from the beds simply by picking them up and carrying them ashore, and make excellent garden fertilizer; or they may be destroyed by applying a teaspoonful of quick lime or carbide to their backs. They are destroyed by the corrosive action of the chemical which does not affect any oysters with which it may come into contact. Mutilation of starfish is of little use in attempting to destroy them, for a whole starfish can be regenerated from a single ray joined to a portion of the central disc. Starfish are often seen with one or more short rays and this is generally an indication of regeneration of lost rays.

Chemical Control of Predators and Pests

In the United States in recent years there has been some study of the use of chemical pesticides in the control of oyster pests and predators. Many chemicals have been screened and some have been found to be efficacious in destroying various pests. Some of these chemicals are quite specific in being able to destroy only certain types of predators and this is important because of the need to protect oysters and other shellfish. Chemicals, mainly organic, have been used to kill oyster drills, crabs or shrimps, and starfish.

So far there has been some, though not widespread, use of such pesticides in oystering areas in the United States. Research is still going on to discover how much of the pesticides can be taken up by the shellfish themselves, for oysters have been shown to accumulate, in about a month, 70,000 times as much of the insecticide DDT as is found in surrounding waters. Also, more study is required on the effect of the pesticides on the whole environment—how they affect plankton and how they affect all of the minute organisms associated with oyster ground. In other words, is it possible that the secondary effects of these poisons may be worse than the effects of the predators?

Often, but of course not always, it is possible to adjust cultural methods to reduce the effects of predators and pests but this requires a very detailed knowledge of the biology and behaviour of these animals. There is little doubt that pesticides will, in the future, have an important role in the control of at least some shellfish predators, but with the present state of knowledge regarding total effects such as it is, it would be unwise to jeopardize what one already has. The oyster industry is waging a continual battle against pollution so the industry has to be very wary lest it be branded as a polluter itself, by its use of pesticides in marine waters. Another problem in connection with pesticides is their occurrence in shore waters as a result of runoff from farm lands where insecticides or herbicides are used. How significant this is in the area of marine pollution is not known.

DISEASE

Oysters are known to be susceptible to diseases of various sorts but none of these appears to be harmful to man. As yet, little is known about these diseases. While there has been relatively little trouble in British Columbia from oyster diseases, the grower should be aware of the disease problem. Diseases may affect oysters in various ways, the most serious of which is, of course, mortality. This may occur with or without obvious symptoms. An outstanding case of mass mortality in oysters in the past was the devastating destruction of large populations of the flat oyster *(Ostrea edulis)* in Europe, especially England and France, in 1920 and 1921. The cause is still not known, but there are some indications that it was a disease.

Malpeque Disease

Another instance was the disease which struck the Canadian Atlantic oyster in Prince Edward Island in 1915 and has since been known as the "Malpeque disease" from the place name in that province. The symptoms were weakness, and failure to grow and to spawn. A secondary symptom was the occasional appearance of yellow-green pustules on the body. Just before death, the affected oysters may be emaciated or they may be quite fat. All ages are susceptible, and death occurs in late winter, early spring, or in late summer. Fewer than 2% of the stock survive after the 6 years that it takes for the disease to run its course.

Even after many years of study, the cause of the Prince Edward Island mortality is still not known but much information on how to handle the disease has been obtained. For instance, the small number of oysters that survive the disease can form the nucleus of a new disease-resistant population. With proper planning, and the use of the surviving oysters, it required about 20 years for the fishery in Prince Edward Island to recover.

In 1936 there was another outbreak there and, in spite of a quarantine that was imposed on Prince Edward Island oysters, mortalities began to show in New Brunswick in 1954, and now Cape Breton Island is the only oystering area in the Maritimes to remain unaffected. The rehabilitation of the New Brunswick beds was hastened by transplanting 4–5 million disease-resistant oysters from Prince Edward Island to various areas in New Brunswick, and the prospects for the recovery of that fishery are bright.

Shell Disease

Another example of disease is the one which attacked the Dutch oyster industry in the 1930's and 1940's. The inner surfaces of the shell of European flat oysters developed irregular green spots and warts. Oysters with a high level of infection failed to grow and mortalities ensued. Long study finally demonstrated that the cause of the shell disease was a fungus distributed by water currents, the disease being prevalent in old decaying shells of other species of molluscs. By removal of the deposits of old mollusc shells and by bathing the infected oysters in a weak solution of a mercury base disinfectant, it was possible to bring the disease and mortalities under control.

Diseases in Chesapeake Bay

Still more recently, devastating mortalities have occurred in the eastern United States in Delaware and Chesapeake bays, as well as in the Gulf of Mexico. Microscopic details of three types of disease organisms have been described. One is a fungus, *Dermocystidium;* the other two are haplosporidians, *Minchinia nelsoni* and *Minchinia costalis,* better known by the code names "MSX" and "SSO," respectively. Intensive study of both the life cycles and methods to control these diseases is still going on.

Summer Mortalities

In British Columbia there has been little evidence of disease in the Pacific oyster since it was first introduced. Very few mass mortalities have been reported, and these have all occurred in Boundary Bay during summers warmer than usual. Mortalities somewhat similar in nature have been reported from Washington State, and some of them have been serious enough to cause concern, but the cause has not yet been determined.

Foot Disease

In the fall of 1956 an oyster disease occurred in Pender Harbour; 10% of the oyster population, of both Japanese and local origin, was affected. Most of the oysters concerned were about 4 years old, but only those on certain beds were involved, as were oysters transplanted from Drew Harbour on Quadra Island about 50 miles across the Strait of Georgia from Pender Harbour. The symptoms were practically identical to those described for the oyster disease known in France as "maladie du pied," or foot disease, which occurs in both the European flat oyster *(O. edulis)* and the Portuguese oyster *(C. angulata)* and is attributed to a fungus. The adductor muscle scars were partly covered with black proturberances up to half an inch high and nearly an inch in diameter. The thin outer covering of these protuberances was of a chitinous nature. On some shells the base of the abnormality was expanded considerably by a raised portion of nacre covering an extension of the puslike secretion contained within. The secretion contained a heavy bacterial concentration in addition to rather large (10μ) circular bodies which constituted the main portion of the material. There has been no report of a similar occurrence since, although occasionally an oyster may be found with such a growth.

DENMAN DISEASE

In 1960 an outbreak occurred of a disease characterized by deep pustules on the surface of the body and mantle (Fig. 107, 108) and/or by pus-filled sinuses.

FIG. 107. Pacific oyster showing pustules typical of the Denman disease. × 1.

Initially the disease was confined to an area between Henry Bay and a point about 3 miles southward on Denman Island in Baynes Sound (Fig. 1), with the main locus within Henry Bay itself. The mortality from this initial outbreak was estimated to be more than 30%. The disease develops in early spring, usually in April, when water temperatures are about 47 F, and are just beginning to rise from the winter low of about 44 F; it disappears by about mid-July when water temperatures have reached about 64 F. In this area oysters are nearly always in excellent condition and the dead or dying oysters also had a very high condition factor.

Other characteristics of the disease are

(1) Greatest mortality occurs in oysters at the lowest tide level.
(2) Older age groups (more than 2 years old) seem to be affected most.
(3) The localized nature of the outbreak.
(4) Recovery from the disease by about 10% of those infected.
(5) Aquarium tests indicate the disease can be acquired by undiseased oysters from adjacent diseased ones.

During the period of the first outbreak in 1960, the disease was not observed on the opposite shore of Baynes Sound, only a few miles away, and it was not reported from elsewhere in the province. In 1961, much the same pattern as that

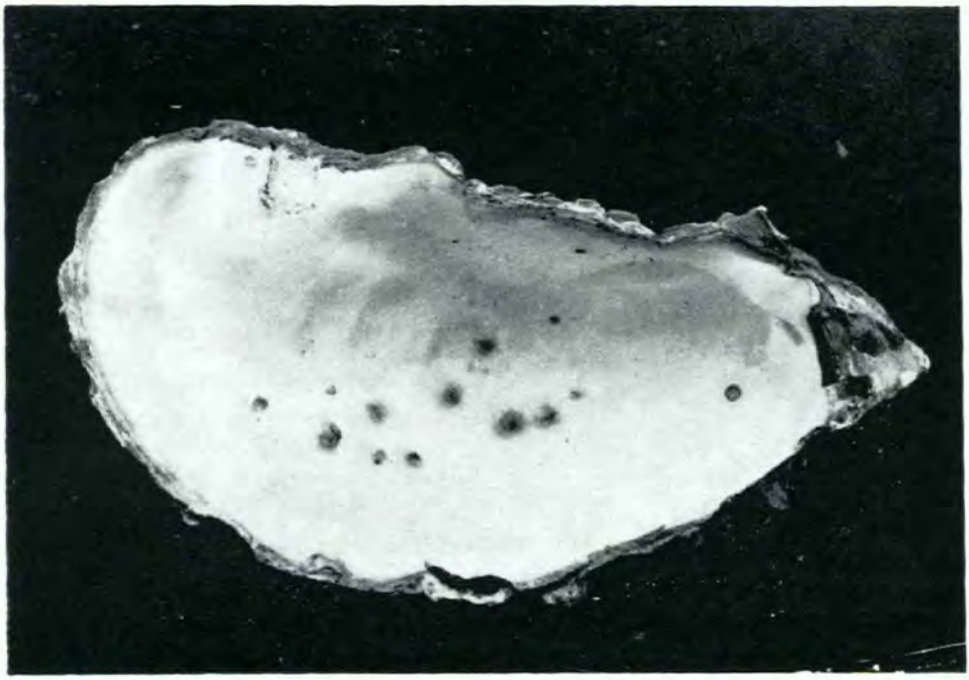


FIG. 108. Interior of a Pacific oyster shell showing the markings caused by pustules of the Denman oyster disease. × 0.7.

shown in 1960 recurred at Henry Bay. However, it was also reported in Ladysmith Harbour where the total average mortality over the whole of one bed was 13%, with 30% at the lowest tide level. The disease was also observed at Crofton where the average mortality reached 16%.

In 1962, the pattern was the same at Henry Bay but the level of infection (10%) and mortality were somewhat reduced. In Ladysmith Harbour, the bed which had been heavily infected in 1961 was only lightly attacked, but this could have been due to the fact that the grower sensibly moved the oysters from a lower to a higher tide level during winter.

In 1963, at Henry Bay, the level of infection of 22% rose slightly over that of 1962 and in 1964 it was still higher with a maximum of 30% infection in mid-March. There were no reports of the disease from other areas in either 1963 or 1964.

So far, the causative organism has not been identified. In many ways it resembles the "Malpeque" disease. It should be pointed out, however, that the occurrence of pustules may not be a primary manifestation of the disease. Pustule formation seems to be a typical reaction of oysters to many forms of stress. It has been learned, though, that oysters may recover from the disease and that, in the following year, they may or may not contract it again. While the cause is unknown, enough has been learned about the cycle of the disease to permit the oyster grower to cope with it, if the disease reaches significant proportions. The fact that the greatest infection occurs at or near the zero tide levels indicates that any oysters at lower tide levels

should be moved to the 5-foot level (Strait of Georgia levels) prior to the period of infection in March and that the low grounds should not be planted before June.

In addition, because there appears to be little mortality in oysters up to 2 years of age (although they may have the disease), it is possible to hold oysters under that age limit at the lowest tide levels.

Growers should keep a careful record of any mortalities out of the ordinary and, if exceptional, they should be reported.

ORGANISMS ASSOCIATED WITH OYSTERS

In addition to the acquisition of a thorough knowledge of the oyster itself, the grower should know something of the other animals and plants that grow on an oyster bed along with, and sometimes on, oysters. These are an important part of the complex environment in which the oyster lives. Some of these organisms affect the oyster directly, others indirectly, but all exercise an influence on its well-being in one way or another. Some are predators such as the starfish or drills, some are parasites such as the red copepod *(Mytilicola),* some are competitors such as the clams, some use the oyster shell as a place of attachment, others as a place of refuge, others as an incubator on which they deposit their eggs.

All oyster beds do not have identical sets of animals and plants, for these vary with the local hydrographic conditions and with the bottom consistency of the oyster bed. Many of the organisms on an oyster bed are so small as to be invisible or inconspicuous but what they lack in size they make up for in numbers. Among these are bacteria, one-celled animals of various kinds collectively called Protozoa, attached forms of diatoms and the larval or young forms, still microscopic in size, of many larger animals.

Of the diatoms, one in particular becomes so abundant in late winter and early spring that, where currents are not too strong, it covers intertidal rocks and parts of oyster beds and oysters with a brown mat of slime. This is the chain diatom, *Melosira.* To what extent oysters may feed on this is not known, but it harbours many species of Protozoa which are likely to be suitable oyster food.

Sponges

There are several species of sponge that occur on oyster beds and, quite often, on the oysters themselves. These may be yellow, purple, or green, generally encrusted, with slightly raised water pores. They may compete to a limited extent with the oyster for food but they seldom occur in sufficient abundance to require corrective measures. In addition to the encrusting type of sponge there is another *(Cliona)* which bores into the shells of molluscs but this is dealt with in the section on pests.

Coelenterates

This is the group of animals that includes the jellyfish, hydroids, anemones, and corals. Only the hydroids and anemones are found associated with oysters. The hydroids which have the appearance of a small bush occur mainly on raft culture oysters. Of the anemones, the very large brown or white *Metridium,* found mainly on piling, occurs on oyster beds only infrequently. More abundant is the small

Diadumene, about ½ inch in diameter, green with vertical gold stripes. This is found on the oyster shells, particularly in areas where Japanese seed has been planted, for it is an Asiatic species. On some oyster beds such as those on the north end of Denman Island, occurs a burrowing anemone called *Pachyceranthius.* None of the anemones interferes with the well-being of the oyster.

Worms

There are several worm groups that live on oyster beds and these are flatworms, roundworms, and ribbon worms.

The flatworms are also called wafer worms or oyster leeches. Those associated with oysters are generally quite small, not more than an inch in length and ½ inch wide, brown, and difficult to see on an oyster shell where they occur only on the underside. They are wafer thin and in movement they appear to slide rather than creep. A Japanese species *(Pseudostylochus ostreophagus)* that has become established in Puget Sound assumes pest proportions there in some years. So far, flatworms have caused no difficulties in the British Columbia oyster industry.

The ribbon worms (nemerteans) are unsegmented, thin, highly extensible, and are usually brightly coloured. They are found among clusters of oysters or mussels where there is a certain amount of mud. Those on oyster beds are purple, green, or chocolate brown with white transverse stripes. They feed mainly on other types of worms and are of no danger to oysters.

The group known as seaworms (polychaetes) are segmented, and many species occur both in and among oysters. One group of them is free-living and is well known because of its usefulness as fish bait. One species, which attains a length of nearly 2 feet, normally lives burrowed in the ground but occasionally emerges from the burrows during the summer spawning season and may be seen swimming at the surface in the evenings.

Another group of seaworms lives in calcareous tubes attached to oyster shells. Some, called *Spirorbis* (Fig. 109), have tiny white coiled shells; the larger sinuous shells up to 2 inches in length contain *Serpula.* Neither of these is dangerous to oysters, but another one, called *Polydora,* lives near the shell edges and can cause harm. This one is described in the section on pests.

There are several others that live in membranous tubes buried in the bottom with just a small portion protruding above the surface of the mud or sand. One of these is *Euclymene zonalis,* which lives in muddy sand and has a tube less than ⅛ inch in diameter. In some years it multiplies in such great numbers that it causes the ground to become soft enough for oysters to sink into it. The only solution to this situation is to plough the ground to destroy the worms or allow it to lie fallow until the worms die off. So far, Boundary Bay is the only area where this worm has caused difficulty.

Crustacea

Many species of crustaceans, a group which includes crabs, shrimps, and sand fleas, are found on oyster grounds. The three species of crabs which are able to do damage to oysters are described on page 158.

FIG. 109. Coil worm *(Spirorbis)* on oyster shell and oyster spat. × 1.

There are two species of *Hemigrapsus* which are very abundant in the intertidal zone. These shore crabs seldom exceed a shell diameter of 1½ inches; one species, smaller than the other, is grey or green, while the larger one is generally red-brown. They are most often found under stones or clusters of oysters. Another rather hairy yellow crab *(Telmessus)* is not nearly as abundant as the shore crabs, nor is the spider crab *(Pugettia)*. These crabs are all scavengers and do no harm to oysters and in many ways act as garbage disposal units on the oyster bed.

The barnacle is also a crustacean, although it does not look it except in the larval stages. The common shore barnacles *(Balanus glandula* and *Chthamalus dalli)* have very definite zones where they settle. If oysters are held below this zone there will be little barnacle settlement on them but if placed in the barnacle zone, heavy settlement, particularly from the larger *Balanus glandula,* may be expected. This species settles most extensively within a week or 10 days before or after April 1 in most areas of the Strait of Georgia, although there may be some settlement throughout most of the summer. Other than increasing the weight of the oyster, and causing a nuisance to shuckers, barnacles occasion little harm to the oyster industry.

Pill box bugs *(Exosphaeroma),* flattened dorsoventrally, are isopods which are found on the underside of oyster shells in those situations where there is a fair amount of fresh water rather high in the intertidal area. Amphipod sand fleas (flattened laterally) are found in similar locations; neither harms oysters. Two other isopods *(Limnoria lignorum* and *Limnoria tripunctata)* cause no harm to oysters but

they are wood borers and can destroy untreated piling or other wooden structures quite rapidly. These animals, less than ¼ inch in length, are also called gribbles or pinworms, and copper paint or creosote treatment of wood prevents their initial settlement.

Molluscs

Many species of molluscs occur on oyster beds and the more common ones are shown in Fig. 110. Full details on all the clam species that may be found are given in Handbook No. 17 on intertidal bivalves, published by the Provincial Museum at

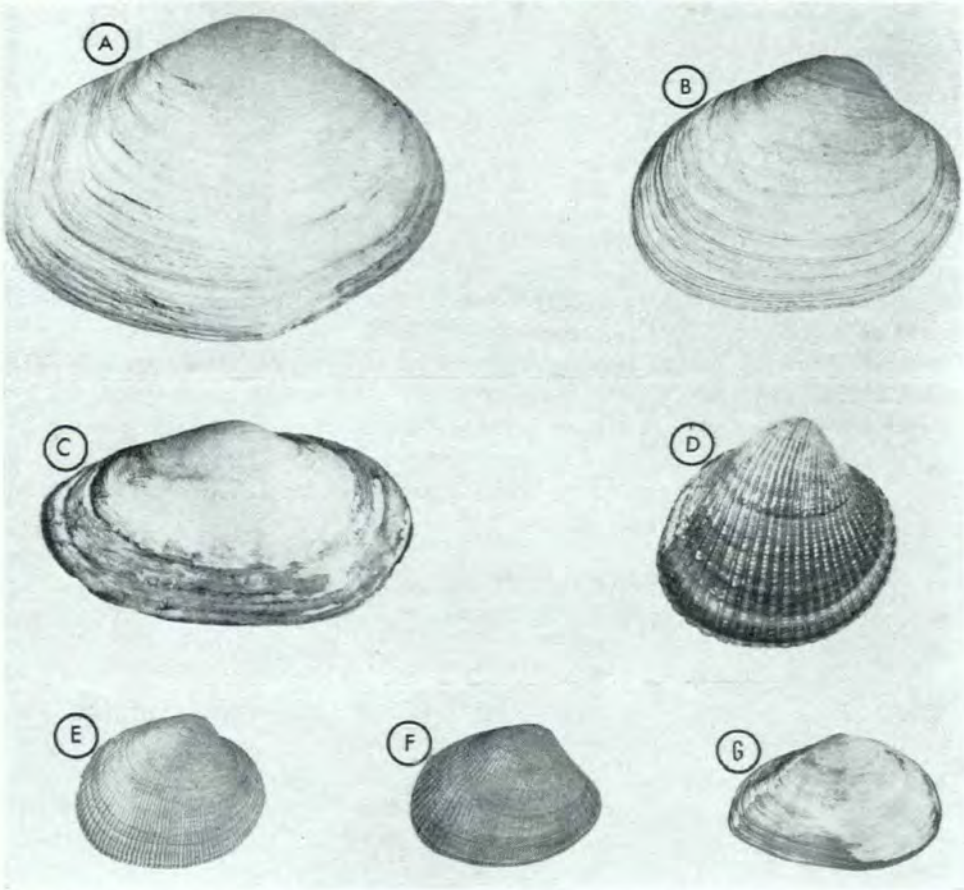


Fig. 110. Common clams found on oyster beds: (a) horse, (b) butter, (c) softshell, (d) cockle, (e) littleneck, (f) manila, (g) sand.

Victoria. The clams and mussels are likely to compete with oysters for food to a limited extent but on most oyster beds they are not very abundant. Mussels may become pests on certain beds particularly at the higher tide levels. In addition to the clams, there are several species of snails, two of which are oyster predators. These drills are described in detail elsewhere. A very common snail on most oyster

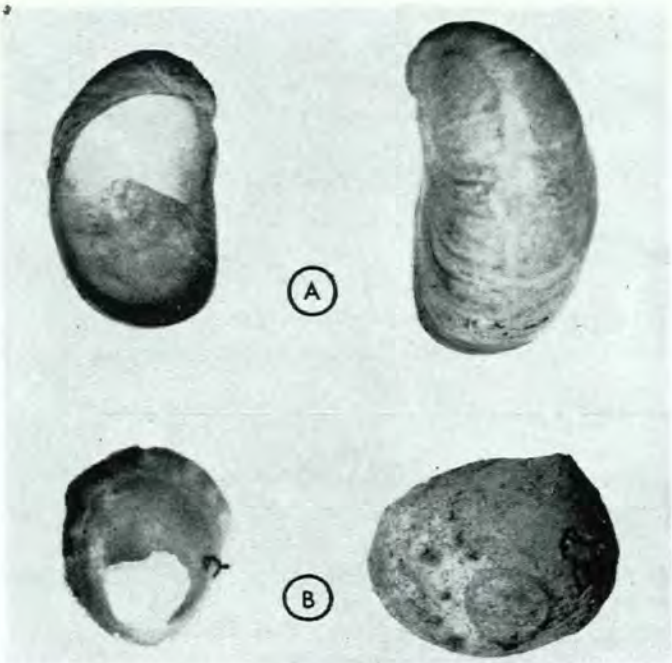


FIG. 112. Slipper shells associated with oyster beds. (**A**) *Crepidula fornicata* (× 1.5): does not yet occur in British Columbia. (**B**) *Crepipatella lingulata* (× 1.5): common on British Columbia oyster beds.

ECHINODERMS

The echinoderms which occur on oyster beds include starfish, sea urchins, and sea cucumbers.

About five species of starfish occur commonly on British Columbia oyster beds. Of these only one, the leather star, *Dermasterias imbricata* (Fig. 106) is not an oyster predator. The others were dealt with in the section on predators.

On a few beds, the green urchin *(Strongylocentrotus drobachiensis)* is found, and, on beds with a good deal of nearly pure sand, the sand dollar *(Dendraster excentricus)* is seen. Neither of these is harmful to oysters.

Cucumbers occur mainly on raft culture oysters.

TUNICATES

These are the sea squirts and will seldom be found on bed oysters but may be quite numerous on raft culture oysters or on seed strings, particularly in Pendrell Sound.

EELGRASS

There are a number of seaweeds (algae), as well as a single flowering plant, the eelgrass *(Zostera marina),* that occur on oyster beds. Eelgrass occurs mainly at

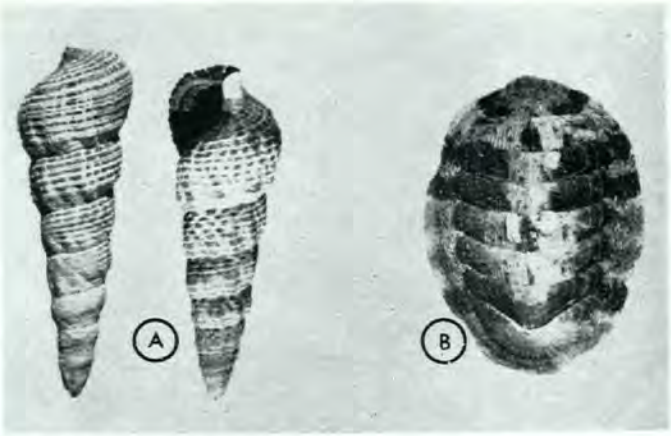


FIG. 111. *Batillaria zonalis* (× 1.3) (**A**) and one of several species of common chitons (× 0.7) (**B**).

beds is *Batillaria zonalis* (Fig. 111), which is another species of Japanese origin. Fortunately, it is not harmful. A native snail *(Thais lamellosa)* (Fig. 105), sometimes called the native drill because it does drill and eat barnacles, mussels, and clams, is normally harmless to oysters.

In addition to the shelled snails, there are the nudibranchs or sea slugs which have lost their shells in the evolutionary process. The sea lemon *(Anisdoris)* is a fairly large, bright yellow nudibranch about 2 inches in length. Another is the brown spotted *Diaulula*. Less abundant, and usually found stranded, are the swimming *Melibe* and *Dendronotus*.

Several species of chitons (Fig. 111), or coat-of-mail shells, with 8 overlapping shells, are often found clinging to oyster shells but these also are harmless for they feed by browsing.

British Columbia is one of the few oyster growing areas in the world that does not have the large slipper shell *Crepidula fornicata*. It is originally an American Atlantic coast species but has spread to many oystering areas, including Puget Sound. It inflicts no direct damage on oysters but attaches itself to oyster shells in considerable numbers, thus tending to smother the oyster. This *Crepidula*, or slipper shell, is shown in Fig. 112 so that it may be recognized. It is hoped that it will not become a problem in British Columbia. The common slipper shell on British Columbia oyster beds is *Crepipatella lingulata*, also shown in Fig. 112.

The shipworm is another mollusc that affects oyster growers indirectly owing to its destructive attack on untreated wood in floats or scows. Two species occur in British Columbia and the native species *(Bankia setacea)* reaches a length of nearly 4 feet and is found throughout the coast. The other species is the Atlantic shipworm *(Teredo navalis)* and is known at the present time to occur only in Pendrell Sound, where it has created difficulties for the seed collectors there. Copper paint, creosote, or fibreglass are the only practical protective coatings against the shipworm.

the lower levels of the beach and in British Columbia it is seldom a problem in growing oysters. Oysters may be grown successfully in eelgrass but the main difficulty arises in harvesting. However, a considerable portion of any eelgrass bed dies off during winter and if harvesting of oysters from an eelgrass bed can be delayed until early spring, there is usually not enough grass left to interfere significantly with harvesting. In the State of Washington, some beds have such a luxuriant growth of eelgrass that it has to be cut by means of specially designed drags.

Seaweed

On most oyster beds, in spring, there develops a flat, green-coloured seaweed called *Ulva.* Usually, it does not last long and seldom poses a serious problem. On other beds another flat-bladed seaweed, brown and called *Punctaria,* also develops in spring. It can become so plentiful that the oyster bed may be completely covered and the oysters hidden; it can interfere significantly if the oysters have to be picked up, either for harvesting or relaying. The simplest solution here is, if possible, to use the bed either before or after the occurrence of the weed.

Another weed, *Enteromorpha,* is green and is formed of long hollow strings which can form a very thick solid mat over an oyster bed in late spring and early summer. Normally, if there is warm weather during the low-tide periods, the sun will dry it enough to cause it to float off the oyster bed in quite large rafts. If the weather is wet, however, the *Enteromorpha* may persist until it dies and rots. In this case, the underlying oysters may suffer some mortality. Major mortalities from this cause have not been reported from British Columbia.

Another prominent weed is the so-called Japanese weed *(Sargassum muticum)* (Fig. 75, 76) which was introduced from Japan with oyster seed, and which first gained a solid foothold in British Columbia waters between 1941 and 1945. It requires a rocky bottom just below the zero tide level but some fronds may be found higher up. The main objection to this weed is the nuisance it occasions by becoming entwined in the propellors of small boats. However, it may be of significance in the economy of shore waters because of the considerable amount of organic material which is produced from it.

LEASES AND LEASING

Leasing Crown Land

All foreshore, that is, land covered by water below the high tide mark, is held by the Crown in the right of the Province. This means that the title to this land is held, with few exceptions, by the Province of British Columbia. Some of these exceptions are the Federal Harbours, such as Victoria, Vancouver, Nanaimo, and Alberni, whose foreshore is administered by the Government of Canada. One other notable exception is foreshore along the Vancouver Island side of Baynes Sound, which was granted by the Crown to the Esquimalt and Nanaimo Railway, from whom leases in this area were obtained until recently, when the area reverted to Crown control. There are several other small areas held outright by private owners.

British Columbia Crown Lands are administered by the Lands Service of the Department of Lands, Forests, and Water Resources at Victoria. All inquiries relating to the leasing of foreshore should be directed to the local Provincial Land Commissioner or the Superintendent of Lands, Victoria.

The British Columbia Government, for many years, has adhered to the policy of not disposing of any foreshore outright. The Government will, however, lease foreshore for various purposes, for varying lengths of time, as provided in the "Lands Act." One of the purposes for which the Government will lease foreshore is shellfish culture which includes the growing of clams and oysters.

Details of the method of obtaining a foreshore lease are described in a booklet entitled "The Acquisition of Crown Lands in British Columbia" published by the Province of British Columbia Lands Service, from whom it may be obtained.

Method of Acquiring Leases

In recent years the procedure has been as follows. Upon receipt of an application by the Superintendent of Lands to lease foreshore for shellfish cultivation, the application is first cleared by the Lands Service of the Department of Lands, Forests, and Water Resources. If sufficient information is not available within the Service the application is reported on by a Land Inspector of the Lands Service; it is also cleared through the British Columbia Commercial Fisheries Branch and Department of Health. If the area applied for is unsurveyed and has been cleared by the Commercial Fisheries Branch after an examination and the Department of Health, the report being favourable and no protests having been filed, the application is then approved, subject to survey, and the applicant is advised to have his surveyor get in touch with the Surveyor-General of the Lands Service for the necessary instructions. When the survey is completed and the applicant's surveyor has reported to the Surveyor-General, the survey is gazetted. After the survey has been gazetted and no valid objections having arisen, the applicant is advised as to the amount of rental payable and, upon receipt of payment, a lease is prepared for execution. (Detailed information on rentals, taxes, etc., may be obtained from the Superintendent of Lands, Victoria, B.C.) The lease is then forwarded in duplicate to the applicant for signature, after which it is returned to the Lands Service for final execution by the Deputy Minister of Lands.

Often considerable time is required for the final completion of an application to lease foreshore. This is particularly true when foreshore has to be surveyed. In many cases the survey cannot be made except at extreme low tide, and as sufficiently low tides occur in daylight in the summertime, and at night in winter, it is often difficult or impossible to have a survey and examination made during the winter months. This delay does not occur if the land being applied for has already been surveyed.

Applicants for foreshore should keep in mind the time required, especially when surveys have to be made. Another cause of potential delay in the final completion of a lease is the fact that, before the lease can be granted, the Superintendent of Lands must be satisfied that all public health requirements have been met. In certain areas which have already been surveyed by the Sanitary Division of the

Department of Health, there is very little delay on this account. In other areas, it may be necessary to have a survey made before the Department will give its approval from the standpoint of public health.

Immediately upon receipt of the issuance of a lease by the Lands Service for oyster or clam culture purposes, the lessor is required to register the holdings with the Commercial Fisheries Branch. Forms for this purpose may be obtained on application to the Commercial Fisheries Branch, Parliament Buildings, Victoria, B.C. There is no fee for this registration.

Lease Forms

Since the conditions under which oyster ground may be leased are such an important part of oyster culture operations in British Columbia, a review of the changes in these conditions over the years is given.

The actual lease form and its provisions have gone through a number of changes over the years. The first lease form of which there is knowledge was a generalized lease form with no specific provisions relative to shellfish and was signed by the Minister of Lands.

Then followed a form signed by the Commissioner of Fisheries in which the purpose of the lease was specified as that of an "oyster fishery," with a specified term of 10 years. The lease form also stated that the lease could be forfeited if the lessee was not "actively operating the said premises as an oyster fishery or for the planting, breeding culture, and production of oysters." Of interest also was the stipulation that any Chinese or Japanese could not be employed for work on the lease.

Later, about 1936, the lease form was changed again and was then signed by the Deputy Minister of Lands and the Minister of Fisheries, the Commission having been changed to a Department. This form also stated the tenure to be 10 years with an additional stipulation that the lease could be cancelled at any time, if, in the opinion of the Provincial Health Officer, the operation of such lease had become a menace to public health. This was, of course, at a time prior to the advent of the present sanitary regulations regarding shellfish. Also the lessee was bound to conform to the various provisions of any health act, Provincial or Federal.

About 1950, further changes were made and the new form included all molluscs in the purpose for which the lease was issued, whereas formerly the lease was for either an oyster fishery or a clam fishery. The lessee was thus protected against anyone else trespassing on his lease to dig clams, which up to then could be done, and which led to considerable conflict. The new form increased the period of the lease from 10 years to 21 years. The longer term gave the lessee increased security of tenure, encouraging him to improve and develop the ground in the knowledge of a fair degree of permanency. The new form differed from the old in that, while the lessee might still not interfere with fishermen who are legally fishing over areas covered by the lease, nevertheless the fishermen might not, in so doing, in any way injure the oysters on the ground in question. Under the old lease form the lessee did not have this protection.

In the older form the Minister of Fisheries had the right to wholly cancel a lease if it was not being actively operated. Under the new terms, there was still this authority, but, also, he could then cancel if it was proved that the lease was not being properly operated for oyster culture. This provision took into consideration the fact that one oyster grower might be properly operating his lease, and because of the lack of proper operation by a leaseholder on adjacent ground, the work of the former may be to a large extent nullified.

The new lease form also provided for a renewal in the event that the Minister of Lands intended to continue to lease the foreshore in question. This assured the lessee that he might, under normal circumstances, apply for and receive a renewal of the lease in question. This proviso for renewal was not in the old form, and while there was an understanding that the lease would be renewed, there was nevertheless no assurance that such would be the case particularly when, in the case of renewal, as in the initial acquisition of the lease, the aquiescence of the owner of the upland adjoining the lease had to be obtained. These measures were put into effect in order to provide stability and security to the people intending to make a business of oyster culture. The provision relative to the employment of Japanese or Chinese labour on oyster leases was deleted.

In 1957 the Provincial Department of Recreation and Conservation was created, and the status of the Provincial Department of Fisheries was altered so that it became part of the new department as the Commercial Fisheries Branch.

At this time still further alterations to the lease form were made. The previous form was discarded for a generalized foreshore lease form not designed specifically for shellfish. The only protective clause that remained referred to prior right of renewal. Presumably, because it was not spelled out, the term of the lease and the specific purpose may be variable and at the discretion of the Provincial Lands Service, so apparently the oyster industry lost the basic security of tenure it once had. In late 1961 there was a return to a form nearly similar to the 1950–1957 version. Here again, however, the term of the lease is not specifically designated. The lessee is required to make "reasonable and diligent use" of the lease.

An additional clause in the newest form, and not in previous ones, refers to the right of the Crown to grant rights-of-way across, through, under, or over any portion of Crown-granted leases. A point common to all the above-mentioned lease forms, and one about which the leaseholder must be aware, is that all foreshore leases are subject to the "Navigable Waters Protection Act."

Cost of Leases

The cost of survey and publication must be borne by the lessee. The cost of the final survey, which must be done by a licensed B.C. Land Surveyor, varies with the location and the ease or difficulty in finding previous survey markers, as well as the size and shape of the lease. Normally, at least $200 must be considered for this part of the leasing procedure. The lessee is required to pay "rent, taxes, rates, duties and assessments whatsoever now charged or hereafter to be charged." In other words, there are annual lease fees and, in addition, the foreshore is assessed, and school and land taxes are charged to it in advance. The minimum annual rental

is $25, and the fees for the first 5 years are normally $1 per acre per year for the first 5 years, after which it is subject to review and adjustment then, and at successive 5-year intervals. Most leases are increased to $5 per acre per year after the initial 5-year period.

Protection of Leases

Theft of oysters from leased ground, or "poaching," as it is called, is a perennial problem. As mentioned previously, all foreshore, with a few exceptions, is owned by the Crown in the right of the Province. Except from areas held under lease, or otherwise alienated, there is no Provincial statute to prevent the public from gathering wild oysters on non-leased ground, the so-called public beaches, except for public health reasons. In 1966, however, regulations were introduced to attempt to control the commercial harvesting of oysters from vacant Crown foreshore by means of a permit system. Unless oyster leases are appropriately marked and posted with signs, the public may easily wander onto a leased area and unwittingly remove oysters under cultivation.

Under these circumstances, it would seem that the oyster grower's first responsibility would be, in his own interest, to properly mark and sign his leasehold. By so doing, not only has he taken the first step to protect his property, but, in case of prosecution, he has removed the onus from himself and placed it on the defendant.

Stealing oysters is an offense against the Criminal Code of Canada. The pertinent information is given in Appendix B. It is evident that there are laws on the statute books adequate to give the oyster growers protection against theft of their oysters from oyster beds. Probably less evident is the fact that, in order to benefit from these laws, the oyster grower has the responsibility to see that his oyster beds are properly marked and signed so that there may be no doubt in the case of a prosecution.

ADMINISTRATION

History

Oyster growers soon realize they have to deal with a number of governmental agencies, some Provincial and some Federal. An understanding of the respective jurisdictions of these agencies may assist growers in their dealings with them.

The British North America Act provided that the legislative rights to all of Canada's inland and coastal fisheries would be vested in the Federal Government thus providing jurisdiction over all tidal and nontidal fisheries except those of Quebec. The nontidal (freshwater) fisheries are administered by the Province through the Fish and Wildlife Branch of the Department of Recreation and Conservation.

Through the years since British Columbia entered Confederation, conflicts have arisen between Federal and Provincial authorities on various aspects of fisheries jurisdiction, notwithstanding the delegation of responsibilities in the terms

of union. These problems were generally resolved in the courts or Privy Council and, as a result of a number of decisions, it now stands that regardless of ownership, insofar as tidal fisheries are concerned, the Federal authority controls and regulates the fisheries and, under its agreement with British Columbia, has the obligation to protect and develop them. The Provincial authority regulates the processing of fish within the Province and also taxes the fishery for Provincial revenue, although the exact management of this phase is Federal, through the Federal–Provincial tax-sharing agreement.

The only exception to Federal jurisdiction over tidal fisheries, due to an agreement in 1912, is in respect of shellfish. In British Columbia, with few exceptions, all foreshore is owned by the Crown in the right of the Province. Those fisheries which remain attached to the soil are not only the property of the Crown in the right of the Province, but are assumed to be wholly under the control of the Province. These include clams of all kinds, oysters, abalones, and other molluscan shellfish, as well as kelp and other marine plants. Regulations governing the orderly exploitation of molluscs are made by Federal Order-in-Council at the request of the Commercial Fisheries Branch of the Provincial Government, while regulations governing the harvesting of marine plants are made by the Provincial authority.

Recently, some doubt has been cast upon the legality of these arrangements but, at any rate, it is within this framework that shellfish problems have been met and solved for many years in a reasonably efficient manner.

Government Departments

The following are the various departments of Government and their connection with the oyster industry.

The Commercial Fisheries Branch of the British Columbia Department of Recreation and Conservation maintains overall control of the oyster industry, co-ordinating the interests of the other governmental departments involved. The Branch requires an annual statistical return from oyster growers.

The connection between the oyster grower and the Federal Department of Fisheries has two main aspects. The first is that the Fisheries Protection Branch enforces the fishery regulations regarding shellfish. Until 1967 there were only two regulations regarding oysters, one of which stated: "Except by special permission of the Minister of Recreation and Conservation for the Province of British Columbia, no person shall plant or introduce into an oyster bed any oyster or oyster seed not produced in the Province." This regulation was amended in Sept., 1967 (see page 192).

The second regulation, Section 6(7), states "No person shall dig for or take clams, mussels or oysters of any variety from Nanaimo Harbour, Exit Channel, and adjacent waters lying inside, or south of, a straight line from Pimbury Point, through Newcastle and Protection Islands to Jack Point." The enforcement of this regulation is largely, but not entirely, a matter for the Provincial Department of Health.

The second connection is that the grower is required to provide production statistics to the Department as indicated on the form shown in Appendix C.

As indicated in the section on leasing, all foreshore leases are issued by the Lands Service of the British Columbia Department of Lands, Forests, and Water Resources in Victoria and this department collects the lease fees.

The Taxation Division of the British Columbia Department of Finance assesses oyster ground and collects land and school taxes.

The Provincial Department of Health and Welfare is probably more directly concerned with the day-to-day operation of the oyster industry than any other governmental department. Before a lease is issued, a sanitary survey is made by this department, and a decision made on the sanitary category of the proposed lease. Certificates are required and granted by this department for the operation of shucking and packing plants and for shell stock shippers. Regular inspection of the shucking plants is conducted by sanitary inspectors, with less frequent examination of the bacterial quality of the sea water over the leases.

If the grower is involved in interprovincial or international trade in oysters, the Inspection Branch of the Federal Department of Fisheries and the Public Health Engineering Division of the Federal Department of Health and Welfare may be concerned. The latter department is responsible for the management of the reciprocal agreement between the United States and Canada regarding certification of shellfish (see Appendix D). In 1948 Canada and the United States agreed to accept each other's certification of shellfish plants and growing areas, and each country provides the other with a list of acceptable producers. The certification is based largely on the "United States Public Health Service Manual of Recommended Practice for the Sanitary Control of the Shellfish Industry." Canada has a voice in the formulation of this manual through participation in Shellfish Sanitation Workshops and other conferences. Reciprocal inspection on a Federal level is provided for, and there are joint research projects from time to time; the results of these form, in part, the basis for the U.S. Manual and revisions of it.

To put the situation simply, a British Columbia oyster grower can ship oysters to the United States provided he is on the reciprocal agreement certification list; the basis for his being on this list is his degree of compliance with the British Columbia regulations for shellfish sanitation. The Food and Drug Directorate of the Federal Department of Health and Welfare also examines from time to time the sanitary quality of oysters in samples taken from retailers' stocks.

This multiplicity of organizations may seem a bit confusing at first, and while there appears to be some overlapping, there is actually very little with respect to jurisdiction. They all serve the common purpose of assisting the oyster grower to produce a product that is acceptable and safe for the public and if the grower has any problems he will find willing assistance from the department concerned.

Oyster Regulations

Of interest is the historical development of oyster regulations (other than those pertaining to health in British Columbia) which are summarized as follows:

(1) 1894

Oysters not mentioned in regulations.

(2) 1908

Regulations specify:

(a) $2.50 license fee for fishing oysters.

(b) $2.00 per acre per annum for oyster leases.

(c) Closed season — May, June, July, August in each year.

(3) 1910

Regulations as in 1908.

(4) 1915

Regulations specify:

(a) Closed season — May, June, July, August in each year (license requirement deleted sometime between March 12, 1910, and February 9, 1915).

(5) 1925

Regulations specify:

(a) Closed season — May, June, July, August in each year except on leases. (This order came into effect sometime between May 1, 1923, and March 30, 1925.)

(6) 1940

Regulations specify:

(a) Closed season — May, June, July, and August in each year except on leases.

(b) Permission required from Provincial authorities to import oysters or oyster seed for planting (Order-in-Council June 29, 1939).

(7) 1947

Regulations specify:

(a) Closed season – May, June, July, August in each year except on leases.

(b) Permission required by Provincial authorities to import oysters or oyster seed for planting.

(c) Taking of oysters from Nanaimo Harbour prohibited (P.C. 1948-592, February 17).

(8) 1951

Regulations specify:

(a) Permission required by Provincial authorities to plant oysters or oyster seed not produced in the Province.

(b) Closed season regulation revoked June 7, 1951 (P.C. 2879).

(c) Taking of oysters from Nanaimo Harbour prohibited.

(9) 1957

Regulations specify:

(a) Permission required by Provincial authorities to plant oysters or oyster seed not produced in the Province.

(b) Taking of oysters from Nanaimo Harbour prohibited.

(c) Area Director of Fisheries (Federal) may permit the removal of oysters from Nanaimo Harbour for relaying to approved beds (P.C. 1958 - 693, May 15).

(10) 1965

Regulations as in 1957.

Until recently the small size of the oyster industry necessitated little regulation and up to 1966 there were only two sections of the British Columbia Fishery Regulations dealing with oysters. However, the increased size and complexity of the industry having created problems concerning wild oyster harvesting and oyster drill control, the regulations given in detail in Appendix E were introduced.

RESEARCH

Research on oysters in British Columbia began as early as 1913 with a quite detailed study of the native oyster *(O. lurida)* by Joseph Stafford who had done considerable work on the Atlantic oyster. His work in British Columbia is reported in three papers published by the British Columbia Fisheries Department.

There was a hiatus for some time until about 1928 when the Biological Board of Canada, assisted financially by the Province, began oyster research on all three species of oysters. The research was conducted at the Biological Station at Nanaimo by Dr C. R. Elsey who studied a number of aspects including the detailed structure and function of the oyster gill, oyster growth, breeding, and the artificial stimulation of spawning. The comprehensive publication from this work by Dr Elsey was Bulletin XXXIV of the Biological Board of Canada, entitled "Oysters in British Columbia." This was published in 1933 and is now unfortunately out of print. Assisting Dr Elsey during the summers in the oyster work at this time were Dr G. C. Carl, now Director of the Provincial Museum at Victoria, and the late Dr E. C. Black, of the University of British Columbia.

In 1938 Dr Elsey left the employ of the Biological Board for the fishing industry. Here he maintained his interest and exercised his knowledge of oyster culture for many years. Dr Elsey was succeeded at Nanaimo by the author who had been his student assistant for several summers and had drawn stimulus from him for many years. During the war years and for a brief period afterward, the research, on a somewhat reduced scale, was directed by Dr Ferris Neave.

In 1948, at the instigation of Mr G. J. Alexander, Deputy-Minister of Fisheries for the Province, shellfish research was taken over entirely by the Provincial Department of Fisheries, and a small laboratory was established in Ladysmith in 1949. Research, particularly into the phases of practical oyster culture, was carried on by the author until 1957. In 1957 and 1958 there was another hiatus when no shellfish research was conducted. Late in 1958 the present author rejoined the Fisheries Research Board of Canada (formerly Biological Board) and the responsibility for shellfish research was returned to the Biological Station at Nanaimo, where it rests at the present time.

THE FUTURE OF THE OYSTER INDUSTRY IN BRITISH COLUMBIA

The production of oysters in British Columbia has shown a uniform increase almost from the time oysters were first harvested commercially (Fig. 75). A similar trend has occurred on the west coast of the United States. In contrast, on the Atlantic coast of the United States oyster production has suffered a continuous downward

trend since about 1900. On the Atlantic coast of Canada oyster production in 1920 was only a third of what it was in 1900, and between 1920 and 1940 production remained quite constant at about 4 million pounds (whole oysters) after which there was a gradual increase to 11 million pounds in 1950. Subsequently there was a decline to the present production of about 4 million pounds. By comparison, present production of oysters in British Columbia is 12 million pounds.

This means the demand for Pacific oysters will inevitably increase, for there is little likelihood of drastic increases in production on the Atlantic coast in the near future, beset as that industry is by pests, disease, low seed production, and high dependence on a public fishery. Indeed, it may be forseen, that eventually, due to population increase, the British Columbia oyster industry may not be able to supply the Provincial market.

The darkest cloud in the relatively bright future of the oyster industry in British Columbia is pollution. However, with increased attention to waste disposal and development of economical purification procedures, ground now restricted may be brought back into full production.

As shown previously, the intertidal oyster ground now under lease is not being fully utilized. So far there has been no attempt to develop marginal ground, through either modifying its physical characteristics, or using some of it as it stands, so as to integrate it into a modified scheme of oyster culture (page 92). The raft culture technique has not yet been exploited and its potential should be equal to that of bottom culture. Also the possibility of a modest amount of subtidal culture should not be ruled out.

The reduced supply and increased cost of Japanese seed opens wide the possibility of a significant oyster seed industry in Pendrell Sound. In 1968 the value of seed collected there should approximate the value of shucked oysters produced in the Province. Therefore only the brightest future may be forecast for this industry.

ACKNOWLEDGMENTS

No literature references are given in the text for this would have enlarged the bulletin excessively. In any case oyster growers to whom this work is primarily directed would not have ready access to most of the literature. However, a list of the most important texts are given and most of these contain extensive bibliographies.

The works of Dr C. R. Elsey, Dr C. M. Yonge, Dr P. S. Galtsoff, and Dr V. L. Loosanoff have been drawn upon as well as those of the staff of the Washington State Shellfish Laboratory (Mr C. E. Lindsay, Mr R. Westley, Mr C. Woelke, and Mr C. Sayce) with whom many discussions on oyster culture were held. Most of the material, however, has been taken from the bulletins of the British Columbia Provincial Shellfish Laboratory, Ladysmith, which were produced by the author in mimeographed form in 55 numbers in 8 volumes between 1949 and 1957 while at that laboratory.

Illustrations are the work of the author, photographers C. Morley and P. Fraser, and artists A. Boyden and A. Denbigh.

The encouragement and cooperation of the oyster industry is acknowledged.

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GLOSSARY

adductor — muscle holding two valves together
algae — marine plants or seaweeds which reproduce by spores
amoeba — a primitive unicellular animal
anterior — front or head
aragonite — a form of crystalline calcium carbonate
auricle — chamber of the heart into which blood is received from the body
bioassay — a test in which the quantity or strength of material is determined by the reaction to it of a living animal
B.O.D. — abbreviation for biochemical oxygen demand; the amount of oxygen absorbed by a putrefying waste
box — pair of empty oyster valves
branchial — pertaining to the respiratory organ or gill of an aquatic animal
bushel — 8 dry U.S. gallons or 1.245 cubic feet
byssus — filaments used by a mollusc to attach itself
caecum — a blind pouch usually associated with the alimentary canal
capillary — a tiny, thin-walled blood vessel of small diameter
cerebral — pertaining to the brain
chitin — a relatively inert skeletal material found mainly in insects
cilia — a hairlike process with a rhythmic beat which in molluscs produces a current
cloaca — a posterior chamber into which open the anal, urinary, and genital ducts
coliform — refers to the bacteria found in the colon of the digestive tract
conchologist — a person who studies molluscan shells
conchyolin — a horny substance found in molluscan shells
condition factor — a measure of plumpness or fatness of an oyster
copepod — a class of small Crustacea, some free swimming, some parasitic
Crown land — land under governmental ownership or control
Crustacea — a group of aquatic animals characterized by jointed legs, i.e., crabs, shrimps
crystalline style — gelatinous rodlike organ of certain molluscs, concerned with digestive processes
cultch — material used to collect oyster spat
demibranch — single plate or leaf of a molluscan gill
depuration — term used in the United States for purification of shellfish of bacteria
detritus — term given to fragmented organic material from plant and animal remains
diatom — a one-celled primitive plant enclosed in a siliceous container
dinoflagellate — a motile one-celled organism with some animal and some plant characteristics
diverticulum — lateral outgrowth of the stomach cavity
dorsal — pertaining to the back or part of an animal away from the ground
drill — snail preying upon other molluscs which it penetrates with a drilling apparatus

eelgrass — a green bladelike marine plant which reproduces with seeds; a true plant and not a seaweed
enzyme — chemicals produced by living cells which aid, but do not take part in, chemical reactions
exhalant — emitting or discharge area
faeces — indigestible residues remaining in the alimentary canal after digestion
fertilization — the union of the egg and sperm
flatworm — a group of flat, leaflike worms, many of which are parasitic
fluting — curved platelike outgrowths on the surface of a molluscan shell
follicle — a small, saclike structure
foreshore — land below the high tide mark
ganglion — an aggregation of nerve cells
gaper — a bivalve mollusc dead or in the process of dying, with the valves gaping but with some meat left within
gastric — pertaining to the stomach
gazetted — in this instance when the information is published in the official "British Columbia Gazette"
gill — a leaflike appendage of an aquatic animal and concerned with breathing
glycogen — an animal starch
gonad — the sex gland which produces either eggs or sperm
gribble — a small wood-boring crustacean
halocline — the area of sharp vertical salinity change
hardening — with oysters the process of acclimation to longer and longer periods out of water
hybrid — the offspring of the union between two different species or races
hypostracum — layers of shell material under the area of adductor muscle attachment
incubate — to hold eggs during development
inhalant — the drawing in of a liquid
intracellular — within the cell
invertebrate — an animal without a backbone
labial — pertaining to the lips
lamella — a leaf or platelike structure
larva — an immature stage between the egg and the adult form
lease — rented foreshore area
lessee — individual who obtains a foreshore lease
lessor — owner who rents foreshore area, in British Columbia the Provincial Government
ligament — fibrous springlike material joining two valves
lobe — a rounded or flaplike projection
mantle — a soft fold enclosing the body and which secretes part of the shell
mean — average
microgram — one thousandth of a gram; one gram equals 0.0353 ounce
mouse unit — a measurement unit of paralytic shellfish poison
mucoprotein — conjugate proteins containing a carbohydrate group

nacre — iridescent calcareous substance composing the innermost layer of a molluscan shell
neap — series of tides with a relatively small tidal range
oesophagus — junction canal between the mouth and stomach
Order-in-Council — government order or regulation promulgated by Cabinet order
organoleptic — by actual taste
ostia — mouthlike apertures
ovum — egg
palp — a sensory appendage
parasite — an organism which lives in or on another organism and derives subsistence from it without rendering it any service in return
pedal — pertaining to the foot or feet
pericardium — the space or membrane surrounding the heart
periostracum — the horny outer layer of a molluscan shell
peritoneal — pertaining to the body cavity
pest — a predator or parasite
pinworm — marine wood-boring crustacean *(Limnoria)* also called the gribble
plankton — floating or weakly swimming aquatic animals and plants
pleural — pertaining to the pulmonary cavity
plica — a foldlike structure
poach — a mild term for theft
pore — a small aperture
posterior — the rear; further away from the head
predator — an animal which kills and consumes other animals for food
prodissoconch — larval shell of a mollusc
promyal — in front of the muscle
pseudofaeces — false faeces; waste material not taken into the digestive tract
race — a group of animals generally segregated geographically and differing slightly from the typical members of the species
relay — another term for "transplanting" shellfish from one bed to another
ren — Japanese term for shell string
respiration — the interchange of oxygen and carbon dioxide associated with energy utilization
sac — any baglike or pouchlike structure
salinity — in oceanography the salt content of sea water usually measured in parts per thousand (‰)
sampan — a small Japanese work boat
seed — a young oyster
set — the accumulated settlement or spatfall of oyster larvae
shell stock — general term for unopened oysters in the shell
shuck — to open and remove the oyster meat from the shells
sink float — a raft, usually of logs with the floors sunk below the surface of the water
spat — a newly settled or attached young oyster; a postlarval oyster
spatfall — the settlement of oyster larvae
spawn — common term for eggs and sperm

species — a term used to denote a group of closely allied, mutually fertile individuals
spring — series of tides with a relatively large tidal range
statocyst — an organ for the perception of the position of the body in space
sulphate — a pulp mill process (alkaline) where sodium hydroxide and sodium sulphite are used for cooking the pulp
sulphite — a pulp mill process (acidic) where sulphurous acid with a calcium or magnesium base is used for cooking the pulp
suprabranchial — also epibranchial meaning above the branchium or gill
thermocline — the area of sharp vertical temperature change
thermograph — an instrument for recording temperature
transplant — another term for relay; to move oysters from one bed to another
tubule — a small tubular structure
turbidity — the amount of suspended small particles in a liquid
typhlosole — a longitudinal inwardly projecting fold of the wall of the digestive tract
umbo — (plural umbones) the beaklike projection which represents the oldest part of a bivalve shell
valve — one of several pieces composing the shell of molluscs or barnacles
veliger — the secondary larval stage of most molluscs characterized by the presence of a velum
velum — the ciliated locomotor organ of the molluscan veliger larva
ventral — pertaining to that aspect or side of an animal facing the ground
ventricle — the main contractile chamber of the heart
vesicle — a small bladderlike sac or pouch
viable — capable of living and developing normally
visceral — pertaining to the organs within the body
year-class — a group of animals spawned close together in time during any one year

APPENDIX A

THAT under the provisions of Section 94 of the "Land Act", being Chapter 175, Revised Statutes of British Columbia, 1948, and amendments, all that area known as Pendrell Sound, Redonda Island, New Westminster District, lying north of a straight line between Walter Point and Durham Point, be reserved and set apart for the use, recreation and enjoyment of the public;

AND TO FURTHER RECOMMEND THAT a copy of this Minute, if approved, be forwarded to the Deputy Minister, Department of Fisheries, Victoria, B.C.

DATED this 21st day of November A.D. 1950

APPENDIX B

PROTECTION OF OYSTER LEASE FROM THEFT

EXCERPTS FROM CRIMINAL CODE OF CANADA — PART VII
OFFENCES AGAINST RIGHTS OF PROPERTY

THEFT

269 (1) Every one commits theft who fraudulently and without colour of right takes, or fraudulently and without colour of right converts to his use or to the use of another person, anything whether animate or inanimate, with intent,

(a) to deprive, temporarily or absolutely, the owner of it or a person who has a special property or interest in it, of the thing or of his property or interest in it.

270 (1) Where oysters and oyster brood are in oyster beds, layings or fisheries that are the property of any person and are sufficiently marked out or known as the property of that person, he shall be deemed to have a special property or interest in them.

(2) An indictment is sufficient if it describes an oyster bed, laying or fishery by name or in some other way, without stating that it is situated in a particular territorial division.

PUNISHMENT FOR THEFT

280 Except where otherwise prescribed by law, every one who commits theft is guilty of an indictable offence and is liable

(a) to imprisonment for ten years, where the property stolen is a testamentary instrument or where the value of what is stolen exceeds fifty dollars, or

(b) to imprisonment for two years, where the value of what is stolen does not exceed fifty dollars.

APPENDIX C

B.C. 4 (Revised March, 1963)

DEPARTMENT OF FISHERIES OF CANADA

OYSTER PRODUCTION REPORT FORM

COMPANY: _____ REPORT FOR MONTH OF: _____

ADDRESS: _____ DATE SUBMITTED: _____

Total shucked production in terms of American gallons for the month: _____ gallons.

Marketings During Month		Prices Received During Month From			
Size	Total Number	Local Retail	Wholesale Distributors	Stores, Cafes, Restaurants or Other	Export to U.S.
½ Pts. (8 oz. containers)					
¾ Pts. (12 oz. containers)					
Pints (16 oz. containers)					
Pints Imperial (20 oz.)					
Quarts (32 oz. containers)					
Quarts Imperial (40 oz.)					
Gals. (128 oz. containers)					
Sold in Bulk Quantities - Gals.					
Oysters in Shell					

COMMENTS: List any item of current production marketing interest which you think might be included in the Oyster Marketing Report issued by the Department.

_____

_____

_____
Name of Owner.

This report should be submitted each month either to the local Fishery Officer or should be sent to Office of Area Director of Fisheries, 1155 Robson Street, Vancouver 5, B.C., before the 10th of the month.

The Monthly Report will be issued and mailed about the 15th of the month.

APPENDIX D

PROPOSED MEMORANDUM OF AGREEMENT BETWEEN THE CANADIAN DEPARTMENT OF NATIONAL HEALTH AND WELFARE AND THE UNITED STATES PUBLIC HEALTH SERVICE

In order to bring about improvements in the sanitary practices prevailing in the shellfish industries in Canada and the United States and to facilitate the exchange of information regarding such practices with reference to endorsement of shellfish certifications issued by State, Provincial, and other shellfish regulatory authorities, it is agreed as follows:

1. The "Manual of Recommended Practice for Sanitary Control of the Shellfish Industry," recommended by the United States Public Health Service in 1946 and published as Public Health Bulletin No. 295, is accepted as the statement of the sanitary principles which govern the certification of shellfish shippers.
2. The degree of compliance attained by each state is to be reported to the Canadian Department of Health and Welfare by the United States Public Health Service and the degree of compliance attained by provinces and other regulatory authorities in Canada is to be reported by the Canadian Department of National Health and Welfare to the United States Public Health Service.
3. Whenever inspections of shellfish handling facilities or of growing areas are desired by either party, the other party will facilitate such inspections.
4. This agreement may be terminated by either party on thirty days notice.

APPENDIX E

REGULATIONS CONCERNING THE TAKING OF OYSTERS FROM VACANT CROWN FORESHORE

B.C. 2749 — Sept. 21, 1966

1.(1) No person shall take or have in his possession oysters for commercial purposes other than from a duly registered oyster lease, except as authorized by a permit issued to him by the Minister. A permittee under this clause may only dispose of the oysters so taken to a registered oyster leaseholder.

(2) For the purpose of these regulations any person taking or having in his possession more than 100 pounds of unshucked oysters or more than one gallon of shucked oysters shall be deemed to have taken the oysters for commercial purposes.

2. No person shall market oysters taken from Crown Lands until such time as such oysters have been held on a registered oyster lease for a period of at least two weeks immediately prior to taking for market purposes, as provided by Regulation 7(c) of the Regulations for the Sanitary Control of the Shell-Fish Industry in British Columbia.

3. For the purpose of these Regulations an "area" shall be the same as that defined in the British Columbia Fishery Regulations made pursuant to the Federal Fisheries Act.

4. The Minister may issue permits for the purpose of these Regulations, but each permit so issued

(a) shall cover a specific operation over a specific area of Crown foreshore and shall be for a period not to exceed 30 days,

(b) shall exclude all dispositions made under the provisions of the "Land Act" either prior to or subsequent to the issuance of the permit,

(c) shall be under such terms and conditions as the Minister may prescribe,

(d) shall be subject to the payment of a prescribed fee of ten dollars for each "area" from which oysters are to be taken,

(e) shall be subject to the riparian rights of upland owners fronting on the Crown foreshore covered by the permit,

(f) shall require the permittee to leave the foreshore in a clean, safe and sanitary condition to the satisfaction of the Minister,

(g) shall require the permittee to save the Crown harmless from any claims which may be made against the Province of British Columbia by reason of anything done, or left undone, by the permittee, and

(h) shall be subject to the Regulations for the Sanitary Control of the Shell-Fish Industry in British Columbia.

5. Every person who harvests oysters under a permit granted under these Regulations shall render a statement, on a form supplied by the Minister, within 10 days of the expiry date of such permit. This statement shall record the operation under the permit and shall be submitted to the Commercial Fisheries Branch of the Department of Recreation and Conservation.

6. Every person who harvests oysters under a permit granted under these Regulations shall jointly with the statement in (5) above pay to the "Minister of Finance" a royalty equal to one dollar per ton on all oysters (shell stock) taken.

7. Any person who violates any provision of these Regulations is liable, on summary conviction, to a fine of not less than twenty-five dollars and not more than one thousand dollars.

8. Under these Regulations no one shall be granted a permit to take oysters commercially from foreshore fronting Indian Reserves. Nothing in the foregoing shall prevent, restrict, or control the commercial taking of oysters in the above-mentioned areas by an Indian as defined in the Indian Act.

P.C. 1967–1695 — Sept. 6, 1967

1. Section 34 of the *British Columbia Fishery Regulations* is revoked and the following substituted therefor:

"34. (1) No person shall, except by special permission of the Minister of Recreation and Conservation for the Province of British Columbia,

(a) plant or introduce; or

(b) use or cause to be used any equipment to plant or introduce into an oyster bed or any waters of that Province oysters, oyster seed, oyster cultch or oyster shells from outside the Province.

(2) No person shall, except by special permission of the Minister of Recreation and Conservation for the Province of British Columbia, transport or cause to be transported from any area described in Schedule E any oysters, oyster seed, oyster cultch, oyster shell, marine organisms adversely affecting oysters or any tools, boats, scows or other material used in connection with oyster culture or harvesting."

2. The said Regulations are further amended by adding thereto the following Schedule:

"SCHEDULE E

1. *Boundary Bay Area* which comprises all tidelands in Boundary Bay and Mud Bay inside (north) of the International Boundary Line between Point Roberts and the mainland (Blaine).

2. *Crofton Area* which comprises all tidelands surrounding the Shoal Islands between the Osborne Bay Lighthouse and the Bare Point Lighthouse at Chemainus.

3. *Thetis Island Area* which comprises

(a) all tidelands in North Cove inside (southeast) of a line drawn between Fraser Point and Pilkey Point;

(b) all tidelands surrounding Hudson Island and Scott Island; and

(c) all tidelands in Telegraph and Preedy Harbours inside (east) of a line drawn between Crescent Point and Active Point on Thetis Island.

4. *Ladysmith Harbour Area* which comprises all tidelands inside (west) of a line drawn between Sharpe Point and the white navigation beacon on Holland Bank.

5. *Henry Bay Area* which comprises all tidelands in Henry Bay inside (east) of a line drawn 169° True from Longbeak Point, the northerly tip of Denman Island.

6. *Comox Harbour Area* which comprises all tidelands inside (north easterly) of a line drawn from Goose Spit to the outer end of the government dock in Comox Harbour.

7. *Pendrell Sound Area* which comprises all the waters and tidelands of Pendrell Sound inside (northerly) of a straight line joining Durham Point and Walter Point."

P.C. 1967–2220 — Nov. 30, 1967

1. Section 34 of the *British Columbia Fishery Regulations* is amended by adding thereto the following subsections:

"(3) No person shall, except by special permission of the Minister of Recreation and Conservation for the Province of British Columbia, take or have in his possession oysters for commercial purposes, other than oysters taken from an area described in a registered oyster lease.

(4) Notwithstanding subsection (7) of section 6, the Regional Director may permit, under such conditions as he deems necessary, the removal of oysters from any area described in that subsection for the purpose of transplanting the oysters to leased oyster beds approved by the Provincial Department of Health and Welfare."

Recent Bulletins of the Fisheries Research Board of Canada

No. 150. Greening in tuna and related species. By N. Tomlinson. (1966, 21 p., $1.25.)

No. 151. Special products from freshwater fish. By A. W. Lantz. (1966, 45 p., $2.00.)

No. 152. Sea stars (Echinodermata: Asteroidea) of arctic North America. By E. H. Grainger. (1966, 70 p., $2.50.)

No. 153. Population dynamics of the petrale sole *(Eopsetta jordani)* in waters off western Canada. By K. S. Ketchen and C. R. Forrester. (1966, 195 p., $3.75.)

No. 154. Marine resources of Newfoundland. By Wilfred Templeman (1966, 170 p., $3.50.)

No. 155. Fishes of the Atlantic Coast of Canada. By A. H. Leim and W. B. Scott. (1966, 485 p., $8.50.)

No. 156. Physical oceanography of Dixon Entrance, British Columbia. By P. B. Crean. (1967, 66 p., $1.75.)

No. 157. An economic appraisal of the Canadian lobster fishery. By J. B. Rutherford, D. G. Wilder, and H. C. Frick. (1967, 126 p., $2.50.)

No. 158. Physical and economic organization of the fisheries of the District of Mackenzie, Northwest Territories. By Sol Sinclair, S. Trachtenberg, and M. L. Beckford. (1967, 70 p., $1.75.)

No. 159. Automatic underwater photographic equipment for fisheries research. By P. J. G. Carrothers. (1967, 34 p., $2.00.)

No. 160. Chilling and freezing salmon and tuna in refrigerated sea water. By S. W. Roach, H. L. A. Tarr, N. Tomlinson, and J. S. M. Harrison. (1967, 40 p., $1.75.)

No. 161. Goldeye in Canada. By W. A. Kennedy and W. M. Sprules. (1967, 45 p., $1.50.)

No. 162. The sockeye salmon, *Oncorhynchus nerka*. By R. E. Foerster. (1968, 422 p., $8.00.)

No. 163. Instrumentation for the engineering study of otter trawls. By P. J. G. Carrothers. (1968, 45 p., $1.75.)

No. 164. Index and list of titles, Fisheries Research Board of Canada and associated publications, 1900–1964. By Neal M. Carter. (1968, 649 p., $1.00.)

No. 165. Carp in Canada. By Hugh R. McCrimmon. (1968, 93 p., $2.00.)

No. 166. The eel fisheries of eastern Canada. By J. G. Eales. (1968, 79 p., $1.75.)

No. 167. A practical handbook of seawater analysis. By J. D. H. Strickland and T. R. Parsons. (1968, 311 p., $7.50.)

No. 168. Paralytic shellfish poisoning in British Columbia. By D. B. Quayle. (1969, 68 p., $2.50.)