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OBSERVATIONS ON THE BIOLOGY AND ECOLOGY OF THE FOVEAUX STRAIT DREDGE OYSTER (*OSTREA LUTARIA* HUTTON)

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WELLINGTON, NEW ZEALAND
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SUMMARY

From 1960-1964 the biology and ecology of Ostrea lutaria in Foveaux Strait were studied.

Most mature oysters are over 7 cm. in length (height) and more than three years old.

The breeding season is from October until February, (sea temperature 12°C - 15.7°C).

In Foveaux Strait larvae are incubated for about 26 days and most larvae were liberated in December-January (sea temperature 15°C).

When liberated the larvae have eye-spots and twin shells and most lack the velum. Settlement is soon after release.

Larvae settle on clean surfaces, without encrusting organisms. In Foveaux Strait settlement was heaviest on living oysters, particularly on shells with well developed conchiolin layers in Areas A, B and D.

Observations suggest that spat detached soon after settlement may survive among coarse sediments.

Foveaux Strait oysters can reach marketable size in about two to three years, but in Port Adventure, Stewart Island oysters can reach this size in about eighteen months.

Many benthic organisms compete with the oyster for space and food in Foveaux Strait. Most competition occurs on oyster grounds in the west of the Strait.

Oyster larvae and young oysters have many predators; the most important predators of large oysters are asteroid starfish.

That the ophiuroid Pectinura maculata is a major predator of young oysters is unconfirmed: it does attack larger oysters but these may be already moribund or damaged.

The shell boring sponge Cliona sp. is most abundant in western areas of the Strait.

The trematode parasite, *Bucephalus longicornutus* Manter caused heavy adult oyster mortalities in 1962 and 1963.

INTRODUCTION

The biology and ecology of *Ostrea lutaria* were studied during 1960-1964 as part of an attempt to assess the maximum sustainable yield of Foveaux Strait oysters and to formulate a rational management policy for the Foveaux Strait oyster fishery.

Foveaux Strait separates the South Island of New Zealand from Stewart Island, is about 16 nautical miles wide, has an average depth of 15 fathoms, and is strongly tidal. There has been a dredge fishery for *O. lutaria* in Foveaux Strait for 100 years. Map 1 shows the area, subdivided into the zones and statistical areas used in the management of the fishery.

There has been little previous work on *O. lutaria* biology, but Fleming (1952) studied samples from an oyster bed in Area B. The relationship between sediments and oyster distribution was described by Cullen (1962).

Hollis (1963) studied the systematic status of *Ostrea lutaria* and examined the production, development, larval release, and setting of oysters from Wellington Harbour.

Howell (1963, 1966) studied a trematode parasite infacting *O. lutaria* from Foveaux Strait.

In 1968 Cranfield described an unexploited population of oysters from an area near Ruapuke Island and described spat settlement on this bed.

METHODS

(a) Sampling of Oysters and other benthic fauna

In 1960-1964 regular samples were obtained by dredging and by diving, Stead 1971).

(b) Sampling of oyster larvae

From 1961 to 1964 a sample of 100 oysters was examined for contained spawn at each station.

The most comprehensive data were obtained during the October 1961 to February 1962 breeding period when oysters were examined at 120 stations, and in October-November 1962, when oysters were examined at 46 stations.

In attempts to sample pelagic oyster larvae from surface and mid-waters a plankton net with a three foot diameter circular mouth was used, and both horizontal and vertical tows were made. Two mesh sizes (.35 and .5mm) were used. The same net was attached to a steel dredge frame and either towed slowly over the sea bed or left facing tidal currents. The lower rim of the net mouth was 12 inches above the sea bed.

At some stations a small stationary plankton sampler (shown in Figure 1) was used. This device was designed to face into tidal currents at all times and thus collect suspended material. The lower rim of this net was 5 inches above the sea bed.

(c) Settlement studies

The support to which dredged oysters were attached was recorded. Diving observations were also made.

Spat collection materials, including 6" x 6" x 6" concrete blocks, anchors, heavy chain, oyster shells in mesh containers, and cage-like wood and concrete structures, were placed in different parts of the Strait. Oyster shells, cement washed cork, and wooden blocks were attached at intervals to buoy lines to monitor mid-water settlement. Larval settlement in laboratory tanks was also observed.

(d) Growth experiments

Oyster growth was monitored during 1960-1963 by placing oysters in cages with wire mesh sides and concrete bottoms. The cages were placed on the sea bed in the Strait and in shallow sheltered waters at Ruapuke Island

and Stewart Island. Oyster measurements were to the nearest millimetre. Length is from the umbo to the furthermost rim of the flat shell; width was measured across the shell at right angles to the length axis; maximum depth was also measured.

Oysters were weighed to the nearest gram. Oysters were tagged and distributed at sea, but none were returned.

(e) Hydrology

Sea temperature

A bathythermograph and a reversing thermometer were used in May-June 1960, and the latter was used at intervals from 1961 to 1964 in Foveaux Strait to record temperature at different station areas and depths. Sea surface temperatures were recorded daily at lighthouses at Waipapa Point, Dog Island, Centre Island and Puysegur Point, for about one year in 1962-1963.

In 1963 a thermograph was installed in the Bluff-Stewart Island ferry "Wairua" to record sea temperature.

Salinity

Surface sea water samples were obtained at the above lighthouse stations, except Puysegur Point, in 1962-1963; deeper water was sampled from the Strait using a reversing bottle.

Tidal Currents

Some work on the direction and velocity of tidal currents in the Strait was carried out in 1961 in conjunction with the New Zealand Oceanographic Institute, D.S.I.R. Methods included the use of drifting drogues and air surveillance of fluorescein dye patches.

Sediments

Sediment samples were obtained at most survey dredge stations and the samples subsequently examined by D.S.I.R. scientists (D.J. Cullen 1962, 1967). The sea bed was examined while diving and observations made on sediments in relation to oyster distribution and spat settlement. (Stead 1971).

RESULTS

(a) Incubatory phase

Figure 2 shows a percentage length frequency histogram for oysters containing eggs or larvae, taken from many Strait areas in the period October-November 1962.

Those oysters incubating larvae were mostly over 6.4 cm. in length, with the majority in the 7.5 to 8.0 cm . length range. Growth rate studies (p. 11) suggest that most of these oysters are over three years old with the majority ranging from four to seven. There was no evidence of any differences in spawning season in different parts of the Strait.

The highest proportion of adult stock incubating larvae recorded was 8.5% of 364 oysters taken at one station in Area A in October 1962.

Table 1 shows the average percentage of brooding oysters, and the predominant larval stage, in each month in the incubating period.

TABLE 1

Month	1961-1962	1962-1963	1963-1964	1964	Predominant Larval Stage
September	Not Sampled	Not Sampled	1.6	1.3	Egg-blastula
October	3.8	3.6	3.4	Not Sampled	Egg-blastula
November	5.9	3.2	5.2	"	Early veliger
December	3.9	2.8	Not Sampled	"	Early/Late veliger
January	1.0	0.4	"	"	Late veliger
February	Not Sampled	0.3	0.2	"	Late veliger/Post veliger

Oysters with a differentiating gonad were found occasionally throughout the year but oysters incubating larvae were not found between April and July. Brooding oysters were occasionally seen in August, and somewhat more commonly in September.

Oysters in Foveaux Strait reproduce from August to March, with most reproduction in November - February. The predominant larval stage is shown in Table 1, but post-veliger larvae, without the swimming organ or velum, were found in oysters as early as November, and in increasing numbers until February. Larvae with vela were seen amongst larvae which had lost the velum in January and February.

In February and March 1964 many oysters were found with a differentiating gonad. This suggests a late spawning and coincided with a general improvement in the condition of the oysters after two poor years in 1962 and 1963.

The larvae of O. lutaria develop from the egg to the late and post-veliger stage within the mantle chamber of the parent oyster. When first released from the gonad the eggs are creamy white in colour and about .2 to .3 mm in diameter. The larval mass becomes greyish-brown in colour as the eye-spots and shells develop.

At release, most larvae are between .4 and .5 mm in length - with a black eye-spot, twin brownish, bi-convex shells, and a prehensile foot. In most cases the velum has been lost. The larval stages of O. lutaria are described in detail by Hollis (1963).

(b) Release of Larvae

Hollis (1963) reports that the larval incubation period was about 21 days for O. lutaria from Wellington Harbour held in laboratory tanks. Observed samples from Foveaux Strait incubated larvae for 24-28 days.

Foveaux Strait oysters in sea water tanks released larvae by rapid contractions of the adductor muscle. Many of the larvae were ejected several inches from the parent. Most larvae were released during the first two hours but some larvae were still being released up to 48 hours after the first liberation. After several hours shell contractions became infrequent and larvae were seen crawling on the lip of the shell outside the mantle.

Most newly released larvae were post-veligers but some still bore vela.

Data in Table 1 indicates that most liberation of larvae in Foveaux Strait occurs in the December/January period, when mean sea temperatures are above 15°C. (See Figure 7).

(c) Pelagic Phase

(i) Plankton Sampling

Plankton samples were obtained from depths ranging from 5 inches above the sea bed to the surface in different areas in Foveaux Strait during the oyster breeding areas from 1961-1963. Most of the samples were obtained in the period November 1961 to January 1962 when many adult oysters were incubating veliger larvae, but no oyster larvae were caught.

(ii) Laboratory Observations

Veliger larvae in newly-opened adult oysters are usually inactive, but when sea water is added they swim actively. Veliger larvae released in aquaria swam to the surface. After about 30-40 minutes of intermittent swimming they sank slowly and usually remained on the bottom of the tanks, but sometimes swam upwards again. Larvae without vela sank on release from the parent and used the foot for locomotion on the bottom.

This suggests that in Foveaux Strait veligers, if released, are subject to tidal dispersal before settlement, but that post-veliger larvae would remain on the sea bed close to the parent oysters. Only a small proportion of larvae are released as veligers.

(d) Settlement of Larvae

(i) Experimental Work - Spat Collectors

Most spat collecting materials were lost due to the loss of surface marker buoys, but a small amount of data was obtained. Three concrete 6" x 6" x 6" cubes were placed among oysters south of Ruapuke Island in Area C on 10 November 1960. On 25 January 1961 these cubes bore 17 spat from 2-5 mm long. Spat also settled on other collectors set in October-November and examined in January-February.

No spat settled on collectors set in April and examined in August. There was no settlement on collectors attached to buoy lines at intervals from one foot above the sea bed to the surface throughout the breeding season. Cages containing live oysters were sunk in the Strait during the surveys and spat settled on these. One double-tray cage 2' x 2' x 18" (height) containing 24 oysters from 3 to 9 cm. long, was set in 5 fathoms of water in Lagoon Bay, Ruapuke Island, on 6 February 1963. There were no other oysters in the vicinity. When examined on 26 August 2963, oyster spat of different sizes were found attached to the oysters and to the cage. Spat were most abundant in the lower half of the cage. Another cage of 24 oysters was set in 4 fathoms on a sand bottom devoid of oysters in Lucky Bay, Stewart Island, on 29 November 1961. This cage was retrieved on 4 December 1962, and the oysters and the cage bore numerous spat and young oysters. Similar settlement occurred on cages placed in other shallow, sheltered inlets at Stewart Island. Most settlement occurred on the oysters, and to a lesser extent on the wooden frame of the cages; few spat were above the upper tray of oysters. The anchor and chain of a buoy placed among oysters in Area H in 1963, and lifted by an oyster boat in 1966 was encrusted with oysters of various sizes, some of them marketable. These observations suggest that oyster larvae in Foveaux Strait are benthic, that settlement is localised and occurs soon after larval release, and that most settlement occurs in the December-February period.

(ii) Laboratory Observations

In aquaria post-veliger larvae use the foot to crawl. Two oyster shells were placed in a tank containing newly-released larvae. One shell was live, with an intact, outer conchiolin layer, and the other was an old white shell without conchiolin. More larvae settled on the live shell than on the dead shell. In another tank nine larvae settled on a clean shell, within an hour of their release. Just before final attachment the larvae pivoted about the settlement area on the foot. The foot was still visible several hours after settlement. Other larvae attached to the bottom and sides of the tank, on clean stones, and on pieces of wood.

(iii) Settlement on the Oyster Grounds

In Foveaux Strait spat are most abundant on live oysters. Spat and young oysters occur on most parts of the live shell, but are most common on the outer lip of the curved shell (left valve). (Plate I). Clusters of up to 60 oysters of all sizes were recorded on the oyster grounds in Areas A, B and D. Live oysters with an intact outer conchiolin layer bore most spat. Oysters with an intact conchiolin layer occur in all areas, but are most frequent in the eastern zone. By comparison fewer spat were seen in deeper water in Areas E and G, where many of the oysters had lost part or most of the conchiolin. Spat did not occur on shells encrusted with bryozoa or heavily infected by Cliona. In Areas A and B, many spat often occurred on oysters encrusted by a fine reddish sponge. In dense aggregations the spat and attached oysters were often elongate in shape due to competition for space. Spat were most abundant on Areas A, B and D. These areas have been subjected to prolonged commercial exploitation for many years. Fewer spat were recorded on the unworked oyster ground in Areas C, E_2 and H, although these oysters on the unworked grounds had intact conchiolin layers and were on similar sediments to those in Areas A, B and D.

It is anomalous that spatfall is higher in the exploited areas. Oystermen recall that several years before the 1960 survey there were more large individual oysters and fewer attached "wing" oysters in Areas A, B and D.

More settlement occurred on oysters on coarse pebble bottoms than on sandy bottoms. On pebble bottoms most of the oysters is exposed, but on sandy bottoms many oysters are partly buried. Oysters were found attached to dead oyster shell or to other dead lamellibranch and gastropod shell. Most attachment to dead shell was to articulated oyster shells with an intact conchiolin layer; this suggests that settlement occurred while the oyster was still alive. In the Strait relatively few oysters were attached to old white shells, but this was more frequent in Stewart Island inlets.

Oysters were sometimes found attached to stones larger than about 5 cm. in diameter but rarely occurred on smaller pebbles. O. lutaria was sometimes seen attached to the shell of large living molluscs, particularly on the lower shell margin of the gastropod Astraea heliotropium, "circular-saw". Clusters of young oysters also occur on the lower parts of the holdfast of the ascidian Pyura pachydermatina "sea-tulip". Spat were also seen on miscellaneous objects such as bottles, pieces of timber, iron and chain, etc. Very few oysters occur on rocks in the Strait, but in sheltered areas (e.g. Paterson Inlet, Port Adventure, Lord's River, and Port Pegasus) spat and oysters were abundant on intertidal rock.

Many oysters of all sizes, showing no sign of previous attachment were seen in Foveaus Strait during the suveys., Small living oysters less than 1 cm. in length were found several inches below the surface of some coarse pebble-shell areas, and groups of unattached oysters of similar size and shape were found among dense fauna patches. Most single oysters were recorded from Areas E and G, but they occurred in all areas.

(e) Growth of Oysters

In 1960-1963, about 250 oysters of various sizes were put in cages in various positions in Foveaux Strait and the Stewart Island inlets, and their growth observed. Up to 24 oysters were put in each cage.

Growth in Port Adventure, (a shallow water, sheltered inlet where good quality oysters occur naturally), was compared with growth in the deep water, strongly tidal conditions of Foveaux Strait.

Some of the Strait cages were lost. In all cages, several oysters died and were replaced. Some oysters grew from spat to market size in the period 1961-1963. Figures 3-6 show the growth in shell length and whole weight for the oysters observed. Each point represents an observation date. Figure 3 shows the increase in length of oysters in Port Adventure. Most of these oysters came originally from the Strait, but in 1961, 1962 and 1963 the growth of the spat in the cages was monitored.

February 1961 spat were market-sized 21 months later. One spat set in February 1962 was market sized 18 months later in August 1963.

Caged spat grew at similar rates in each year from 1961 to 1963. Oysters over 90 mm. in length showed little growth. Growth took place mostly in summer and little growth was recorded in May-August when several caged oysters died. This mortality coincided with oyster mortalities elsewhere in Port Adventure and the Strait. Mean sea temperatures were below 11°C in this period.

Figure 4 shows the increase in whole weight of oysters at Port Adventure. Growth was rapid; most oysters reached approximate market weight in less than one year. One oyster, weighing 2 gm. in October 1961 weighed 90 gm. about 22 months later in August 1963.

Very little weight increase occurred from May-August 1962, but later growth was rapid.

Figure 5 shows length increases for oysters held in Strait cages. The growth was generally slower than that in Stewart Island areas; most samples took over two years to reach marketable size. Little growth took place in oysters over 70 mm long. Figure 6 shows the growth in whole weight of oysters in Strait cages. Initially increases in weight were small, but as the oysters developed, more shell deposition occurred than in Port Adventure samples and weight increments increased. Even very large oysters in Strait cages increased in weight. Oysters introduced into Port Adventure from the Strait assumed the physical appearance of O. lutaria growing naturally in the inlet. Bryozoa and other epibionts on the oyster shells usually disappeared after a few days and the shell valves became thinner, harder, and more close fitting. Rapid growth at the shell rim occurred, and the shell depth increased in relation to other dimensions. The flesh became creamy-white in colour, and filled the shell cavity, the condition factor increasing to an average of .6 compared with .4 in Strait oysters. Stead (1971) compares whole flesh weights of naturally occurring oysters from Port Adventure and Strait areas. The flesh to shell weight ratio is higher in Port Adventure.

(f) Hydrology

(i) Sea Temperature

Figure 7 shows mean sea temperatures during the survey period.

These were recorded at various points in the Strait between Centre Island and Waipapa Point. There was generally little difference in temperature with position or depths but Houtman (1966) reports that "although the waters of Foveaux Strait are usually isothermal and isohaline from surface to bottom, at least in winter, horizontal gradients of temperature and salinity exist because of admixture with waters of subtropical origin, chiefly at the outer boundaries of the Strait".

Temperatures from early 1963 to April 1964 were generally lower than in the period October 1961 - June 1964. The highest sea temperature recorded in the Strait was 15.8°C on 20 February 1963 in Area E, and the lowest was 8.9°C on 27 August 1963 in Area A. Sea temperatures at Port Adventure and other sheltered shallow water inlets at Stewart Island were generally .5 - 1°C above the mean Strait temperatures.

(ii) Salinity

The average salinity of 13 Strait samples was 35.12°% and for 2 samples from Port Adventure the average was 34.88°%. Garner (1961) recorded surface salinities of 35.5% in Foveaux Strait in 1955. Houtman (1966) states that fresh water run-off dominates the inshore salinity pattern along the coast of the South Island in Foveaux Strait. The Waiau, Oreti, Mataura, and Aparima Rivers discharge fresh water into the Strait along this coast.

(iii) Tidal Currents

No quantitative data on current direction and velocities were obtained, but observations of water movement in the Strait showed that:

The greatest apparent turbulence and current velocities occurred in the Ruapuke Island and Bluff Hill areas, especially during the ebb tide, when the strong outflow from the harbour mixes with the westbound current through the Strait. Strong turbulence also occurs off Saddle Point, Stewart Island during the flood tide the rapid eastward flow leaving an eddying area south-east of the Point. Line turbulence on the surface was seen in Areas E and G, caused by water deflected over sand banks, which were often over 30 feet in height in these areas.

The flood tide was generally stronger than the ebb. After heavy rain, discolouration of sea water was seen at the mouths of the large rivers flowing into Foveaux Strait from the north. This discolouration sometimes extended 2-3 miles out to sea.

(g) Other Benthic Fauna

Dredging and diving revealed an abundant and varied fauna on the oyster grounds in Foveaux Strait.

The species identified at each survey station were recorded. These data, distribution maps, and fauna lists are available for reference at the Fisheries Division Laboratories at Wellington and Bluff.

(i) Competitors of the Oyster

These compete with the oyster for space and food. Food competitors probably include lamellibranch molluscs, bryozoans, ascidians, barnacles, sponges, coelenterates, and brachiopods, all of which are abundant on the oyster grounds. Competition for food in suspension is probably not significant where there is no overcrowding. Although most organisms were well dispersed over the sea bed, especially in areas subjected to regular commercial dredging, large clumps of animals, (known locally as "mullock") occurred frequently in Areas E, F and G.

The main components of these aggregations were nesting mussels (*Musculus* sp.) joined by their fibrous byssus threads into large clumps, bryozoans such as *Steganoporella* sp. and *Cellepora* sp. and also various large sponges. Other animals frequently found among the clumps included: ophiuroids, asteroids, echinoids, holothurians, lamellibranchs, gastropods, cephalopods, crustaceans, worms, ascidians, etc. Oysters found among these clumps were usually small and mis-shapen or elongate, and of poor flesh condition. Oysters away from but near the congested areas were usually of good size, shape, and flesh condition.

Oysters were most crowded in the unexploited western areas, and particularly close to Saddle Point, Stewart Island.

Various animals and algae occur on the living oysters in Foveaux Strait. These included bryozoans, sponges, barnacles, slipper limpets, chitons, lamellibranchs, calcareous tube worms, ascidians, shell borers, brachiopods, coelenterates and various small plumose and laminate red algae. Encrusting bryozoans were present on most of the Strait oysters. Few oyster spat occur on heavily colonised shell. In areas near Ruapuke Island, oysters were found under dense patches of the ascidian Pyura. The Pyura holdfast often enclosed the oyster shell.

(ii) Predators of the Oyster

Starfish are probably the most important oyster predators in Foveaux Strait.

The most abundant and widespread starfish in Foveaux Strait is the ophiuroid Pectinura maculata, known locally as "five-fingers" (Plate 2).

The number of P. maculata in the 3ft survey dredge was recorded at each station. 30 samples taken at random contained an average of 17 P. maculata and 47 live oysters. The greatest number of P. maculata taken in a five minute dredge tow was 480. Diving observations showed the average densities of P. maculata to be about one to each two square yards on most commercial oyster beds. Large numbers occurred on the Ruapuke Beds (Area B) together with numerous articulated dead oyster shells. P. maculata were also observed in areas without oysters. P. maculata is incapable of opening an oyster by pulling apart the shells. Living and dead oysters were often found containing Pectinura or part of the arm. This was particularly so in 1962 and 1963, when oysters were in poor condition due to parasitic infection. Usually the oyster flesh was partly consumed. The ophiuroid may, however, have been seeking oysters already killed by the parasite, or moribund.

During the survey, several thousand Pectinura from most parts of the Strait were opened and their gut contents examined. Small oysters, up to a centimetre in length, were found inside .02% of them. Most Pectinura contained minute gastropods, lamellibranchs, worms, and soft organic material. The strong jaws of Pectinura are capable of crushing shellfish and it is possible that newly released oyster larvae and spat are subject to this predation, which could be very significant in view of the large numbers of Pectinura on the oyster grounds.

Other ophiuroid species found less frequently in the Strait included Ophionereis sp. and Ophiopteris sp., but their feeding habits are unknown.

Several species of asteroid starfish were found in Foveaux Strait, the most common being Coscinasterias calamaria, the eleven-armed starfish (Plate 3) which measures up to 10 inches across the arms.

This starfish, though not as abundant as Pectinura, occurs widely in the Strait, but is most common on oyster grounds. Coscinasterias was watched opening oysters and spat during diving. The starfish enclosed the oyster with its arms, the tube feet adhering to the shells, then pulled the shells apart. The starfish "stomach" was everted into the shell cavity to digest the oyster flesh.

Astrostole scabra ("seven arms") starfish was also seen attacking oysters in Foveaux Strait. This starfish was abundant on unexploited oyster ground on the boundary of Areas F-H in 1963, but was uncommon elsewhere (Plate 4).

Stichaster australis, the "reef star" was abundant in the sheltered inlets of Stewart Island. These large starfish (many 10 inches across the arms) were seen attacking scallops on the mud bottom in deeper water and oysters and mussels attached to rock along the shore.

A gastropod, Lepsiella sp., about 4 cm. in length, was observed drilling the shell of a large living oyster in Area E, in Foveaux Strait in 1963. The radula of the gastropod cut out an irregular hole about 4-5 mm. across, in the centre of the curved oyster shell.

Several such "drilled" shells were present in samples from Area E, in 1964, but the overall incidence of "drilled" shells in the Strait was very low. This suggests that gastropod predation of large oysters is not significant in Foxeaux Strait. Other likely predators, mainly of the spat and young oysters, include the starfish Allostichaster, Patiriella, Pentagonaster and others, the echinoid Evechinus; also crabs, octopus, polychaetes, flat worms, gastropods such as Astraea, and fish, all of which occur commonly on the oyster grounds. The only method of controlling predators at present is their removal while dredge contents are sorted on the boat.

(iii) Oyster Parasites

Tow oyster parasites studied in Foveaux Strait were: the shell boring sponge Cliona sp. and the digenetic trematode Bucephalus longicornutus Manter, which infects the oyster flesh.

Cliona sp.

This sponge forms a network of interconnecting passages in the oyster shell, and holes about one millimetre in diameter perforate the outer shell surface. The oyster shell usually thickened difficult to repair, and this may lead to imperfect closure, entailing a variety of dangers."

Korringa (1951) assumed that "it is especially the deposition of conchiolin layers in places threatened with perforation which may exhaust the oyster".

The level of oyster mortalities due to Cliona in Foveaux Strait is therefore certainly influenced by the weakened condition of the oyster and its vulnerability to predators. Large quantities of perforated dead oyster shells found in many western areas suggest high mortalities due to Cliona.

The paucity of attached oyster spat on infected shells, compared with settlement on adjacent uninfected oysters in the western zone, suggests that the presence of Cliona inhibits settlement.

In Foveaux Strait most Cliona infection occurred in crowded areas.

Cliona cannot tolerate low salinities and estuarine oysters are usually unaffected.

Bucephalus longicornutus Manter

In 1960 and 1961 oyster flesh quality was generally good and no internal oyster parasites were noticed.

In January 1962 some living Foveaux Strait oysters were sent by air to Dr R.H. Millar at the Millport Marine Station in Scotland. Thread-like tubules of the sporocyst stage of a digenetic trematode of the family Bucephalidae were found in the visceral mass of some specimens by Millar (1963).

This sporocyst was also found in oysters taken from Foveaux Strait in June 1963 by M.J. Howell. In 1963 some O. lutaria from Wellington Harbour were also infected.

and breaks easily revealing the yellow sponge-filled passages (Plate 5).

Most infection was observed in the western Areas E, F and G, in depths over 16 fathoms, and a very high incidence was recorded in congested areas which had never, or rarely been dredged commercially. In some places most oysters both alive and dead, larger than 5 cm long, were, or had been infected.

Very few Cliona infected shells were found in Areas A, B, C and D, and none were seen in Stewart Island inlets.

Cliona infected oysters from the Strait usually had a thickened and often very friable shell, while the flesh was usually watery, and often bitter in taste. The infection therefore reduces the commercial value of the oyster.

Examination of the inner shell surface of an infected oyster usually revealed a number of raised dark spots, where the tunnels made by Cliona had almost penetrated the mantle cavity.

Yonge (1960) states that: "the mantle surface reacts to penetration of the shell by sealing off perforations with areas of greenish-yellow conchiolin. Should the sponge prove more vigorous, and the oyster became exhausted by the continued effort of secretion, then discoloured patches appear in the mantle opposite the areas of close, although not necessarily of complete penetration, and these spread through the animal causing emaciation and then death".

Old (1941) presumed that "physical exhaustion of the oyster from abundant shell secretion in its efforts to preclude penetration of the sponge, reduces the oyster's natural resistance against pathogenic organisms and other dangers. Perfor-ations under the muscle scar are especially

The life cycle of *Bucephalus* is described by M.J. Howell (1966). Figure 8 shows the suspected life cycle in diagrammatic form (after Howell 1963).

The following observations were made in Foveaux Strait in 1963-1964.

Specimens of *Kathetostoma giganteum* - ("monkfish" or "stargazer"), dredged during 1963 in Foveaux Strait, were found to contain the adult trematodes in their gut. These fish, (up to a length of about two feet) are often taken in oyster dredges in the Strait. *K. giganteum* buries itself in the bottom sediments leaving only the eyes and part of the mouth exposed. Thus camouflaged, the "monkfish" captures small bottom feeding fish. Small fish up to 3 inches in length were found in the gut of "monkfish" from the Strait. Howell (1963) reported that 77% of *K. giganteum* from Foveaux Strait contained the trematode and five or more adult worms were present in 38% of the infected fish. Several other fish from Foveaux Strait were examined, but no bucephalids were recovered.

The host of the metacercaria is not known. Howell reports that no metacercaria were found in small fish from Foveaux Strait though live specimens were later infected in laboratory experiments.

The sporocysts were not detected in the Strait during 1960 and 1961. During 1962 and 1963, oyster condition was poor and the sporocyst tubules clearly visible. Plate 6 shows a badly infected oyster with the visceral mass teased out to show the sporocyst tubules (Howell 1966).

Table 2 shows the percentage incidence of sporocyst infected oysters dredged in Foveaux Strait in 1963 and 1964. These were oysters in which the sporocyst tubules were clearly visible.

No data are available for 1962.

TABLE 2: Incidence of *Bucephalus* sporocyst infection.

LOCALITY	1963 (Aug-Nov)		1964 (Feb-July)	
	Number of oysters sampled	% Incidence	Number of oysters sampled	% Incidence
AREA A	402	18%	-	-
AREA B	-	-	200	12%
AREA C	426	24%	100	3%
AREA D1	114	10%	100	20%
AREA D2	181	24%	200	18%
AREA E1	390	15%	100	13%
AREA E2	47	36%	100	16%
AREA F	-	-	100	25%
AREA G	105	24%	300	8%
EAST ZONE	1,056	25%	600	12%
WEST ZONE	609	16%	600	16%
WHOLE STRAIT	1,665	20%	1,200	14%

A general recovery from the effects of the parasite occurred in 1964 and this was accompanied by improvements in oyster condition in most areas. During 1963 a high incidence of infection was recorded in oysters from previously unexploited oyster patches in Areas C (39%) and E2 (38% and 34%).

Howell (1966) found a higher average incidence of infection of oysters from Areas A and B in Foveaux Strait during 1963-64, compared with Areas D, E and G, i.e. 40% against 23%. The two levels of incidence are probably related to the distribution of the host fish which is most abundant in pebble areas such as A, B, D2 and E2.

The percentage infection was highest from June to September. Howell records the highest incidence for 1963 in September.

The smallest infected oysters from Foveaux Strait were about 5 centimetres long; possibly only sexually mature oysters are infected by *Bucephalus*.

Effects of the Parasite on the Oyster

Heavily infected oysters from Foveaux Strait were either gaping or easy to open. In this condition the oyster is more vulnerable to predation.

The flesh of a badly infected oyster is translucent and yellowish, the tubules show clearly within the visceral mass, and sometimes on the gills.

Both Millar (1963) and Howell (1966) found that, in heavily infected oysters, the gonad tissue was progressively destroyed by the sporocysts, casuing parasitic castration.

Of the oysters sent to Millar in 1962, 22 were examined on arrival; of these 3 contained bucephalids; 67% of those oysters which subsequently died were infected, whereas of those which remained alive 15% contained the parasite Millar (1963). Howell (1966) found that over half of the heavily infected oysters died.

It can be assumed that the parasite caused high oyster mortalities, possibly exceeding 50% of all adult stock in places in Foveaux Strait in 1962-63. This would account for the sharp decline in catch per hour rate in this period.

DISCUSSION

Reproduction:

Ostrea lutaria has a slightly shorter breeding season in Foveaux Strait than in Wellington Harbour where Hollis (1963) observed that the oyster reproduced for at least eight months of the year. Larvae occurred in seven months of the year in Foveaux Strait, occasional oysters with a differentiating gonad were found through the year in Foveaux Strait, but most reproduction takes place in three months.

Hollis (1963) suggested that O. lutaria in Wellington Harbour might breed at temperatures as low as 10°C. The lowest sea temperature recorded in Foveaux Strait during the surveys was 8.9°C, but mean winter sea temperature is usually higher than this. Most breeding in Foveaux Strait occurred when temperatures were highest, in November-February.

Pelagic Life:

Examination of plankton samples and studies of settlement in the Strait indicate that the pelagic life of larvae is brief and that most larvae remain close to the sea bed. Larvae lacking the velum probably only crawl over the bottom near their point of liberation. Such restricted movement is confirmed by the localisation of spatfall in the growth observation cages. Larvae released as swimming veligers may spread further, but examination of oysters incubating larvae at a late stage of development suggests that few veliger larvae are released.

Settlement:

Laboratory observations showed that larval settlement occurred soon after release; presumably it is also rapid in Foveaux Strait, depending on the availability of suitable settlement surfaces.

Most oyster settlement was observed on living oysters in well-dredged parts of Areas A, B and D in depths less than 15 fathoms. Observations suggest that an intact conchiolin layer is attractive as a settlement surface. The numerous spat on many living oysters in eastern areas suggests several other contributary factors: that the larvae had settled on their "parent" oyster, or possibly the attraction of larvae to areas already colonised by other oyster spat. Cole and Knight-Jones (1949) recorded that more Ostrea edulis spat settled on collectors which already bore some spat, while experimental destruction of these early spat caused a reduction in subsequent spat settlement.

Korringa (1952) suggests that perfectly clean surfaces are less attractive to oyster larvae than those bearing some fine growth.

However, marine organisms such as bryozoa and Cliona reduce larval settlement in Foveaux Strait.

Oystermen have reported a higher incidence of attached spat and "wing" oysters in Area G since 1961 after several years of exploitation.

Tidal currents and sediment composition are also important in larval settlement, as more shell is exposed for larval settlement on firm substrates.

The elliptical shape of some oyster beds, oriented in the direction of tidal currents, and with highest oyster densities along the longest axis, suggests that currents play a major part in extending these areas of oyster ground. Cranfield (1968) records highest spat-fall intensity along the central axis of an oyster bed and a reduced spatfall in the lateral areas.

Independent Larval Survival

Hollis (1963) showed that settlement of O. lutaria larvae can be postponed for several days if conditions are unsuitable.

Thousands of larvae are released from a mature oyster, and even under ideal conditions in Foveaux Strait only a certain proportion would achieve settlement in the vicinity of the "parent", especially in sparsely populated areas.

While diving, clouds of fine sediments were often raised from the sea bed by the tides in the Strait.

It therefore seems possible that larvae which have not achieved settlement during their first slack water are carried over the sea bed by the currents. Most larvae at release have an eyespot, shells and foot, but have lost the velum. Most are .4 to .5 mm long and negatively buoyant, and are capable of filter feeding, thereby increasing their weight. The smallest sediment particles recorded from the main oyster grounds in the Strait were .2 to .5 mm in size, Cullen (1962), thus it is unlikely that larvae are choked by inorganic particles in the Strait. Larvae may crawl into favourable positions within the sediments using the foot. Other larvae may be buried or trapped under shells and epifauna. Larvae within the sediments may remain unattached or survive on small supports. In this position they may be less subject to predation than exposed spat, the twin biconvex shells also providing some protection from mechanical forces.

Current velocity is reduced near the sea bed due to friction, and downward currents through coarse sediment banks were observed while diving. This circulation of water would provide life support for larvae buried in the sediments.

It may be significant that O. lutaria in localities such as Paterson Inlet, Wellington Harbour, Tasman Bay and Golden Bay, where the sediment is mainly fine soft mud, does not occur in quantities comparable to those of the same species in Foveaux Strait.

Growth

Studies of oyster growth in Foveaux Strait and Port Adventure show a higher growth rate in the latter habitat, suggesting that more favourable conditions for growth and fattening exist in these Stewart Island inlets than in the Strait. Other shellfish in these estuarine areas were also nearly always in good condition. Higher water temperatures, lower salinities and abundance of food are thought to be mainly responsible.

Availability of food, presence of competitors, overcrowding, and high incidence of oyster parasites cause fluctuations in oyster condition and growth rate in the exposed Strait environment. Although no quantitative data are available, survey studies suggest that growth rate of oysters is higher on eastern Areas such as A and B, than in Areas E and G for example.

On eastern areas the shells are normally thin and hard, showing good growth at the rim, whereas many oysters from deeper water had thickened shells due to presence of Cliona, but had reduced growth at the rim.

Other Fauna:

Ostrea lutaria has colonised wide areas of the sea bed in Foveaux Strait despite competition from many animals and predation by others. Newly released larvae and young attached spat are subject to attack by many species, suggesting high mortalities at this early stage. The full significance of Pectinura as a predator of young oysters is not yet known.

Mature oysters are not normally subjected to a high level of predation unless previously weakened by parasites and lack of food, but in combination, parasites and predators cause high mortalities, especially when parasitism reaches epidemic proportions.

Commercial Dredging

Survey results and observations suggest that commercial dredging is sometimes beneficial, by removing old or infected oysters, reducing overcrowding in dense aggregations of fauna, and by grading the sediments.

CONCLUSIONS

The main factors contributing to survival and regeneration in Foveaux Strait oysters and oyster beds are considered to be:

(a) The incubation of larvae and their release at a late stage of development.

(b) The fact that most larvae are benthic at release and that settlement is rapid and localised.

(c) The rapid growth rate of O. lutaria.

(d) The large size of inorganic sediment particles and the firm nature of most of the sea bed.

(e) The strong tidal currents in Foveaux Strait, and local weather conditions.

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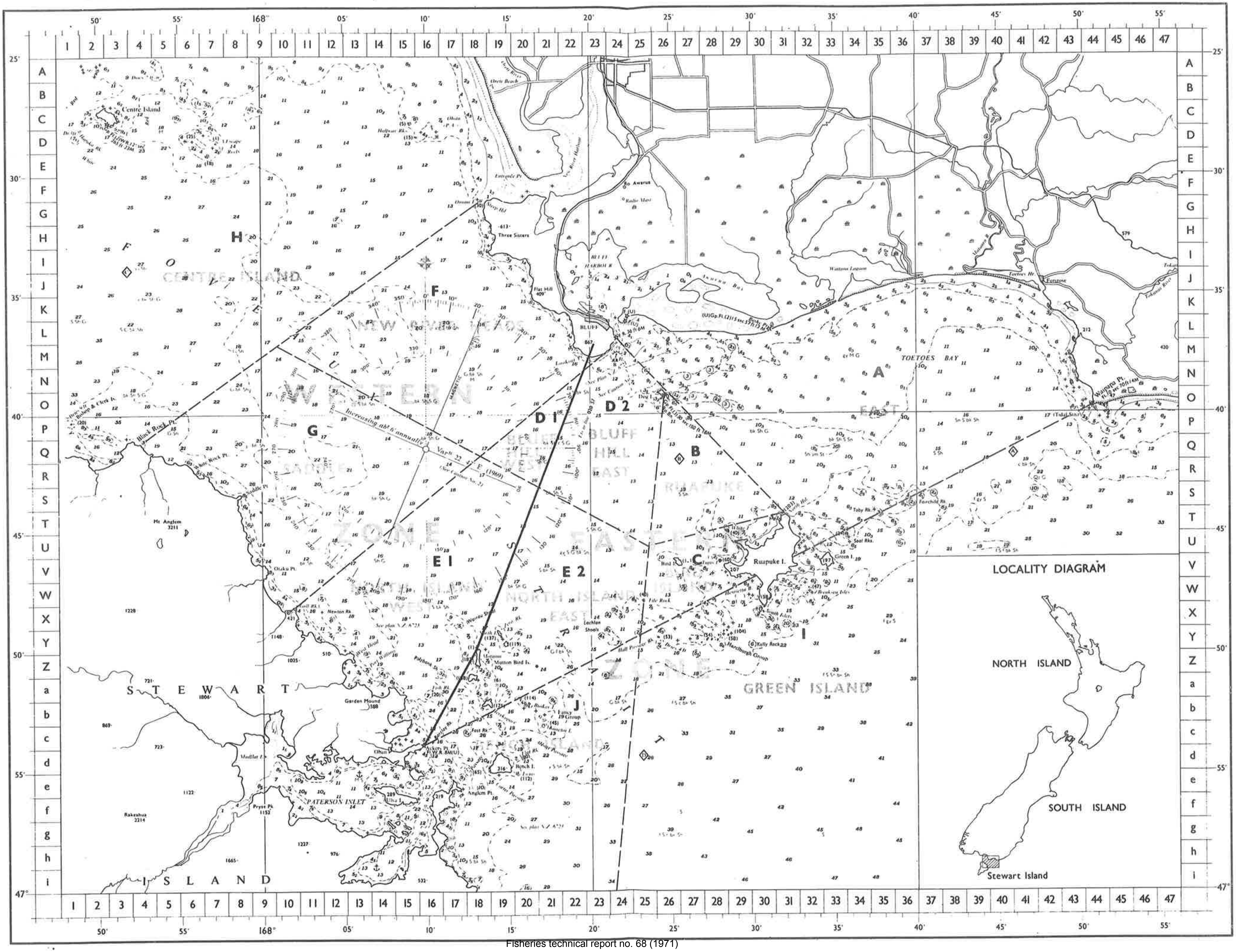
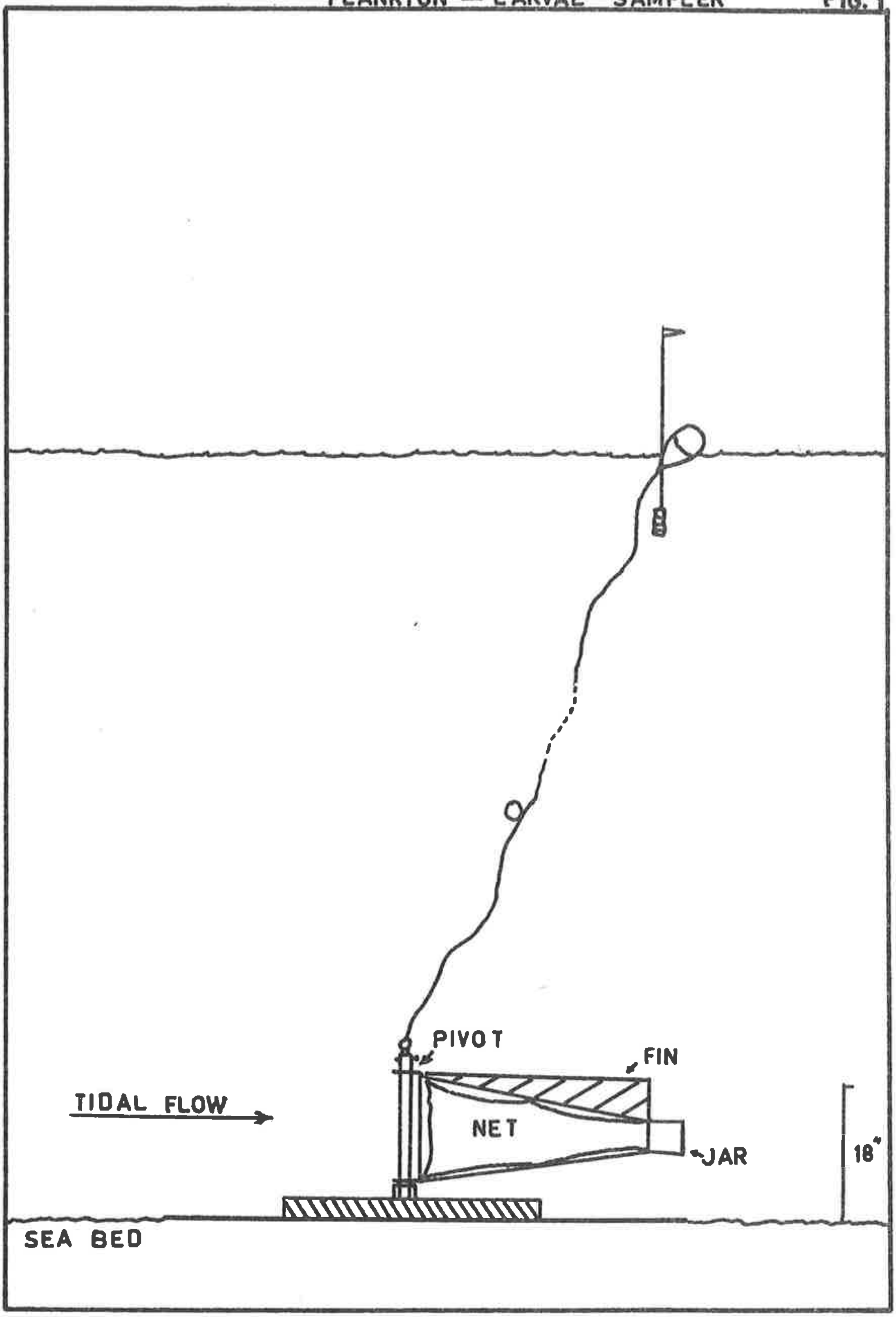
FOVEAUX STRAIT OYSTER SURVEY 1960 - 64 LOCALITY MAP SHOWING STATISTICAL ZONES AND AREAS

MAP I



PLANKTON — LARVAE SAMPLER FIG. 1



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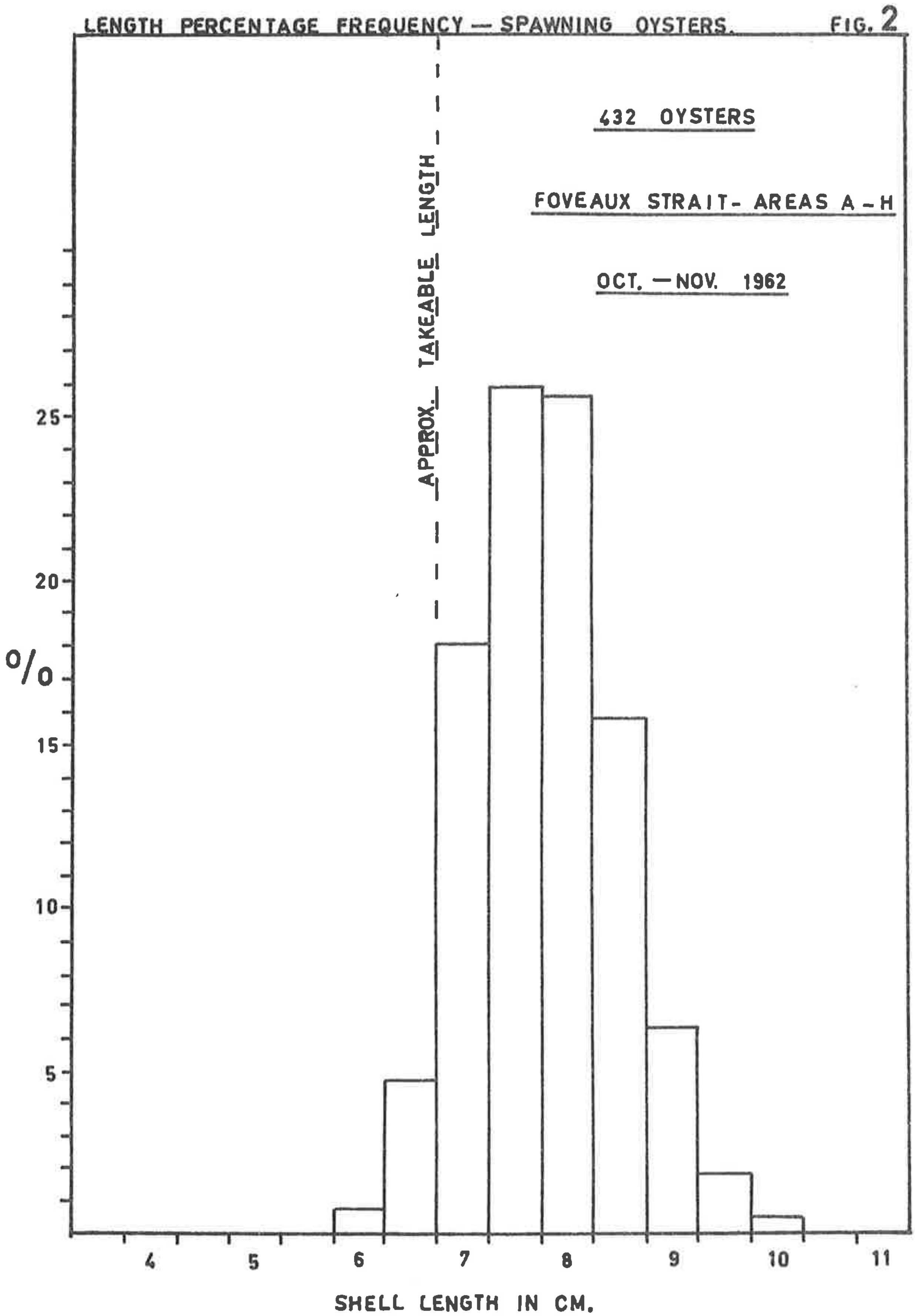
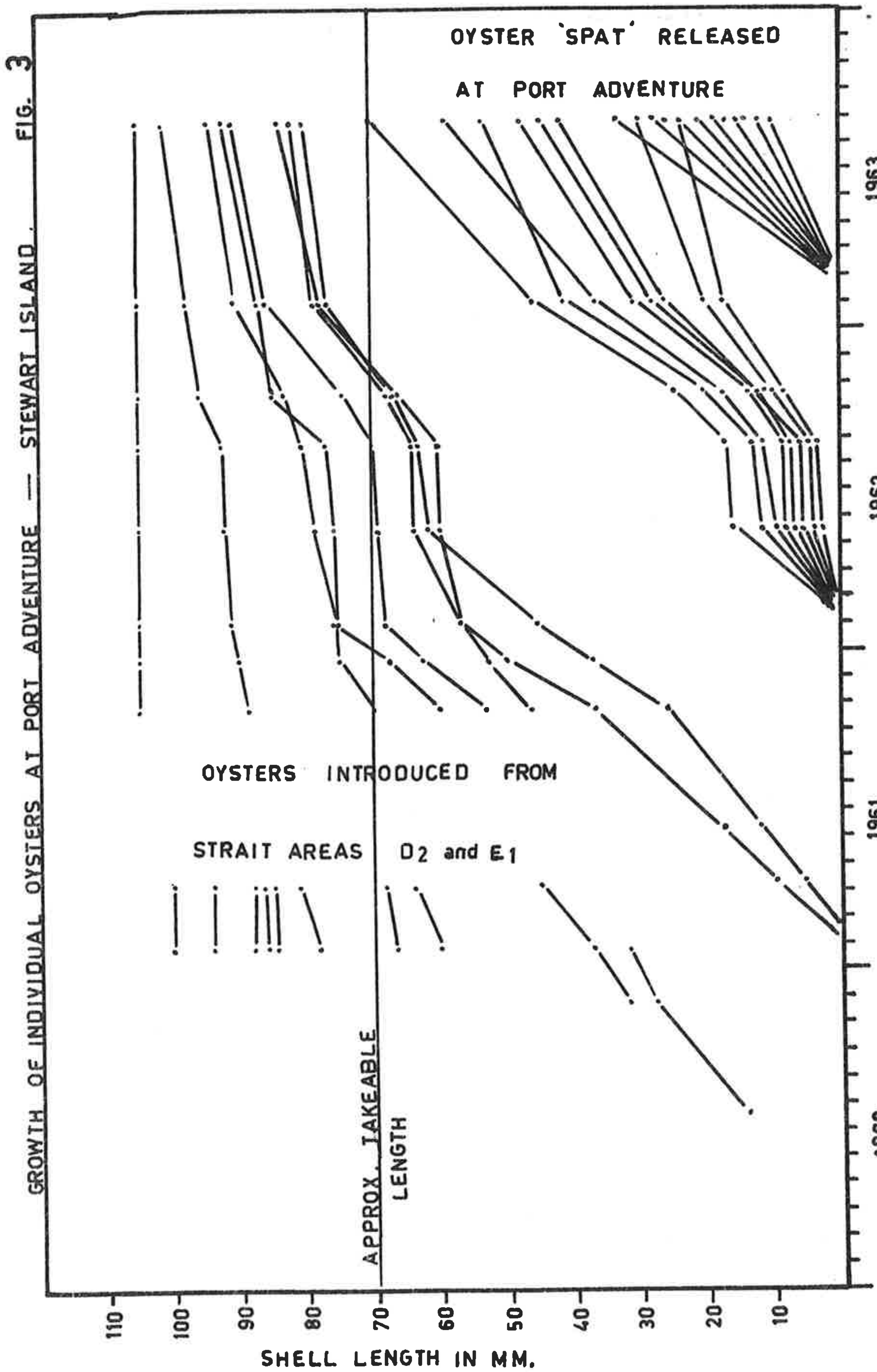

LENGTH PERCENTAGE FREQUENCY — SPAWNING OYSTERS.
FIG. 2
432 OYSTERS
FOVEAUX STRAIT - AREAS A - H
OCT. — NOV. 1962
APPROX. TAKEABLE LENGTH
%
25
20
15
10
5
4
5
6
7
8
9
10
11
SHELL LENGTH IN CM.



GROWTH OF INDIVIDUAL OYSTERS AT PORT ADVENTURE — STEWART ISLAND. FIG. 3

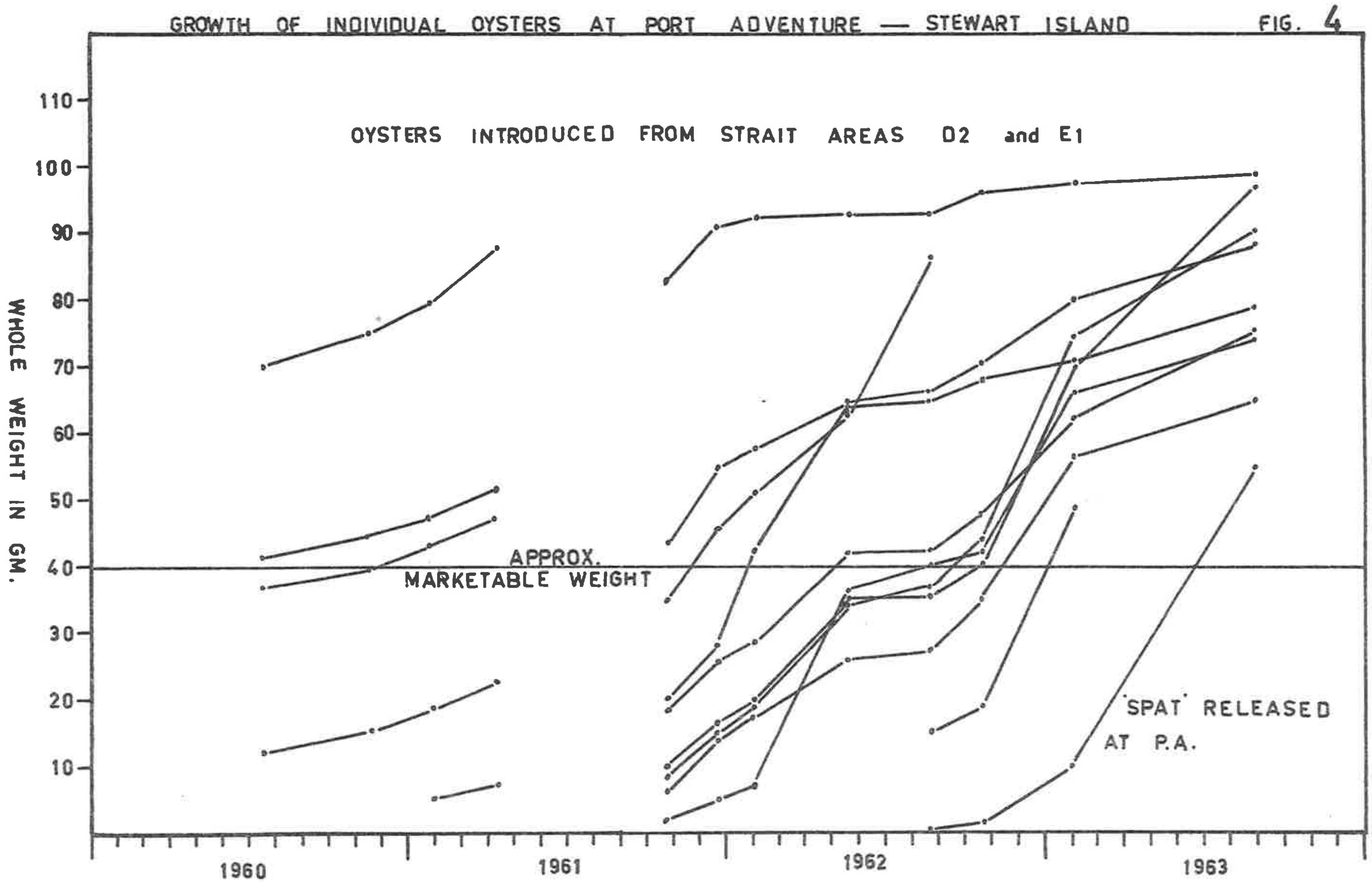
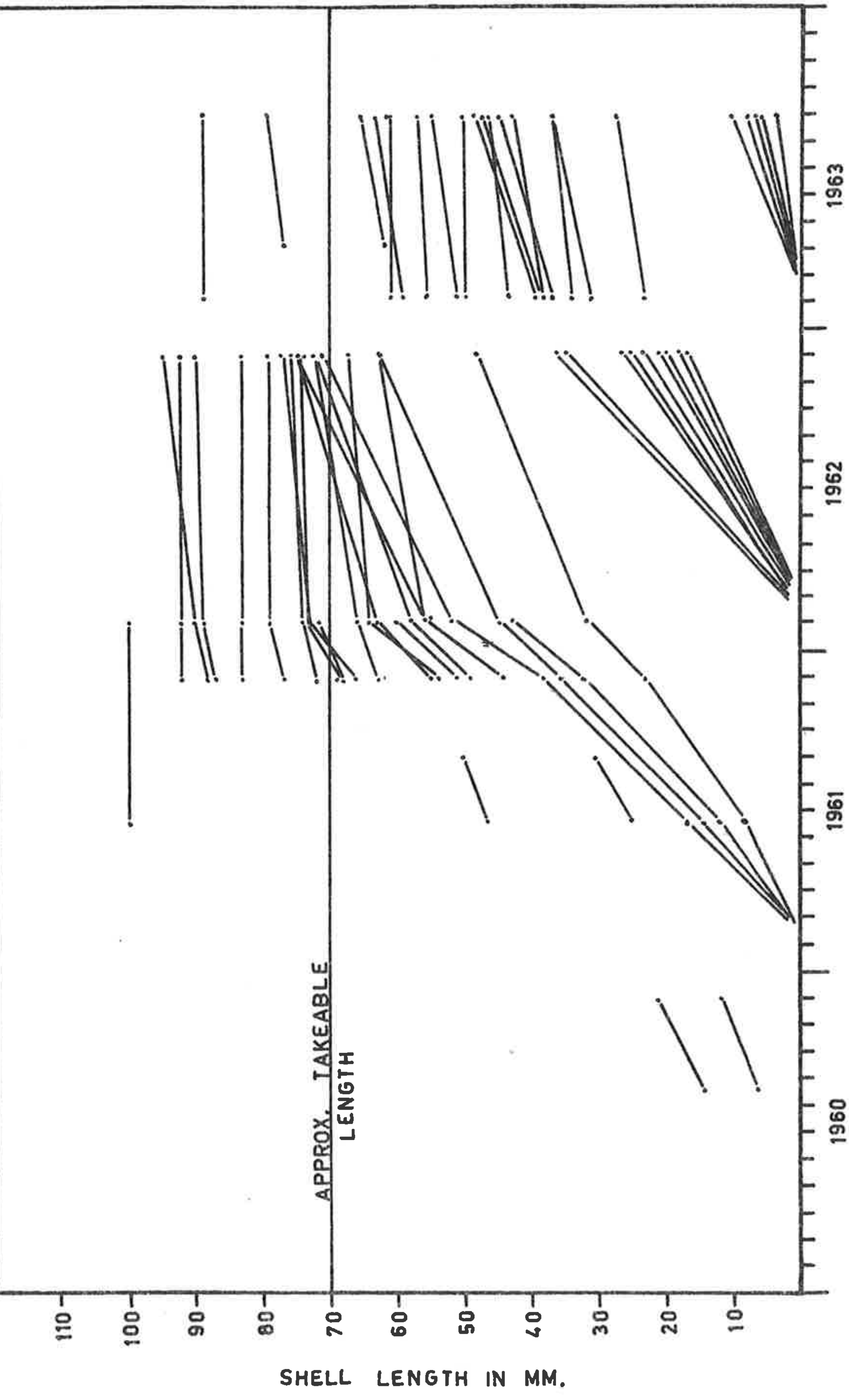

GROWTH OF INDIVIDUAL OYSTERS AT PORT ADVENTURE — STEWART ISLAND
FIG. 4
OYSTERS INTRODUCED FROM STRAIT AREAS D2 and E1
WHOLE WEIGHT IN GM.
110
100
90
80
70
60
50
40
30
20
10
APPROX. MARKETABLE WEIGHT
'SPAT' RELEASED AT P.A.
1960
1961
1962
1963

FIG. 5

GROWTH OF INDIVIDUAL OYSTERS IN FOVEAUX STRAIT



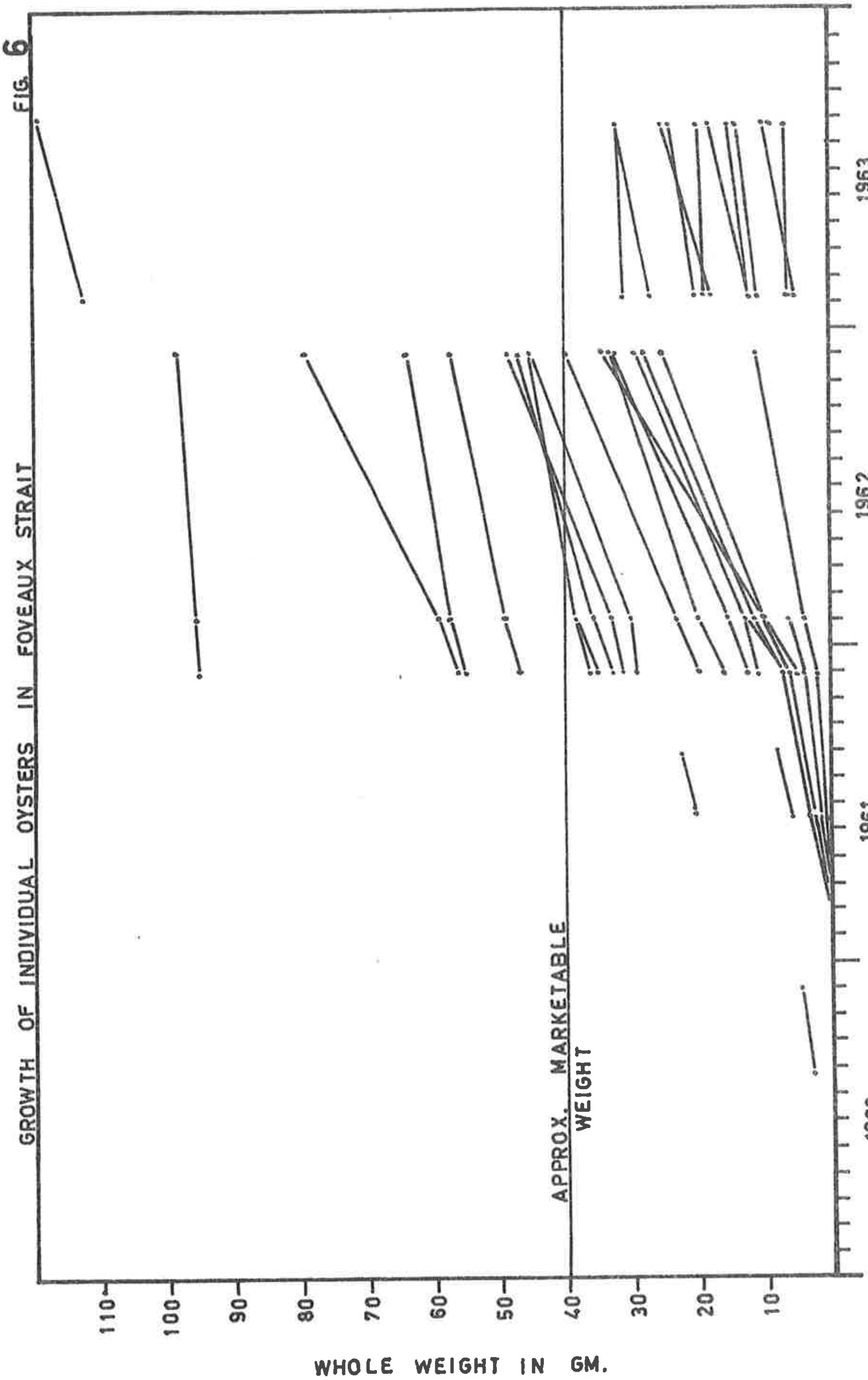
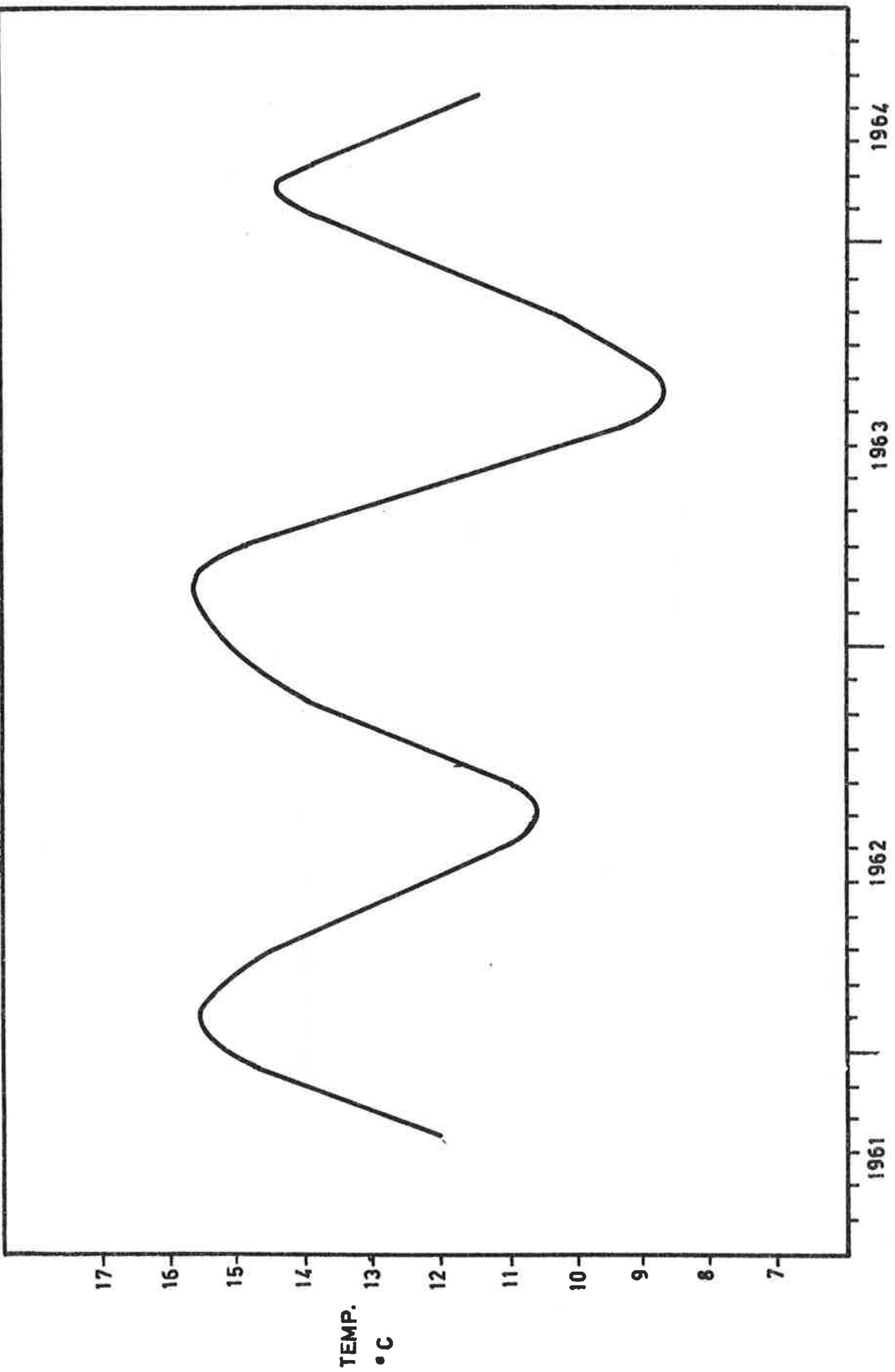
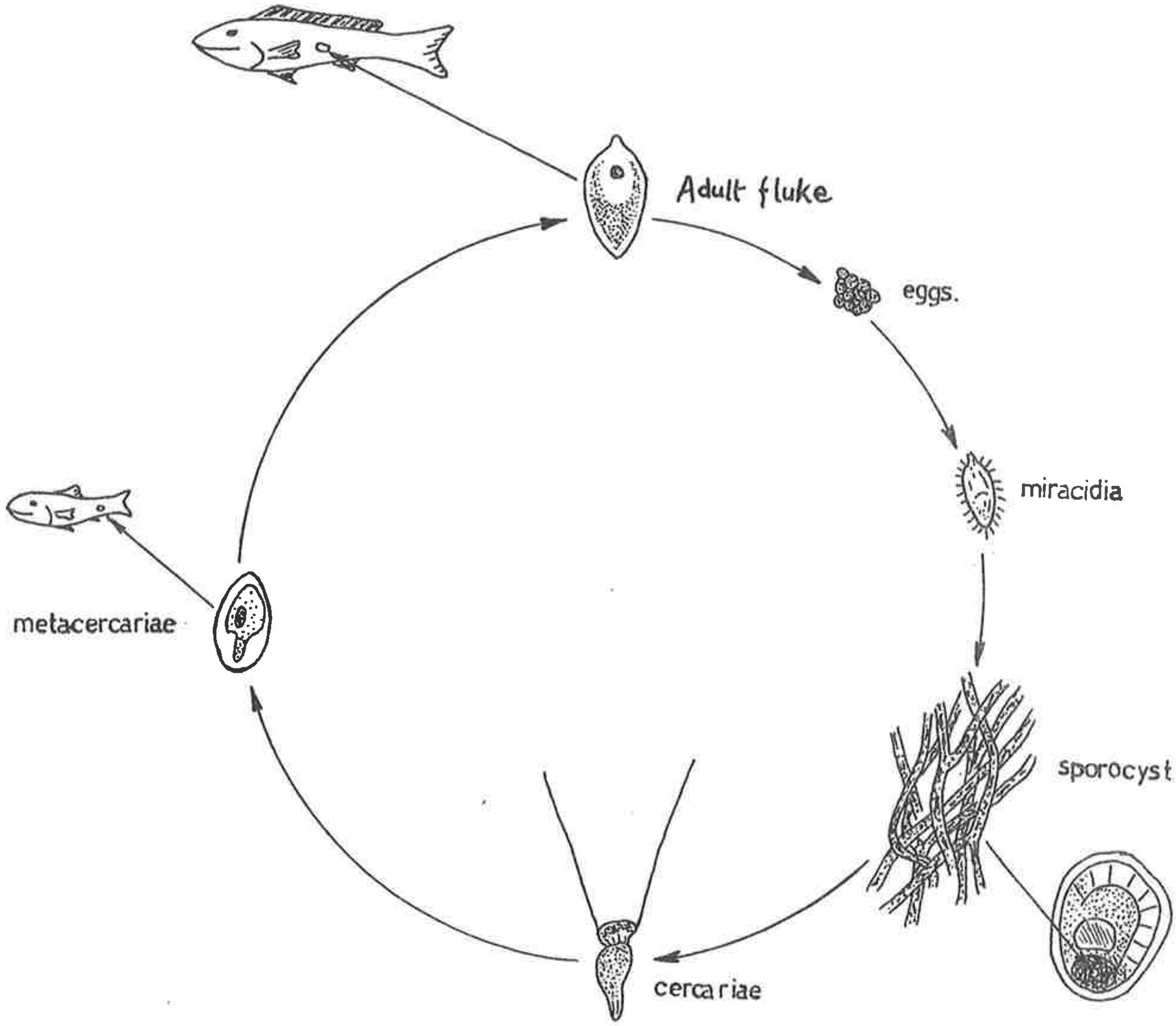


FIG. 6
GROWTH OF INDIVIDUAL OYSTERS IN FOVEAUX STRAIT
APPROX. MARKETABLE WEIGHT
1960
1961
1962
1963
110
100
90
80
70
60
50
40
30
20
10
WHOLE WEIGHT IN GM.



MEAN SEA TEMPERATURE — FOVEAUX STRAIT. FIG. 7

FIG. 8



THEORETICAL LIFE-CYCLE OF A TREMATODE PARASITE INFECTING FOVEAUX STRAIT OYSTERS - HOWELL (1963)

Plate 1 - Oyster Clumps

Area A 1964

Area G 1969

Plate 2 - Pectinura maculata

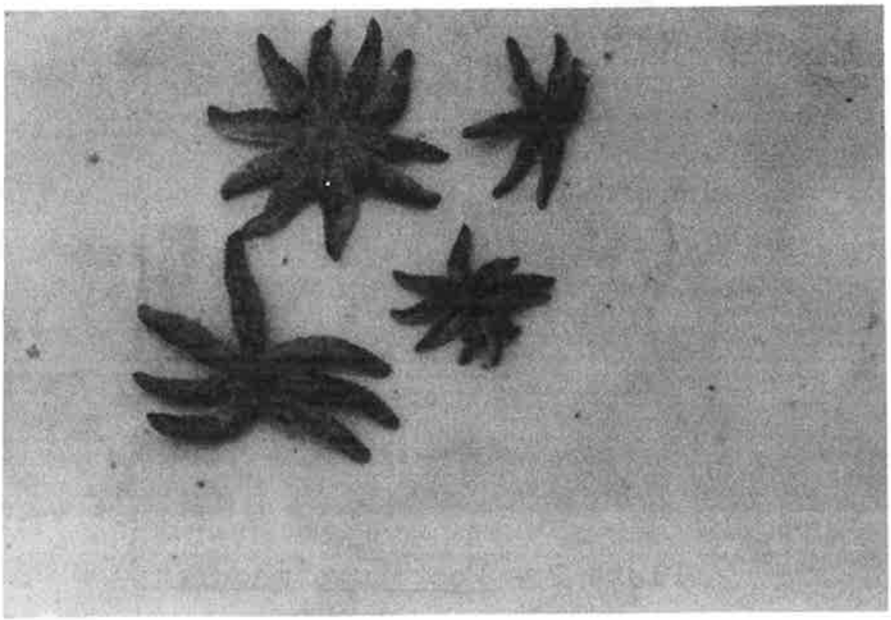


Plate 3 - Coscinasterias calamari

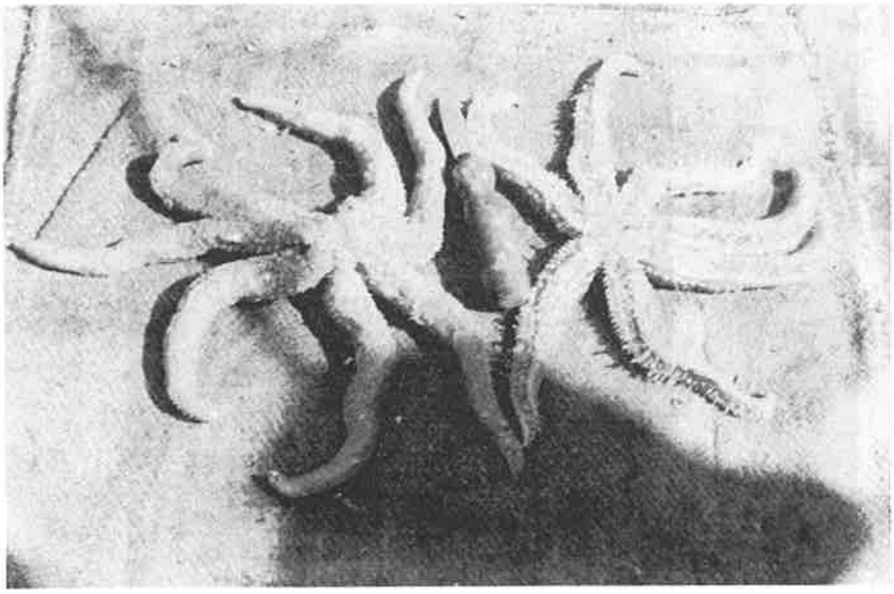


Plate 4 - Astrostole scabra

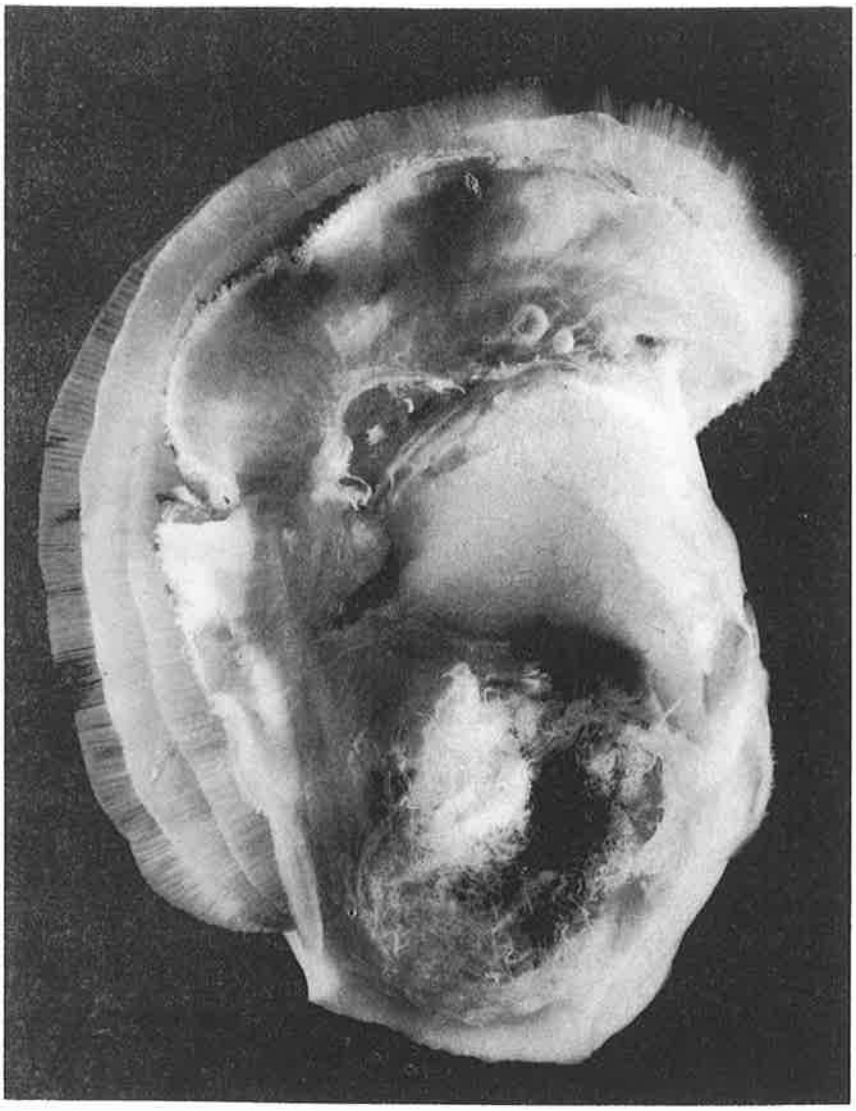


Plate 6 - Oyster infected by <u>Bucephalus</u>. Sporocyst tubules visible in teased gonad tissue.