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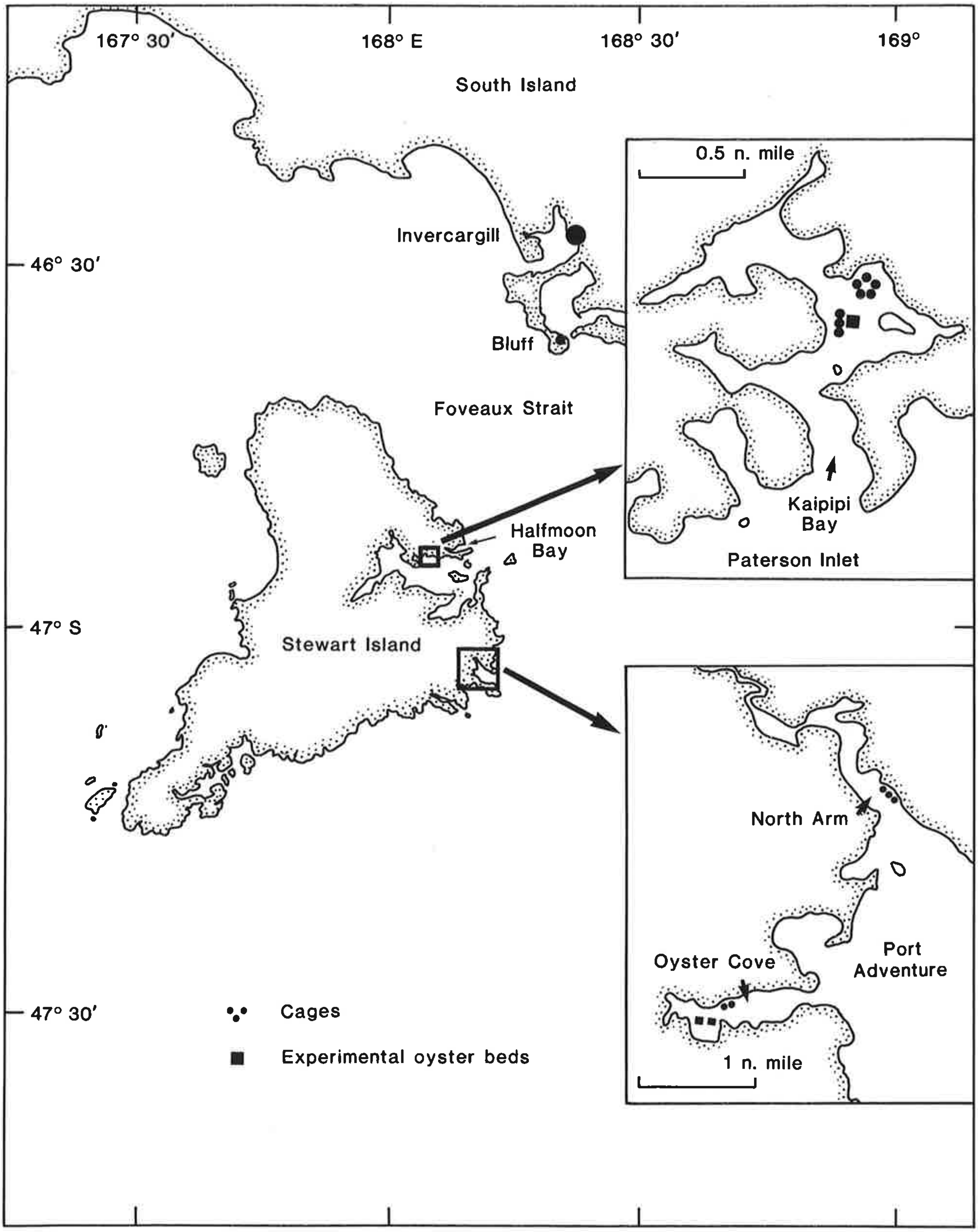

Fig. 1: Map of Stewart Island with the experimental sites in Paterson Inlet and Port Adventure.

Abstract

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Experimental on-bottom and off-bottom cultivation of dredge oysters, *Tiostrea (Ostrea) lutaria*, at Stewart Island, New Zealand during 1969–72 suggested their potential for commercial farming. Data on oysters transferred from the Foveaux Strait oyster beds to cages at Stewart Island, and on spat naturally settled and on-grown on the cages, show dredge oysters can grow to about 40 mm in height in 18 months under the experimental off-bottom conditions, but would take at least 3 years to reach the current marketable size for wild dredge oysters (57 mm in length). Spat settled abundantly on natural and artificial substrates near incubating adult oysters. Settlement densities were affected by water movement, light intensity, and the surface texture of the substrate. Oyster shell rejects from the Foveaux Strait fishery, both recently opened shell and old bleached shell, were suitable substrates for spat catching. About 50% mortality of the spat occurred shortly after settlement; adult mortality (in continuously submerged oysters) was generally much less than 50% and was probably related to salinity fluctuations. Off-bottom cultivation could provide the necessary control over growth, spawning, and spat catching to enable viable farming of *Tiostrea lutaria.*

Introduction

During Fisheries Research Division investigations of the biology of oysters on the Foveaux Strait beds in the late 1960s and early 1970s, some experiments were undertaken on aspects relevant to oyster farming. The experiments were small-scale and short-term, but they provided almost the only data available on dredge oysters, *Tiostrea (Ostrea) lutaria*, grown under farming conditions.

Present interest in diversification of marine farming in New Zealand has prompted the publication of the results 15 years after the experiments were completed by the author. Stewart Island was chosen as the experimental site because of its proximity to the oyster beds in Foveaux Strait, but the general results should be applicable to other potential marine farming sites around New Zealand.

The biology of New Zealand dredge oysters has been discussed in relation to the wild fishery in Foveaux Strait (Cranfield 1975, 1979; Stead 1971) and briefly, with respect to farming techniques, in the only previous publication on dredge oyster farming (Waugh 1969). The experiments described here concentrated on growth and settlement under experimental farming conditions.

Potential farming techniques

There are essentially two different techniques for farming oysters:

1. For on-bottom cultivation the oysters are placed directly on a suitable area of sea bed. This simple method is used extensively in France and The Netherlands, and it was discussed by Waugh (1969).
2. For off-bottom cultivation the oysters are held in suspension, either from the sea bed or from the sea surface. This method is used throughout the world for farming rock oysters on racks, trays, rafts, or longlines.

Both techniques could be used in farming dredge oysters in New Zealand.

Experimental areas

Two sites on the east coast of Stewart Island (168° E 47° S) were selected for the experiments (Fig. 1).

Kaipipi Bay is a small arm off Paterson Inlet. It is accessible by track from Halfmoon Bay, the population centre of the island. The local fishermen's co-operative had expressed interest in establishing an oyster farm in this area. Preliminary inspection showed there was a substantial oyster population in Kaipipi Bay, though most dredge oysters here were small and attached to rocks at about mean low water, and few were established much below extreme low water springs.

Port Adventure is 20 km south of Kaipipi Bay and is accessible only by sea. It was once an important oyster gathering area, and the first commercial harvesting of dredge oysters was from Oyster Cove in the 1860s. Substantial numbers of oysters are still present, mainly attached to rocks and stones around mean low water, but some are partially embedded in sandy mud. They are generally larger than oysters at Kaipipi Bay, deep shelled, and of more regular shape than oysters from Foveaux Strait. Oyster Cove was also the site for experiments in 1960–63 in which a few oysters were transferred from Foveaux Strait for on-growing (Stead 1971).

Both Kaipipi Bay and Port Adventure have areas of firm, flat sea bed covered with 1–2 m of water at low tide.

Methods

Experimental oyster beds

To investigate the feasibility of on-bottom cultivation, small artificial oyster beds were established at the two experimental sites. In December 1969 two plots, each 25 × 6 m in area, were marked out on the southern side of Oyster Cove on firm, clean sea bed in 1–2 m of water at low tide. The beds were established by spreading over each plot 20 sacks (each weighing about 75 kg) of old, dried oyster shell taken from commercial shell dumps in Bluff. Five sacks of live oysters, dredged a few hours earlier from Foveaux Strait, were then laid on one bed. The second bed received no live oysters.

In January 1970 a similar 150 m² bed was established in the centre of Kaipipi Bay by spreading 20 sacks of old, dried shell and 10 sacks of live oysters. Each sack of live oysters contained about 800 oysters; therefore, the artificial beds at Kaipipi Bay and Oyster Cove had densities of about 50 and 25 oysters per square metre respectively.

Growth

Oysters of various sizes were transferred from Foveaux Strait and held in cages at the two experimental sites to determine growth rate. Two types of cage were used: 1.0 × 0.5 × 0.1 m wooden framed cages, with 20 mm wire mesh top and bottom, and 1.0 × 1.0 × 0.1 m steel framed cages, with two layers of wire mesh (50 and 20 mm) covering the top, bottom, and sides (Fig. 2). The cages were bridled with floating ropes so that they could be retrieved by grapnel from the surface.

Five of the metal framed cages were placed in Port Adventure in December 1969: three in the North Arm and two in Oyster Cove. All were in at least 1.5 m of water at low tide.

Eight cages were set out in Kaipipi Bay in June 1970: three sited intertidally just above mean low water, two just below extreme low water springs

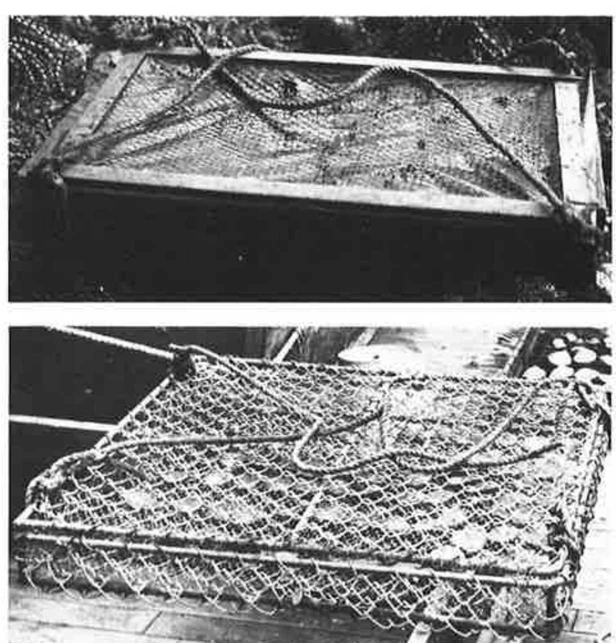

Fig. 2: Cages used for the farming experiments; wooden framed (top) and metal framed (bottom).

(i.e., just permanently submerged), and three near the artificial oyster bed in about 1.5 m of water at low tide.

The cages contained combinations of individually tagged oysters (each measured for length, height, and width, to the nearest millimetre) and untagged oysters in three discrete size groups determined by height (small, 35–45 mm; medium, 60–70 mm; and large, 80–100 mm). Height (*H*) is the maximum measurement from hinge to outer margin; length (*L*), the maximum measurement at right angles to height; and width (*W*), the maximum thickness measured perpendicular to length and height.

The cages were examined after 6, 9, and 18 months in Port Adventure and after 6 and 14 months in Kaipipi Bay. The oysters were remeasured to assess growth, and the numbers of dead oysters were recorded to determine mortality.

Spat settlement

During December 1971-February 1972 settlement was investigated in the North Arm of Port Adventure. In early December 11 cages (6 metal framed and 5 wooden framed) were placed on the sea bed in about the same position as the cages used for the earlier growth experiments. Each 1 m^2 metal framed cage was divided in half by a vertical wire netting partition. The cages were stocked with live oysters of various sizes and with different types and combinations of potential settlement surfaces (Table 1). The live oysters were dredged from Foveaux Strait a few hours before they were placed in the cages. They were graded into 5 mm size groups by being passed through a series of metal rings (ring size approximated length).

The oyster shell used as a settlement surface included recently opened shell (opened immediately before being placed in the cages) and dead oyster bed shell (also dredged from Foveaux Strait). The density of spat already on these shells was determined by counts on subsamples of the shells. There were no spat on the old bleached shell, which had been gathered from commercial shell dumps in Bluff. About 200–250 pieces of shell were used as settlement substrate in each cage or half cage.

The cages also contained 280 × 140 mm settlement plates of four types: clear perspex, sandblasted glass, smooth plate glass, and asbestos (Polite). Plates in the metal cages were wired to the inside of the top netting, whereas those in the wooden cages were wired to the inside of the bottom netting. Each cage contained one plate of each type (Fig. 3). Three of the cages were lined with polyvinyl chloride (PVC) plastic sheeting top and bottom to restrict the flow of water.

The cages were re-examined after 3 months, in February 1972, and the density and success of settlement were estimated from counts of live and dead spat on shells and settlement plates. Mortality and growth of the adult oysters were also recorded.

Fig. 3: Metal framed cage showing the four settlement plates attached to the top netting.

TABLE 1: Cage, oyster, and settlement substrate data for the spat settlement experiment in the North Arm, Port Adventure, December 1971

Cage No.	Type	Oysters Initial No.	Oysters Size range (length, mm)	Settlement substrate*	Remarks
226	Wooden	100	36–40	OBS	
126	Wooden	100	46–50	OBS	
34	Wooden	100	56–60	OBS	
96	Wooden	100	61–65	OBS	
190	Wooden	50	56–60	OBS	Black plastic sheeting top and bottom
285 Side A	Metal	0		DOBS	
Side B	Metal	0		OBS	
23 Side A	Metal	50	61–65	ROS	
Side B	Metal	50	61–65	WMR	
200 Side A	Metal	50	61–65	DOBS	
Side B	Metal	50	61–65	OBS	
265 Side A	Metal	85	36–40	DOBS	
Side B	Metal	90	36–40	OBS	
69 Side A	Metal	50	61–65	DOBS	Black plastic sheeting top and bottom
Side B	Metal	50	61–65	OBS	
231 Side A	Metal	50	61–65	DOBS	Clear plastic sheeting top and bottom
Side B	Metal	50	61–65	OBS	

*OBS, old bleached shell; DOBS, dead oyster bed shell; ROS, recently opened shell; WMR, wood, metal, rope.

Results

Experimental oyster beds

The experimental sites were revisited in June 1970, 6–7 months after the beds were laid, and all three beds were virtually non-existent. At Kaipipi Bay there was heavy silting and overgrowth with seaweed, mainly the brown necklace seaweed, *Hormosira banksii*. No live oysters were found. At Oyster Cove most of the oyster shell had sunk into the sea bed. Although no adult live oysters were recovered, several shells bearing small attached oysters up to 15 mm in length were found on the bed which had received the five sacks of live oysters.

The quantities of shell and oysters laid on these plots had been insufficient to form stable, artificial beds, so a further 30 sacks of dried shell were laid over the two plots in Oyster Cove in September 1970. After a further 17 months, in February 1972, these artificial beds were intact, clearly visible, and apparently stable.

Growth in cages

Adult growth

Measurements of the small, medium, and large oysters after 9 and 18 months in Port Adventure showed substantial differences in the growth of the three groups and small differences between the two locations (Table 2). The small oysters increased in height by an average of 19% in 9 months and 40% in 18 months, the medium oysters by 7% and 12% respectively, and the large oysters increased by less than 1% in the 18 months. Growth in the North Arm was slightly better than in Oyster Cove.

The increase in the range of size of the oysters within the small and medium groups between December 1969 and June 1971 suggested significant variation in growth between individuals (Fig. 4). This was confirmed by measurements made on individually tagged oysters on four occasions between December 1969 and June 1971. For a

TABLE 2: Size (height, mm) of untagged oysters in cages at Port Adventure in December 1969, September 1970, and June 1971

	Small oysters				Medium oysters				Large oysters			
	Sample size	Mean height (mm)	% increase*	% mortality†	Sample size	Mean height (mm)	% increase	% mortality	Sample size	Mean height (mm)	% increase	% mortality
Oyster Cove												
Dec 1969	70	40.0 (±2.6)‡			40	65.4 (±2.8)			43	88.5 (±4.7)		
Sep 1970	66	46.1 (±5.6)	15.3	5.7	38	69.2 (±3.5)	5.8	5.0	40	88.1 (±4.3)	−0.5	7.0
Jun 1971	53	51.7 (±5.5)	29.3	19.7	38	71.9 (±3.5)	9.9	0.0	38	88.2 (±4.0)	−0.3	5.0
North Arm												
Dec 1969	65	40.3 (±2.3)			55	65.0 (±2.4)			80	88.6 (±3.9)		
Sep 1970	50	49.5 (±5.7)	22.8	23.1	55	70.5 (±4.5)	8.5	0.0	76	89.4 (±4.0)	0.9	5.0
Jun 1971	24	60.4 (±3.4)	49.9	52.0	43	74.0 (±4.6)	13.8	21.8	65	89.1 (±3.9)	0.6	14.5

*% increase is relative to December 1969.

†Mortality is the difference between sample sizes on the successive dates, relative to the dates.

‡Standard deviation is in parentheses.

more comprehensive assessment of the increase in total size than that provided by the increase in one dimension (e.g., height), a "volume equivalent" (*VE*) incorporating all three measured dimensions was calculated for each tagged oyster at each successive time of measurement. The *VE* was derived from the formula for the volume of a cone or pyramid: $V = 1/3(b \times a)$, where V is volume, b is area of base, and a is altitude. The oyster length and height measurements have been used to approximate the area of the base to a circle of radius $1/4(L + H)$. Thus,

$$VE = 1/3\pi\left(\frac{L + H}{4}\right)^2 W$$

There was substantial individual variation in the growth (measured as change in *VE*) of oysters of all three size groups (Fig. 5). Measurements from the North Arm and Oyster Cove showed that small oysters increased by an average of 193% over the 18 months, but individual increases varied from 80 to 363%. Medium oysters increased by an average of 14% (range 0 to 36%), whereas for large oysters the average change in *VE* was −2% (range −13 to +13%).

No meaningful growth data were obtained from the cages in Kaipipi Bay because of the very high levels of mortality at this site.

The growth of the adult oysters used as breeding stock during the spat settlement experiment was also directly related to their initial size: 66% of the smallest (36–40 mm) oysters, 9% of the medium (46–50 mm) oysters, and 1% of the large (56–60 mm) oysters grew into the next, or a subsequent, ring size within the 3 months of the experiment (Table 3). The largest (over 60 mm) oysters showed no apparent growth.

Juvenile growth

No oysters smaller than 35 mm in height were used to stock the cages for the growth experiments; however, some data on the growth of juvenile oysters at Port Adventure were obtained from measurements of spat which settled and grew attached to the adult experimental oysters in the cages and to the cages themselves.

When first measured in June 1970, after a maximum of 6 months' growth, most of the spat were 10–15 mm in height. By June 1971, after a maximum of 18 months over two summer settlement periods—peak settlement occurs in Foveaux Strait during December-January (Cranfield and Allen 1977)—there were numerous attached oysters up to 60 mm in height (Fig. 6).

The size frequencies of oysters attached to cages in Port Adventure in June 1971 suggest two separate age classes (Fig. 7). Oysters up to 25 mm in height probably represent the later settlement (December 1970-January 1971), whereas the 25–60 mm individuals probably settled during the previous (1969–70) breeding season. The suppression of the older age class in the North Arm sample may be related to the heavy mortality which occurred there during the final period of the experiment (*see* Table 2).

Mortality in cages

Between December 1969 and June 1970 there was 4% mortality in the cages at Port Adventure. During the winter of June-September 1970, a further 5% mortality occurred. For both these periods mortality was the same at the two sites in Port Adventure. During the following period, September 1970-June 1971, there was 12% mortality at Oyster Cove and 23% in the North Arm. These

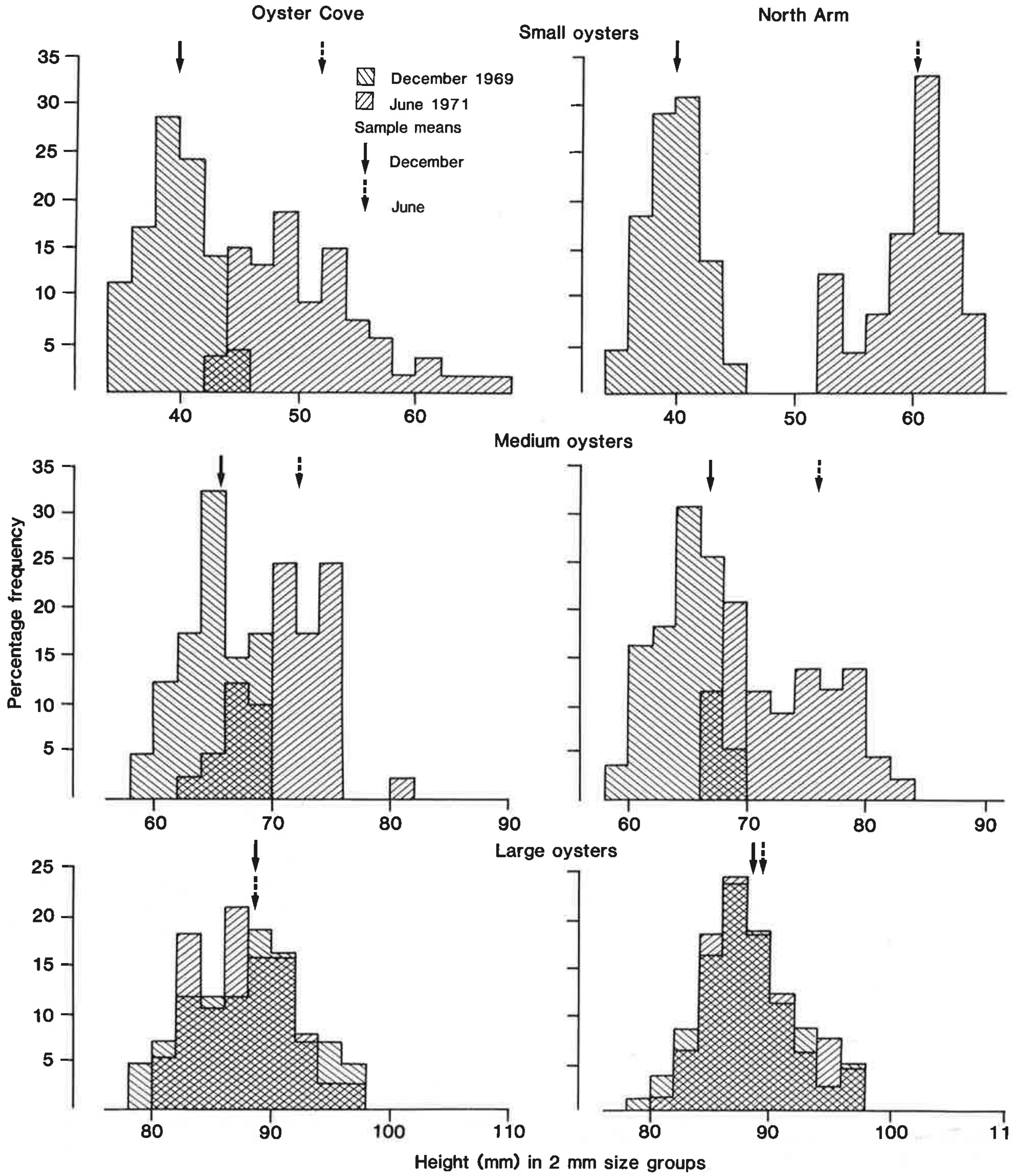

Fig. 4: Growth of small, medium, and large oysters in cages at two sites in Port Adventure between December 1969 and June 1971.

mortality figures are relative to the number of oysters alive at the start of each period and are derived from combined totals for tagged and untagged oysters of all sizes. For untagged oysters, heavy mortality occurred in the small oysters during September 1970-June 1971, particularly in the North Arm, where over 50% of the small oysters died, compared with less than 20% mortality in Oyster Cove.

Mortality of the brood stock adults during the 3 month settlement experiment in summer 1971–72 varied greatly between the different cages. It ranged from 2 to 18% (*see* Table 3) and was generally much higher than the 4% recorded during the summer-autumn of 1969–70, but it was less than the heavy mortality amongst the small oysters in the North Arm during the period which included the summer of 1970–71.

Mortality in the cages at Kaipipi Bay was much heavier than at Port Adventure and was at least partly related to the specific siting of the cages.

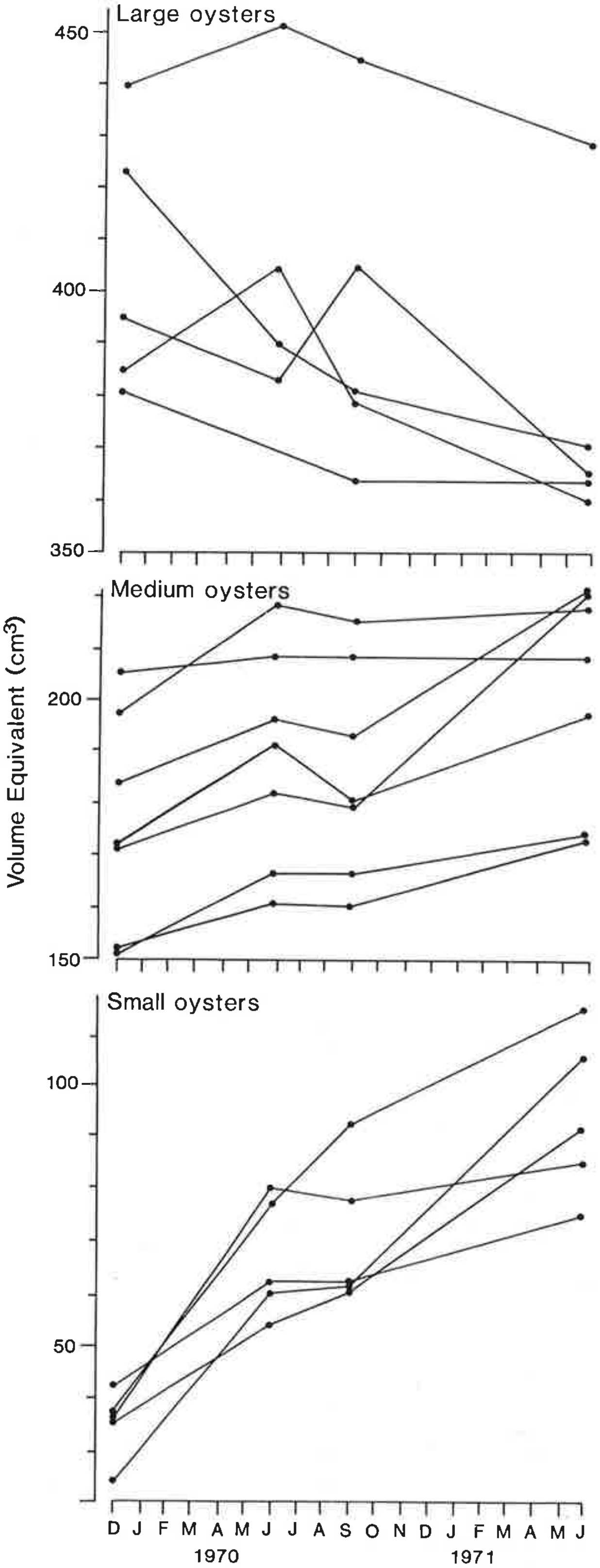

Fig. 5: Growth variation between small, medium, and large individual oysters at Oyster Cove, Port Adventure between December 1969 and June 1971.

During the winter-spring (June-December) of 1970, mortality averaged 59% in the intertidal cages and 37% in cages just below low water. The cages at 1.5 m below low water were not examined until the end of the experiment in August 1971, after 14 months. They showed 99% mortality—100% in the intertidal cages and 85% in those just permanently submerged.

Settlement on plates

Spat settlement occurred almost exclusively (96%) on the lower surfaces of the settlement plates, whether the plates were attached to the top or bottom netting of the cage. There was substantial variation in settlement on the different types of plate (Fig. 8 and Table 4). Spat smaller than 2 mm were susceptible to high natural mortality (Cranfield 1968b), so only spat larger than 2 mm were included in the counts to ensure that a realistic measure of the success of settlement was obtained. Spat showed a marked preference for the rough surfaces of sandblasted glass (56% of total settlement) and asbestos (27%), compared with the smooth surfaces of plate glass (16%) and perspex (less than 1%). More spat settlement occurred on the plates in the wooden cages than in the metal cages.

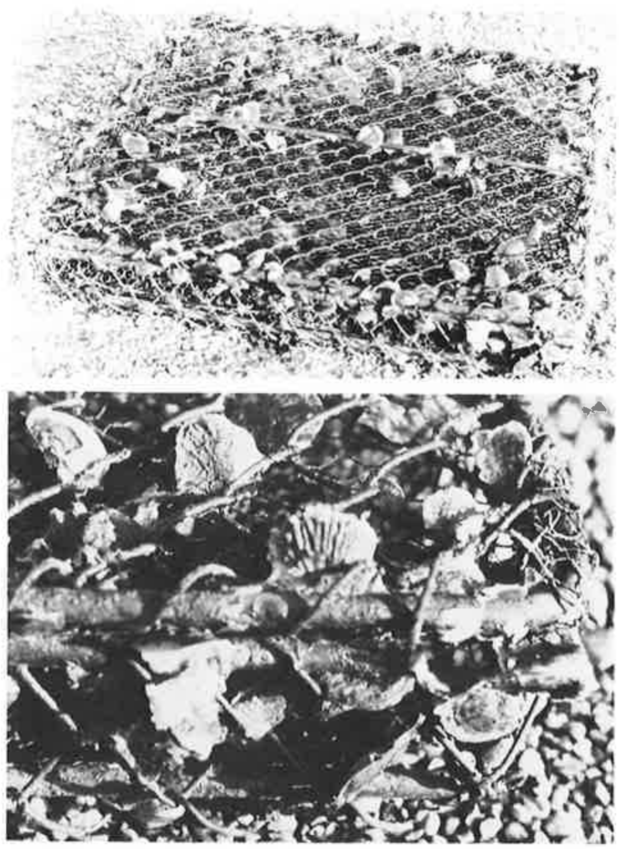

Fig. 6: Settlement of oysters on cages after 18 months in Oyster Cove, Port Adventure; settlement on upper parts of the cage (top) and concentration of settlement on the metal framework (bottom).

TABLE 3: Growth and mortality of adult oysters in cages in the North Arm, Port Adventure during December 1971-February 1972

Cage No.	Ring size (mm)	No. of oysters, December 1971	No. of oysters per 5 mm ring size, February 1972							% mortality
			31–35	36–40	41–45	46–50	51–55	56–60	61–65	
226	36–40	100	2	25	52	8				12
126	46–50	100			8	77	9			5
34	56–60	100					18	79		2
96	61–65	100							92	8
190	56–60	50						43	2	10
23	61–65	100							82	18
200	61–65	100							83	17
265	36–40	175		34	82	33	6			13
69	61–65	100								12*
231	61–65	100							97	3

*Remaining oysters not measured.

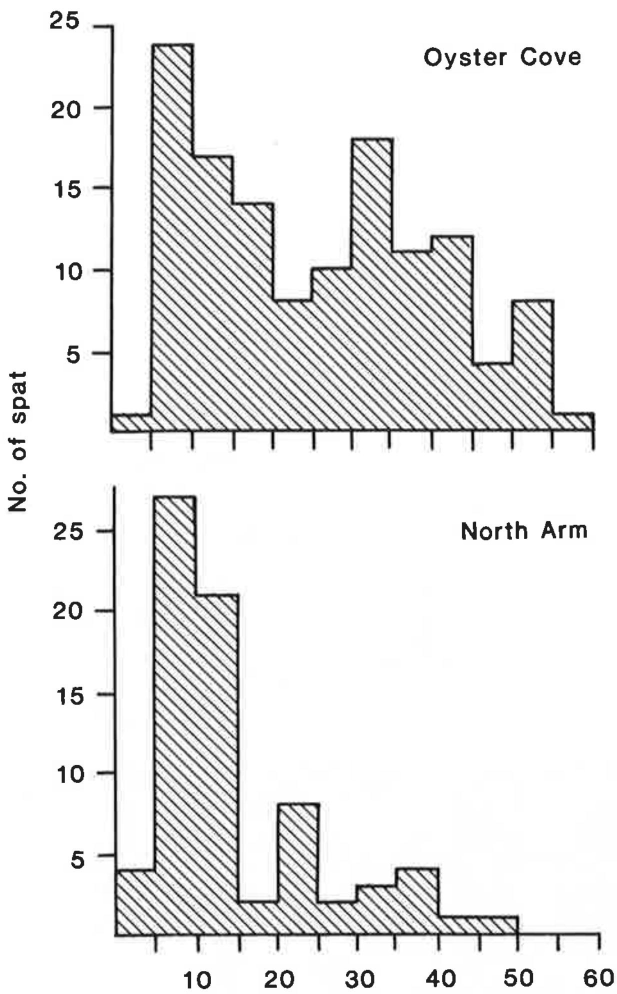

Fig. 7: Size (height, mm) frequency of oysters attached to metal framed cages at two sites in Port Adventure in June 1971.

Most spat were 2–5 mm in height, the largest being up to 11 mm (Fig. 9). Many small dead spat, smaller than 2 mm, were seen on the glass and asbestos plates. Live spat tended to be thin and were closely adhered to the surface of the plates.

Settlement on the plates in the wooden cages varied in relation to the size of the adult oysters (Table 4). Density increased with adult size up to 56–60 mm; though there was no settlement on the plates in the cage with black plastic. A slightly lower density occurred in the cage with the largest (over 60 mm) oysters. In the metal cages there was much higher settlement in cage No. 200, which contained large oysters, than cage No. 265, which had small oysters; though cage No. 23 also contained large oysters, but had very low settlement. Some settlement was also recorded on plates in the cage containing no live adult oysters.

Settlement on shells

Numbers of both live and dead spat on 50 shells (i.e., single valves) from each cage or half cage were counted to provide estimates of both settlement and initial mortality (Table 5). Most spat were 1–2 mm in height, though a few were up to 8 mm. Settlement varied greatly in the different cages, but almost always occurred on only one side of the shell. This probably showed the orientation of the shell at the time of settlement and paralleled the single-sided pattern of settlement on the plates. The density of settlement on the shells also showed the same pattern, with respect to the size of the live oysters, as was seen in the settlement on plates. Highest settlement usually occurred on shells in association with large (56–60 mm) oysters, less with very large (over 60 mm), medium, and small oysters.

To enable comparisons of settlement on the different types of shell substrate, the figures for the total number of spat per shell for both dead oyster bed shell (DOBS) and recently opened shell (ROS) must be corrected for the initial settlement present when the shells were put into the cages. This was estimated at 4.5 and 3.5 spat per shell for DOBS and ROS respectively, from counts made in December on 100 shells of each type. Old bleached shell (OBS) had no live spat or any indication (i.e., attached lower valves) of dead spat.

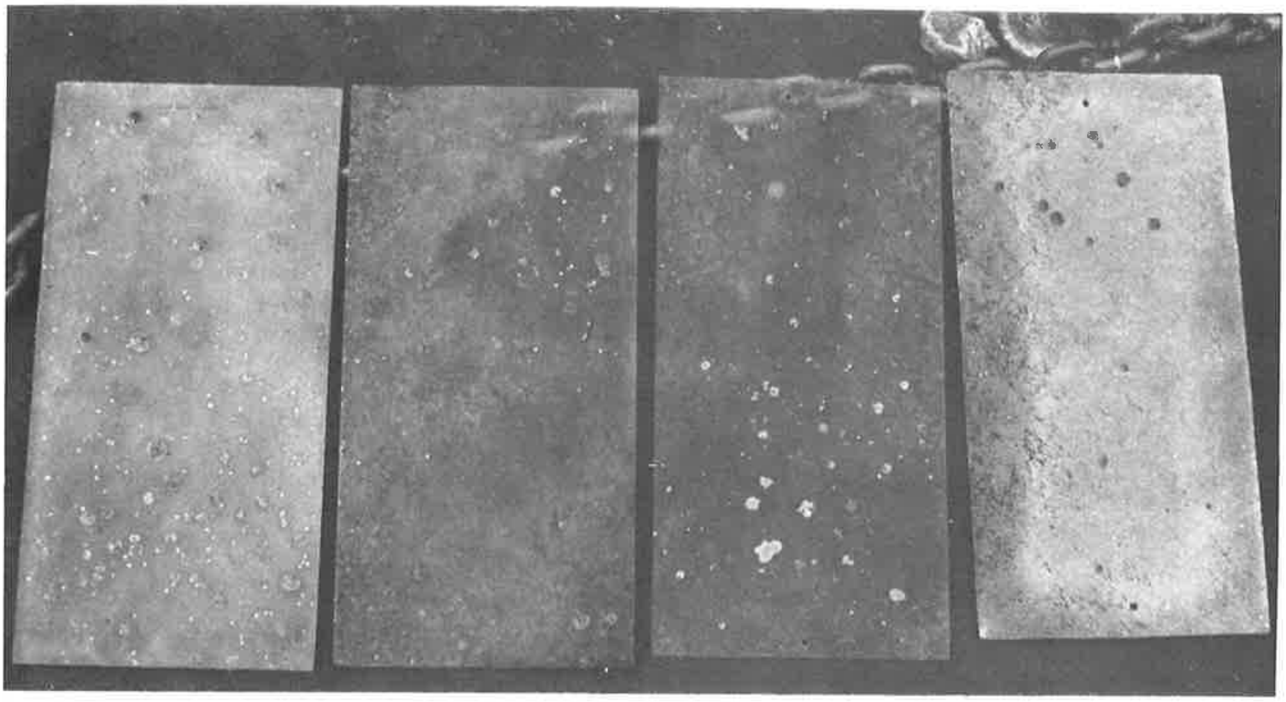

Fig. 8: Settlement on the lower surfaces of the four different settlement plates in cage No. 69 in February 1972, after 3 months in the North Arm, Port Adventure (left to right: sandblasted glass, smooth plate glass, perspex, asbestos).

It appears that the density of settlement in the cages without plastic was generally very low on DOBS and higher, but variable, on OBS and ROS (Table 5). A low level of settlement occurred on shells in the cage with no adult oysters (as was also recorded on the settlement plates). Higher settlements usually occurred in the three cages with plastic sheeting top and bottom, and no settlement occurred on the pieces of wood, metal, and rope in cage No. 23.

Mortality on shells

The high proportion of dead individuals recorded in the spat counts from all cages suggested significant natural mortality occurred shortly after settlement. About 50% mortality occurred throughout most of the cages, with no apparent difference between the types of shell substrate. Mortality was lowest (24–28%) on OBS in the two cages with the lowest settlement densities, but it was also low (35–37%) on OBS which had very high levels of settlement in the cages with plastic sheeting top and bottom.

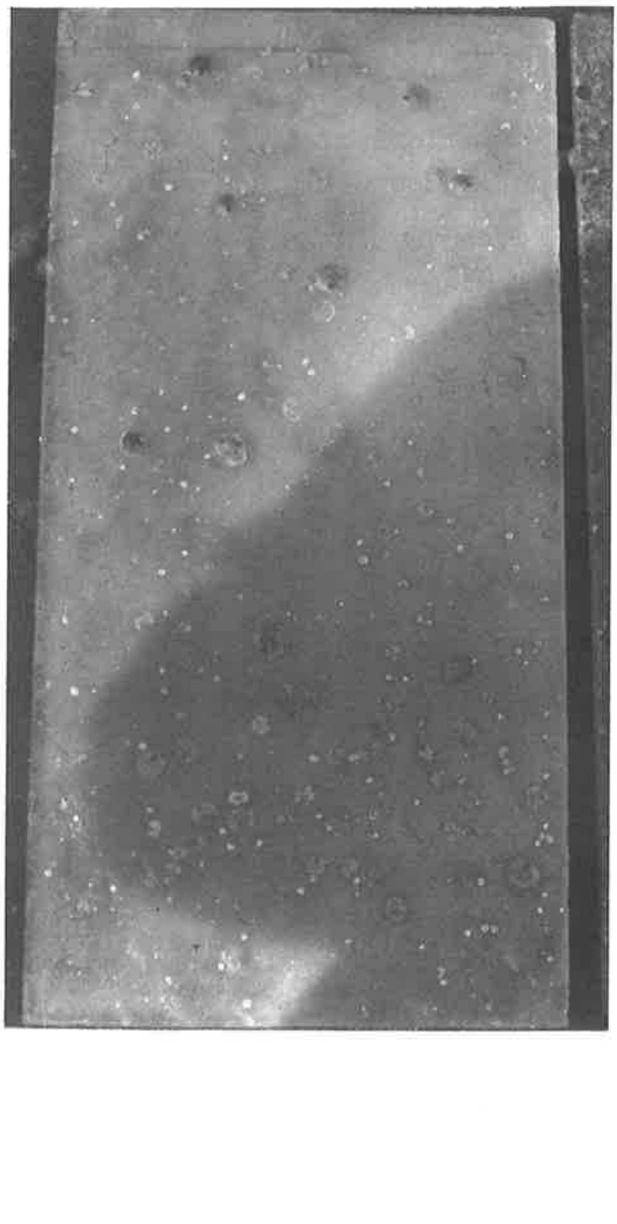

Fig. 9: Distribution and size range of live spat on the lower surface of the sandblasted glass settlement plate from cage No. 69.

TABLE 4: Settlement of spat on upper and lower surfaces of four types of settlement plate in cages in the North Arm, Port Adventure during December 1971-February 1972

Cage No.	Type	Covering	Oysters No.	Oysters Size	Sandblasted glass Lower	Sandblasted glass Upper	Asbestos Lower	Asbestos Upper	Plate glass (smooth) Lower	Plate glass (smooth) Upper	Perspex (clear) Lower	Perspex (clear) Upper	Total No. per cage
					No. of live spat per settlement plate*								
226	Wooden	Mesh	100	36–40	33	0	18	0	11	0	1	0	63
126	Wooden	Mesh	100	46–50	60	0	18	0	17	0	1	0	96
34	Wooden	Mesh	100	56–60	60	0	43	0	12	0	0	0	115
96	Wooden	Mesh	100	61–65	48	0	26	0	31	1	0	0	106
190	Wooden	Black plastic	50	56–60	0	0	0	0	0	0	0	0	0
285	Metal	Mesh	0		10	0	7	0	0	0	0	0	17
23	Metal	Mesh	100	61–65	8	0	3	0	2	0	0	0	13
200	Metal	Mesh	100	61–65	58	2	3	1	1	0	0	0	65
265	Metal	Mesh	175	36–40	12	0	8	0	0	0	0	0	20
69	Metal	Black plastic	100	61–65	26	0	16	0	14	0	0	0	56
231	Metal	Clear plastic	100	61–65	23	22	31	0	12	0	2	0	90
Total No. per plate type					338	24	173	1	100	1	4	0	

*Recorded as number of spat present on 18/2/72.

TABLE 5: Settlement of spat on four substrate types in cages in the North Arm, Port Adventure during December 1971-February 1972

Cage No.	Covering	Oysters No.	Oysters Size	Substrate type†	Mean settlement density* (No. of spat per shell) Live	Dead	Total	% mortality	% shells with spat	Total density after corrections for initial settlement
226	Mesh	100	36–40	OBS	1.1	0.9	2.1	44.7	54	2.1
126	Mesh	100	46–50	OBS	6.1	5.2	1.3	45.9	80	11.3
34	Mesh	100	56–60	OBS	10.3	6.9	17.2	40.1	83	17.2
96	Mesh	100	61–65	OBS	3.1	3.1	6.2	50.3	60	6.2
190	Black plastic	50	56–60	OBS	17.4	10.3	7.7	37.1	92	27.7
285 A	Mesh	0		DOBS	2.4	2.8	5.1	50.1	64	0.6
B	Mesh	0		OBS	0.6	0.2	0.9	27.9	38	0.9
23 A	Mesh	50	61–65	ROS	7.6	6.6	14.2	46.2	100	10.7
B	Mesh	50		WMR	0	0	0	0	0	0.0
200 A	Mesh	50	61–65	DOBS	2.1	2.8	4.8	57.4	100	0.3
B	Mesh	50		OBS	2.6	3.1	5.7	54.9	56	5.7
265 B	Mesh	85	36–40	DOBS	1.9	2.6	4.5	57.3	72	0.0
B	Mesh	90		OBS	1.1	0.3	1.4	23.9	40	1.4
69 A	Black plastic	50	61–65	DOBS	2.0	2.6	4.7	56.7	62	0.2
B	Black plastic	50		OBS	4.0	3.0	7.0	43.4	98	7.0
231 A	Clear plastic	50	61–65	DOBS	21.0	13.4	34.4	38.9	100	29.9
B	Clear plastic	50		OBS	10.1	5.4	15.5	34.8	96	15.5

*Derived from numbers on a sample of 50 single valves.

†OBS, old bleached shell; DOBS, dead oyster bed shell; ROS, recently opened shell; WMR, wood, metal, rope.

Discussion

Experimental oyster beds

Lack of sea bed stability, high siltation, and seaweed overgrowth negated most of the early effort to establish artificial beds, but subsequent consolidation and stabilisation achieved in Oyster Cove showed that artificial oyster beds could be established in this way. The quantity of material, if any, required to stabilise the sea bed would need to be determined for each potential farming site, as would the numbers of oysters such artificial beds could support. Oyster densities on the Foveaux Strait beds may be generally as low as 4–6 per square metre, but dredge oysters can exist in very high densities, up to 150 per square metre, in unexploited beds (Cranfield 1968a, 1979). Food availability is likely to be the main limitation on the stocking density, particularly for cultivation directly on the sea bed, where reduced water movement may lower the replenishment rate of the food supply.

Growth

The cage experiments, in which the oysters were protected both from sinking into the sediment and from the larger predators such as starfish and crabs, provided information on several aspects of off-bottom cultivation. Interpretation of the results is limited by the small scale of the experiments and by the difficulty of estimating natural variability, because of the lack of replication in the experimental design.

The growth rate of dredge oysters is highly variable. This was evident from the tagged oyster data from these experiments. Cranfield (1979) reported that the "rate of growth in Foveaux Strait varies considerably from year to year, from one area to another, and within the same area, from individual to individual". Stead (1971) suggested that growth in Foveaux Strait and at Port Adventure occurred mainly in summer, as it appeared to during these cage experiments. In the 3 summer months of 1971–72 most small oysters increased in length, some by at least 10 mm (Table 3). During the 18 months from December 1969 to June 1971, similar sized oysters showed a mean increase in height of 20 mm. This suggested a concentration of growth in summer. In addition, few of the individually tagged oysters showed any increase in size over the winter of 1970 (Fig. 5).

Stead (1971) showed that oysters transferred from Foveaux Strait to Port Adventure increased in height from 30–40 mm to about 80 mm, and from 50–60 mm to about 90 mm, in 22 months. Stead's "length" is equivalent to height in this publication. He also found that spat reached 10–35 mm in 6 months and 25–70 mm in 18 months.

The growth of the spat which settled on the cages during these experiments in Port Adventure showed that dredge oysters could grow to about 40 mm in height within 18 months of settlement. Growth data for small transferred oysters also suggested that it would take at least 3 years' growth under these experimental off-bottom farming conditions to grow dredge oysters to the current minimum legal size of 57 mm in length (about 70 mm in height). Higher growth rates could be expected under a fully off-bottom cultivation system. Stead (1971) suggested Stewart Island oysters could reach marketable size in about 18 months.

Shell growth under the very sheltered conditions the cages were in, particularly in the rapidly growing smaller oysters, tends to be irregular and thin, frequently with the formation of pronounced "fans" near the inhalent and exhalent currents (Fig. 10). This type of growth is unusual in oysters on the Foveaux Strait beds and tends to produce the deeper, more cup-shaped oyster typically found in these inlets.

No measurements of meat weight or condition were made during the experiments, but under satisfactory feeding conditions (as the high growth rates showed existed at Stewart Island) the

Fig. 10: Small oysters grown in the North Arm, Port Adventure during December 1969-June 1971, with the thin marginal shell growth and formation of "fans" in association with inhalent (double arrows) and exhalent (single arrow) water currents.

increase in overall shell size (volume equivalent) would be expected to equate with increased meat weight. The naturally occurring oysters on rocks in these inlets were generally of good quality. The meat was often larger than in an equivalent sized Foveaux Strait oyster, because of the deeper shell shape, and it had a slightly sweeter taste, possibly from the greater freshwater input into the inlets.

Mortality

The cages effectively protected the oysters from the large starfish which are abundant in these inlets and are probably the major predators on juvenile and adult oysters. The high levels of mortality in the cages probably resulted from the more variable environmental conditions of the inlets compared with Foveaux Strait (Table 6), where adult mortality was reported to be very low (Cranfield and Allen 1979). Desiccation and temperature fluctuation during periods of exposure probably caused the total mortality of the oysters transferred to the intertidal cages, though some of the naturally occurring oysters in these inlets do exist low in the intertidal zone and can tolerate short periods of exposure. Excessive quantities of silt present in the water of Kaipipi Bay after heavy rainfall resulted in a thick deposit on the bed of the inlet and may have contributed to the 100% mortality in the submerged cages. During the final examination of this site, substantial deposits of sawdust were also found on the bottom in some parts of the bay.

All three experimental sites have lower salinity water than Foveaux Strait. This is more pronounced at Kaipipi Bay and the North Arm, both of which have several streams or rivers flowing into them. The significantly reduced salinity caused by the increased freshwater inflow after heavy rainfall is the most probable cause of heavy mortalities in the cages, particularly in the North Arm.

Settlement

Spat settlement experiments showed that spat can be readily caught on substrates placed near mature adults. Almost 70% of the shell material examined at the end of the experiment had some settlement. In cages with a high density of settlement, 85–100% of the dead shells had settled spat. The settlement on individual shells varied greatly, but the density was generally in the range 5 to 10 spat per shell; 80% of shells with some settlement had more than 5 spat, only 20% of these had more than 10 (though one shell had 92 live and 4 dead spat).

No obvious differences were observed in the choice of natural substrates for spat settlement. The clean surface of old bleached shell was obviously suitable (Fig. 11), but dead oyster bed shell, which was generally well covered with various encrusting organisms, also attracted high levels of settlement. The attraction for settlement on recently opened shell suggested some, possibly chemical, quality of this material acted in combination with the clean inner shell surface. Successful settlement in Foveaux Strait was largely on live oysters (Cranfield 1968a), though substantial initial settlement also occurred on dead shells throughout the oyster beds (author's unpublished data).

The cages with plastic sheeting usually had high densities of settlement. In the wooden cage No. 190 both water movement and light were highly restricted by the combination of wooden sides and plastic sheeting, and the heavy settlement on shells was accompanied by dense settlement on the underside of the top sheet of black plastic, but, surprisingly, no settlement on the plates. Settlement was negligible on the black and clear plastics of the metal cages No. 69 and 231, which, with their mesh sides, had less restricted water movement; however, they had substantial settlement on their plates.

Lack of replication in the experimental design made it difficult to determine the relative importance of individual factors affecting settlement, or to explain the apparent anomalies in observations on settlement and spat mortality patterns. However, some patterns were evident. Settlement tended to occur preferentially on undersurfaces which were clean and of rough texture, in areas of reduced water movement and low light intensity. This generally agreed with more detailed observations on settlement patterns in Foveaux Strait by Cranfield (1968b).

The relationship between adult oyster size and density of settlement agreed with data from Foveaux Strait, where most incubating females were medium to large (55–65 mm in length) (Cranfield and Allen 1977). Even during the peak of the breeding season the proportion of incubating oysters in Foveaux Strait was low; up to 3%

TABLE 6: Comparison of environmental conditions at the Stewart Island experimental sites and in Foveaux Strait during 1969–72

			Mean salinity		Mean water temperature (°C)	
	Exposure to open sea	Freshwater input	Summer	Winter	Summer	Winter
Kaipipi Bay	Minimal	Moderate	30.8	32.2	14.8	9.7
Port Adventure						
North Arm	Slight	Moderate	29.8	32.8	13.1	10.7
Oyster Cove	Moderate	Slight	30.6	34.5	13.1	11.2
Foveaux Strait	Complete	Negligible	34.6	34.5	14.4	11.4

(Cranfield and Allen 1977) and up to 8.5% (Stead 1971). However, because an average female can produce about 50 000 larvae (Cranfield and Allen 1977) it is probable that a difference of one or two incubating females could have accounted for the variability in settlement densities between cages.

Not all settlement occurred close to the adults. The settlement recorded on shells and plates in the cage containing no adult oysters showed some larval dispersal from the brood stock held in the cages, or from the naturally occurring oysters of Port Adventure, or both. The precise relationship between numbers of incubating adults, quantities of substrate, and light and current conditions which will produce optimum successful settlement of dredge oyster spat has yet to be defined.

Potential for dredge oyster farming

The problems encountered in establishing the artificial oyster beds for on-bottom cultivation may have been largely attributable to the small scale of the experiments, but they highlight the necessity for detailed preselection investigations of potential farming sites. These should include: a determination of the firmness and stability of the sea bed; an analysis of other physical factors, particularly water movements, salinity fluctuations, and sedimentation rates; and an estimate of pest and predation control requirements.

Off-bottom cultivation may be necessary to achieve a sufficiently rapid growth rate to make dredge oyster farming viable and to provide control over spawning and spat catching. The incubatory habit of *Tiostrea lutaria*, and the extremely brief duration of the free-swimming larval phase, suggest that maximum utilisation of the relatively low larval production (compared with other oysters) should be possible by careful monitoring and control of the environmental conditions at the time of liberation of the larvae and by supplying suitable settlement surfaces.

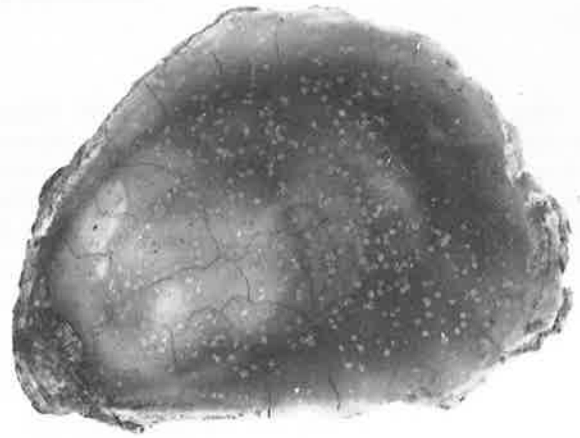

Fig. 11: Old bleached shell with heavy settlement of spat from the North Arm, Port Adventure during December 1971-February 1972.

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