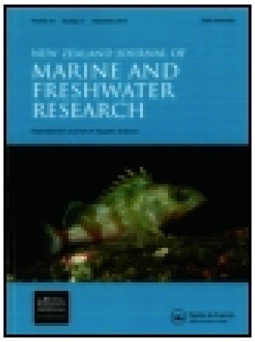

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New Zealand Journal of Marine and Freshwater Research

ISSN: 0028-8330 (Print) 1175-8805 (Online) Journal homepage: https://www.tandfonline.com/loi/tnzm20

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To cite this article: J. P. C. Greenway (1969) Surveys of mussels (Mollusca: Lamellibranchia) in the firth of Thames, 1961–67, New Zealand Journal of Marine and Freshwater Research, 3:2, 304-317, DOI: 10.1080/00288330.1969.9515299

To link to this article: https://doi.org/10.1080/00288330.1969.9515299

SURVEYS OF MUSSELS (MOLLUSCA: LAMELLIBRANCHIA) IN THE FIRTH OF THAMES, 1961–67

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(Received for publication 28 November 1968)

SUMMARY

Surveys are described which were made to determine distribution and relative density of stocks of mussels, *Perna canaliculus* Gmelin (Lamellibranchia: Anisomyaria; Mytilidae), in the Firth of Thames, North Island, New Zealand, during the late autumn – early winter of each year 1961–63 and 1965–67.

Two dredges available for sampling were tested against one another over similar ground. Both gave comparable results, but although the one chosen was never actually calibrated, it gave consistent results which allowed relative changes of abundance to be studied.

In 1961, 206 stations were sampled on a grid of 1 square mile which covered most of the Firth. Early results showed that the densest beds were along the western shore line; there were only small patches of mussels off Coromandel and along the eastern shore. A well-stocked and readily identifiable area of 2 square miles off Matingarahi Point was selected for more intensive sampling on a $^1/_{16}$ square-mile grid. Samples collected there annually showed a rapid decline of the population after commercial dredging in 1961–62; there was no substantial regeneration on the bottom after this, though satisfactory settlement occurred above the bottom on experimental moorings. Declining yields are shown for other areas (Ponui Island and New Brighton) which were also sampled on a $^1/_{16}$ square-mile grid.

Commercial landings of mussels decreased rapidly after 1961, and have not recovered. There have been no regular landings since 1966 but a promising private experiment in small-scale cultivation is described.

INTRODUCTION

There has always been a ready public demand for the green-lipped mussel *Perna canaliculus* Gmelin in the Auckland district, met until 1961 by a steadily increasing dredge yield (Fig. 1). Yields thereafter declined until regular commercial landings ceased in 1966. However, an unknown quantity continues to be removed by amateur divers. *Perna canaliculus* is found extensively round the New Zealand coast from mean low-water neaps down to at least 10 fathoms. It forms dense beds added to by successive oversettlement.

During 1961–66, annual surveys were made in the Firth of Thames from the Marine Department's r.v. *Ikatere*. The aim was to locate the reported positions of commercially exploited mussel beds more precisely and to estimate trends in these mussel populations.

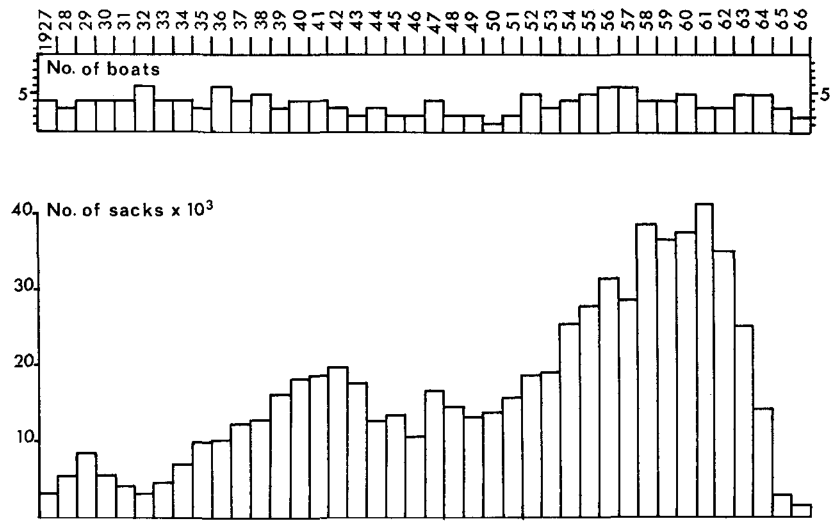

FIG. 1—Annual landings of mussels (sacks) in Auckland district and number of dredging vessels (both part and full time) operating from Auckland, Thames, and Coromandel, 1927–66.

METHODS

AREAS SURVEYED

To find the densest areas of dredgable mussels in the Firth of Thames, the first step was to lay off a grid of 206 squares each 1 mile² from a reference point at 37° S, 175° E (Admiralty Chart 1896; Fig. 2). After searching the grid, an area containing dense mussels (squares Q XVII and Q XVIII) was resurveyed using a superimposed $\frac{1}{16}$ square-mile grid to show distribution in more detail (Fig. 3). From 1962 onwards, surveys off Ponui Island and New Brighton were also made on this smaller grid.

SAMPLING TECHNIQUE

Two dredges of similar bag capacity were used, one a heavy locally-constructed dredge of similar pattern to those used commercially in the Firth, but about $\frac{1}{3}$ the size (Auckland dredge), and the other an imported light diving dredge used commercially in the United Kingdom (Conway dredge—both shown in Fig. 4). Preliminary trials showed that the diving dredge did not always land on the bottom right side up, because the diving plate had a tendency to capsize the dredge when crossing the current; it was removed and additional bottom weight was added by welding on a toothed cutting bar and thickening the skids against wear. After these changes had been made the dredge fished well. The two dredges were then tested against one another for 22 simultaneous tows, one over each side of the vessel (Fig. 5). Their performances were similar but, because the diving dredge was easier to handle (it could be opened at the back), it was used from the main 1961 survey onwards.

Before the main survey, trials were made with various mesh sizes of chicken wire in the dredge bag. Meshes smaller than $1\frac{1}{2}$ in. became clogged by mud and the dredge would not fish properly. However, because the mussels were aggregated into clumps with accompanying oversettlement, distribution of length frequencies did not differ significantly with different mesh sizes. Though commercial dredges use a 4 in.

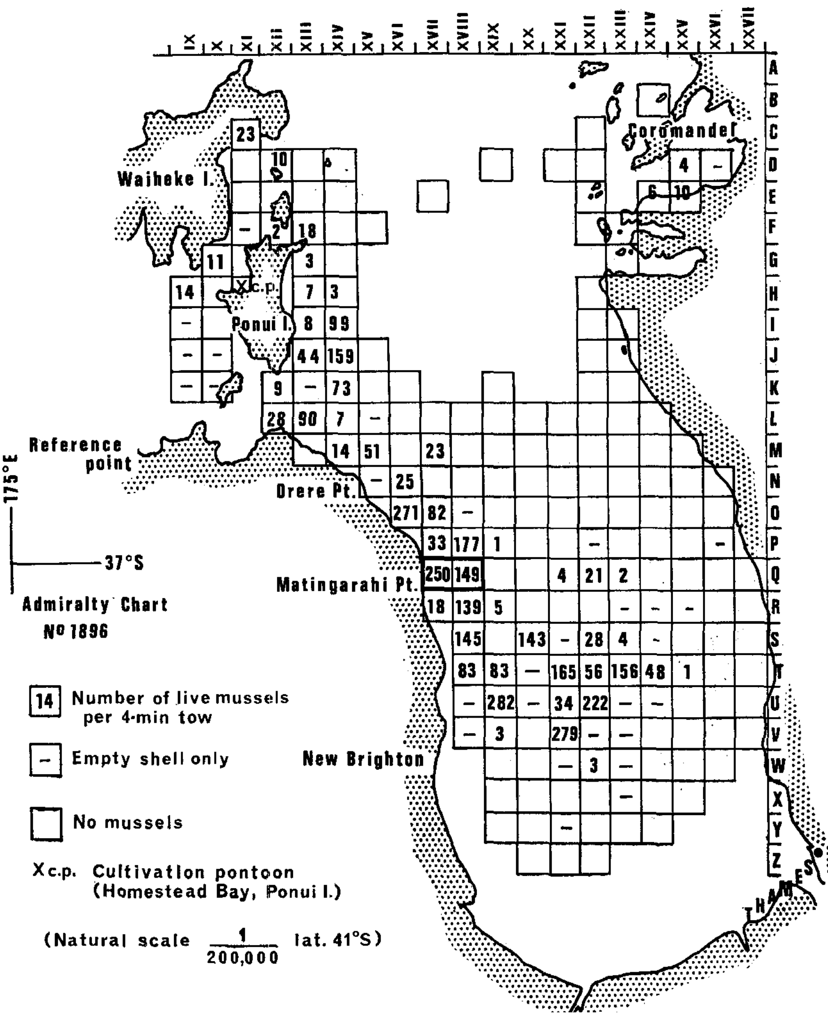

FIG. 2—Square-mile grid survey, 1961.

	XVII 1	XVII 2	XVII 3	XVII 4	XVIII 1	XVIII 2	XVIII 3	XVIII 4
a	0 27 0 0 6	43 7 1 0 6	186 25 22 15 0	180 77 0 0 0	339 0 2 0 1	72 0 0 0 0	0 7 0 0 0	0 0 0 0 0
b	Matinga-	29 54 22 0 0	215 2 1 0 1 X I	8 43 0 0 0 X II	338 0 72 0 0	3 0 7 0 0	0 0 0 0 0	0 0 0 0 0
c (Q)	rahi Pt	10 18 6 0 0	147 52 25 0 3	142 40 26 0 0	160 0 2 2 0	0 8 38 0 0	287 0 0 0 0	11 0 0 0 0
d		12 95 0 0 0	266 6 3 1 0	91 100 25 0 0	97 28 5 0 0	42 0 0 0 0	0 0 0 0 0	0 0 0 0 0

FIG. 3—Annual systematic $^{1}/_{16}$ square-mile grid surveys off Matingarahi Point, 1961–66. The figures in each $^{1}/_{16}$ square mile follow the sequence: 1961, 1962, 1963, 1965, 1966. June 1961, n = 2,678 from 29 hauls; mean catch per 2-minute tow, 92.3. June 1962, n = 589 from 29 hauls; mean catch per 2-minute tow, 20.3. May 1963, n = 257 from 29 hauls; mean catch per 2-minute tow, 8.8. May 1964, no survey. July 1965, n = 18 from 29 hauls; mean catch per 2-minute tow, 0.6. July 1966, n = 17 from 29 hauls; mean catch per 2-minute tow, 0.5. X marks the positions of buoys for observing settlement.

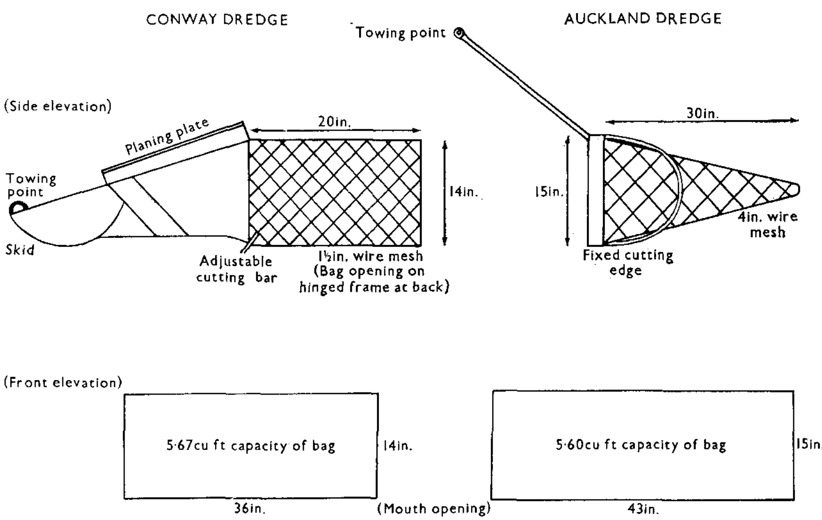

FIG. 4—Comparison of construction of Auckland and Conway dredges.

diagonal-mesh to let mud pass through the bag easily, for the survey a $1\frac{1}{2}$ in. mesh was used to retain individual mussels and invertebrates.

In 1961 each major square was sampled by a standard tow of 0.4 miles (4 minutes at 350 rpm in *Ikatere*) across the centres of the mile grid in an easterly or westerly direction. For the $\frac{1}{16}$ square-mile grid, standard hauls covering 0.2 miles (2 minutes at 350 rpm) were made diagonally across the minor squares. In the 1961 survey, stations were usually fixed in relation to prominent landmarks, but for the small square surveys, dan buoys were set half a mile apart as reference points.

EXPERIMENTAL SETTLEMENT

Two experimental buoys were moored off Matingarahi Point in June 1962 for observation of settlement. They were 44-gallon galvanised and painted steel drums floating on the surface, held by 2-in. iron chain attached to concrete sinkers on the bottom. One was laid above about $4\frac{1}{2}$ fathoms and the other, 6 fathoms; positions shown **X** in Fig. 3.

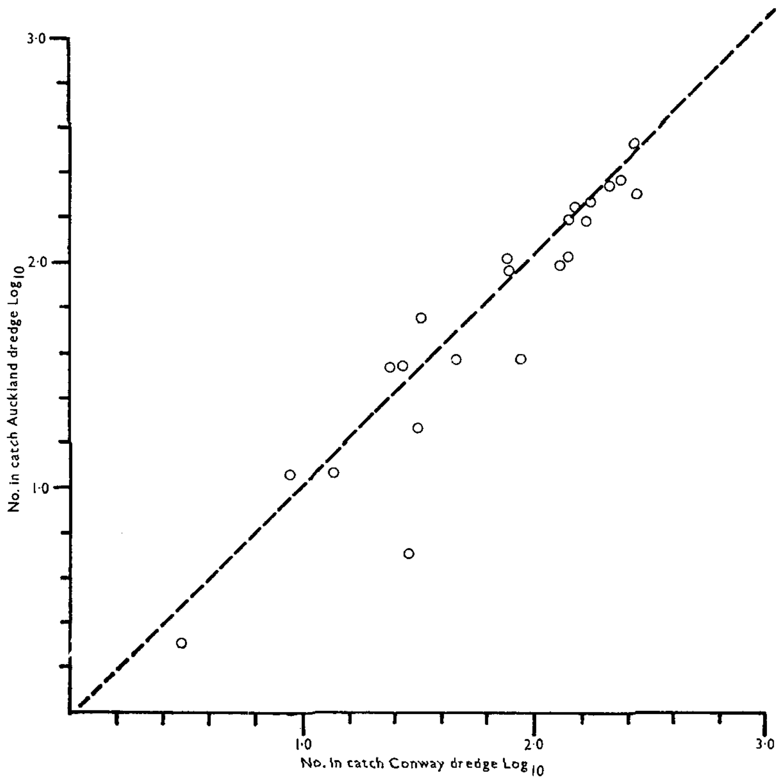

FIG. 5—Comparison of catch from simultaneous dredging, Auckland and Conway dredges, 22 stations.

RESULTS OF SURVEYS

EFFICIENCY OF DREDGES

The sampling equipment was never calibrated, though short observations by naval skin divers suggested that the dredge was less than 50% efficient. This tallies with the observations of Shelbourne (1957) on the efficiency of oyster dredges of similar type; he found they were about 33% efficient. However, because the same gear and methods were used each year, the results obtained probably reflected true changes in abundance.

During the 1962 survey, commercial boats were working in the same area as *Ikatere* off New Brighton, and a comparison of yields was made. The average number of mussels dredged per minute was:

Commercial dredges	94
Survey dredge	13

This gives a much higher commercial extraction rate using dredges with 7½–9 ft-blades than obtained with the survey dredge with a 3 ft blade. Commercial dredges had a far better chance of securing massive clumps of mussels from thick beds because of their greater weight and size of opening; these clumps were sometimes too large to enter the survey dredge and dropped off its blade as it was raised.

DISTRIBUTION OF BEDS AND ASSOCIATED FAUNA

The survey of 206 stations on a 1 square-mile grid done in June 1961 showed the main areas of concentration of mussels (Fig. 2). Later surveys with the superimposed $\frac{1}{16}$ square-mile grid gave satisfactory broad agreement, allowing the main mussel grounds and associated dredge fauna to be outlined as in Fig. 6. The various faunas did not alter their boundaries, but their numbers varied from year to year.

In general, the southern and eastern edges of the Firth contained extensive beds of cockles *Chione stutchburyi* and pipis *Amphidesma australe*. Mud oysters *Ostrea lutaria* Hutton and scallops *Pecten novaezelandiae* were found mainly at the edges of the mussel grounds, especially to the south and east but there was quite a distinct ground of mud oysters in the squares S XXII and T XXII. Polychaete tube worms were fairly widespread, but seldom with mussels. Echinoderms were found to the north, nearer the mouth of the Firth: the heart urchin *Echinocardium australe* was abundant, but 10-armed starfish *Coscinasterias calamaria* appeared only in the deeper, clearer waters off Coromandel, Waiheke Island, and Ponui Island. No quantitative estimations were attempted, because many small animals must have passed through the mesh of the dredge bag.

DECLINE AFTER EXPLOITATION

All surveys were made in late autumn/early winter (June and July). Annual results (from 2-minute tows on the $\frac{1}{16}$ square-mile grid) for two areas (east of Ponui Island and Matingarahi Point – New Brighton) containing worth-while stocks of mussels are summarised in Table 1.

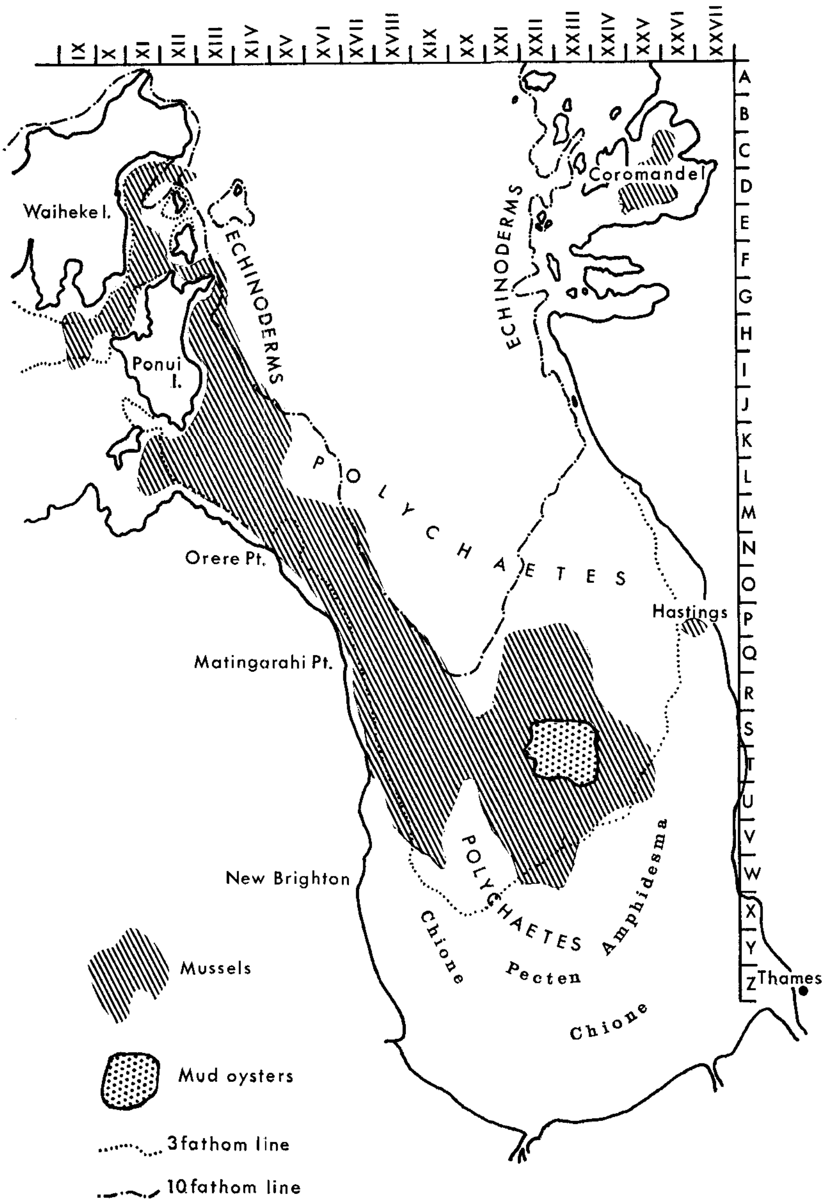

FIG. 6—Main mussel grounds and principal associated fauna in Firth of Thames, 1961.

TABLE 1—Summary of $^{1}/_{16}$ square-mile grid surveys off east Ponui Island and Matingarahi Point - New Brighton combined, 1962–66

Year	Area covered (miles²)	No. of 2-minute tows				Total No. live mussels	Mean catch (mussels/tow)	
		No. mussels	Empty mussels only	Live mussels	Total of tows		Over whole area	Only where present
E. of Ponui Island								
1962	12.25	73	40	83	196	985	5.0	11.9
1963	13.75	73	54	93	220	1,008	4.6	10.8
1964	No survey	......	......	......	......	......	......	......
1965	12.75	115	63	26	204	113	0.5	4.3
1966	No survey	......	......	......	......	......	......	......
Matingarahi Point - New Brighton								
1962	16.25	81	28	151	260	6,997	26.9	46.3
1963	19.25	53	32	223	308	5,112	16.6	22.9
1964	No survey	......	......	......	......	......	......	......
1965	19.25	171	66	71	308	453	1.5	6.3
1966	19.25	103	155	50	308	180	0.6	3.6

Each area showed a decrease in mean catch for those stations where live mussels were present; the number of stations with live mussels also declined. The 1962–63 decrease in mean catch off Ponui Island was not as marked as off Matingarahi Point - New Brighton where the commercial effort was concentrated that year. Attention turned to Ponui Island during 1963, and by 1965 the mussel density in this area was also greatly reduced.

Figure 3 shows the numbers of mussels obtained as the density of mussels fell in carefully repeated annual surveys off Matingarahi Point. In June 1967 the dredging effort was redoubled—more samples were taken at each station—but this still only produced an average of 0.8 mussels per 2-minute tow (*c.f.* 0.5/tow in 1966).

Figure 7 shows the annual distribution of length-frequencies from Matingarahi Point (squares Q XVII and Q XVIII). Distributions for 1961 and 1962 were constructed from representative subsamples. The distribution for 1961 was typical of other areas containing large quantities of mussels; the pronounced mode at 12–13 cm and the distribution's marked negative skew possibly reflect the dominance of one age-group, but more probably result from the species' rapid initial growth rate. This general pattern was maintained even in the smaller 1965–67 samples but with a greatly reduced mode.

GROWTH RATE

Length-frequency measurements of mussels from the two experimental buoys (laid near Matingarahi Point in July 1962) gave only limited information on early growth. No settlement was observed until early November 1962. In May 1963 samples from surface to bottom of the

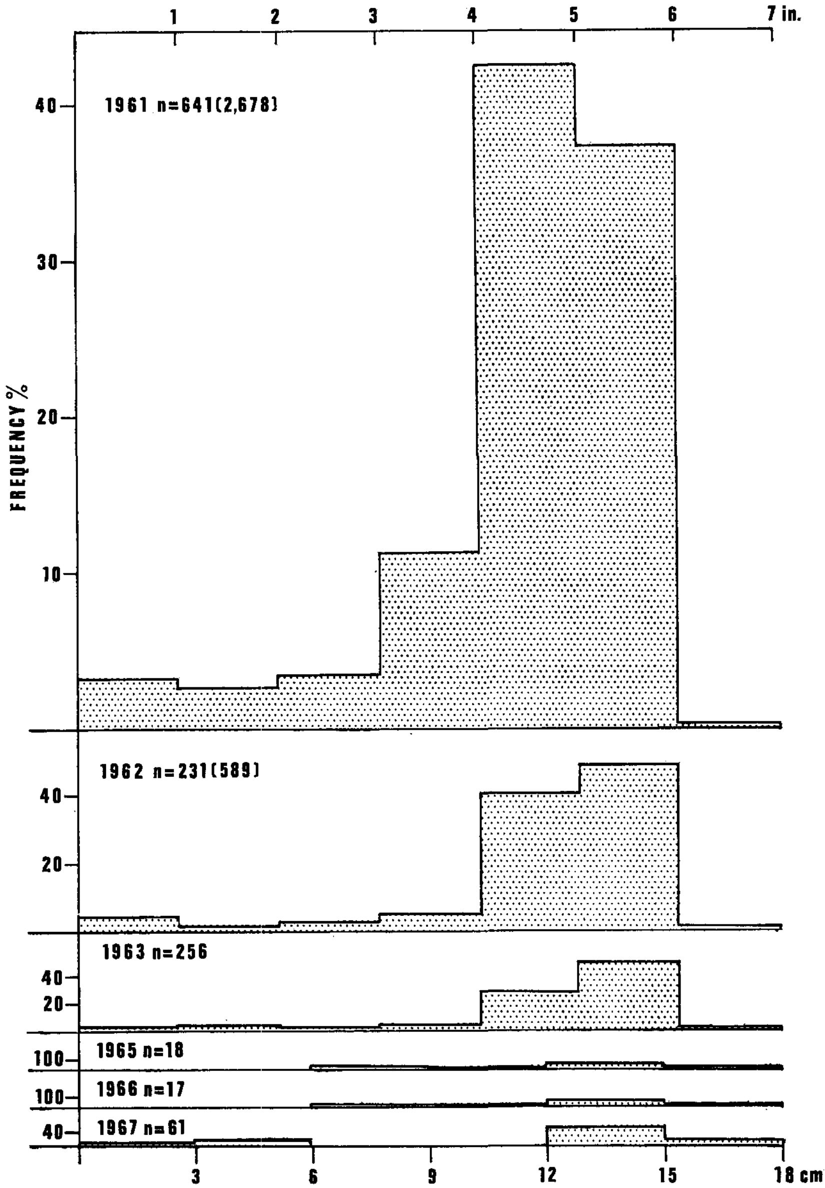

FIG. 7—Percentage distributions of length frequencies from Matingarahi Point, 1961–63, 1965–67. (Scaled to 1961 = 100%.) There was no survey in 1964. Between 1961 and 1966, 29 hauls a year were made; in 1967, 68 hauls were made. Measurements for 1961–63 are in inches; those for 1965–67 are in 3-cm groupings.

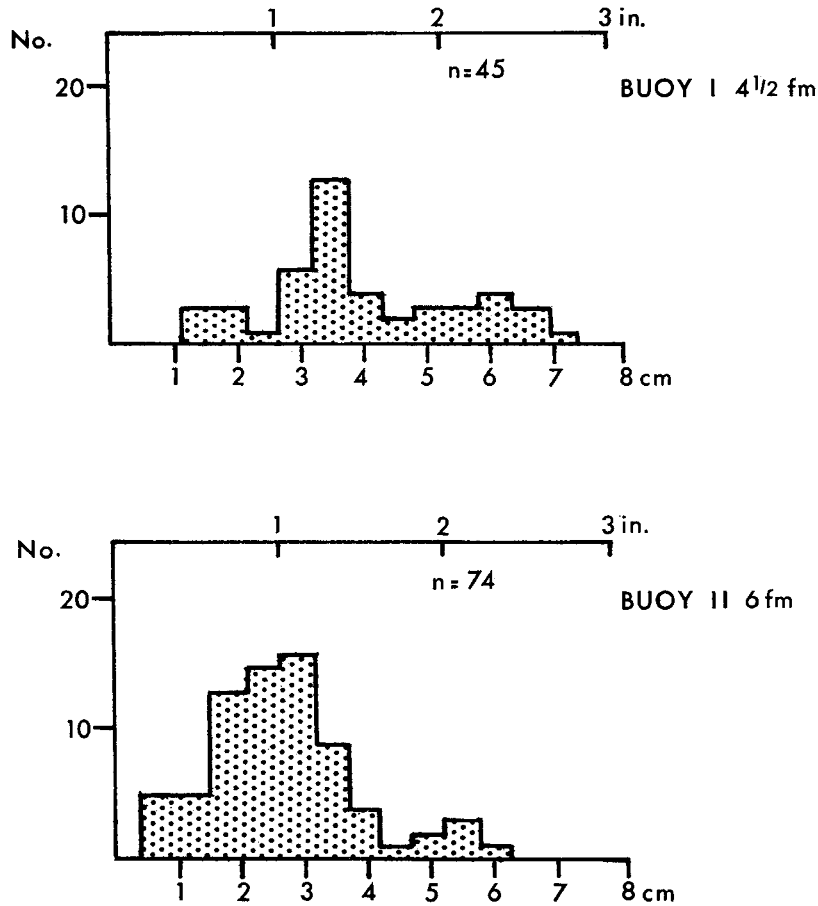

FIG. 8—Distribution of length frequencies of mussels which settled after November 1962, collected in May 1963 from buoys off Matingarahi Point.

mooring chains showed that most specimens were found near the surface and the sides of the buoys. The largest specimens (Fig. 8), about 7 cm long, were unlikely to have been more than 7 months old (November–May). There appeared to have been two settlements, represented by modes at about 3 cm and 6 cm.

SIZE AT MATURITY

In 1961 an attempt to find the approximate size at which mussels reach sexual maturity was made by observation of macroscopic characters (Castellanos 1962). Seven stations off Matingarahi Point were sampled and wherever possible 20 specimens were selected to include all sizes (Fig. 9). From this macroscopic inspection only, the gonad appears to mature soon after the mussel reaches 7 cm in length.

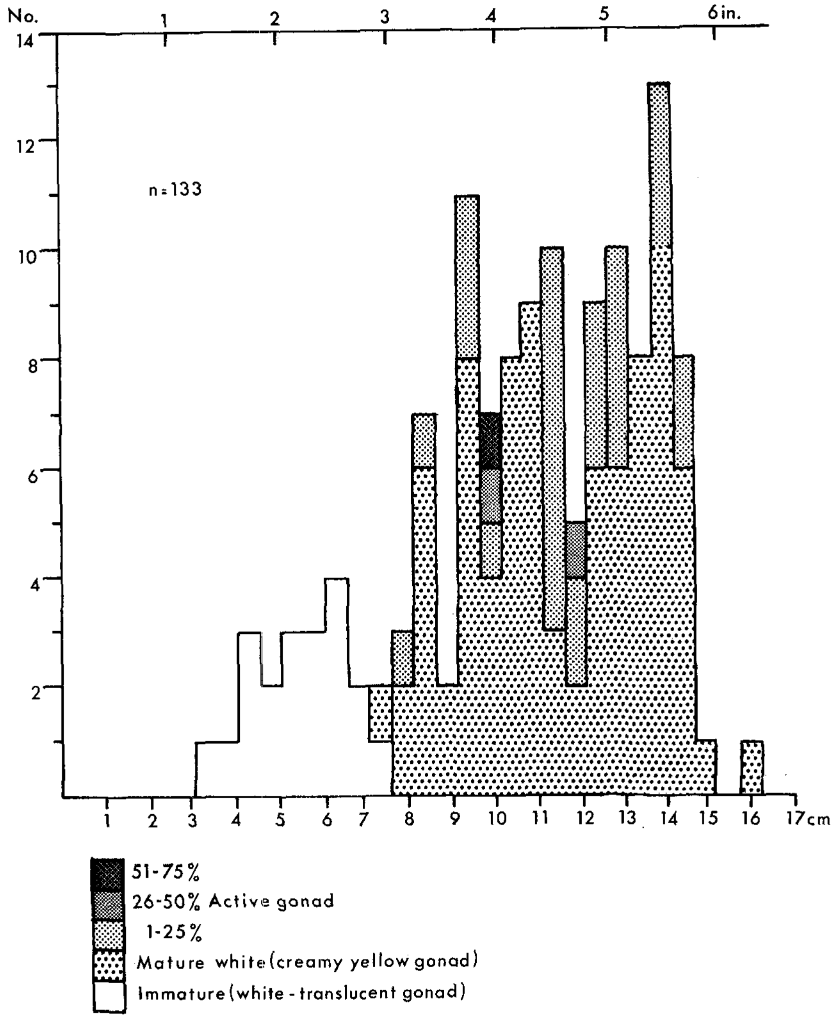

FIG. 9—Relative amounts of visible development in active gonads.

COMMERCIAL EXPLOITATION

DREDGING

Taken from figures published by the Marine Department for the 40 years 1927–66, Fig. 1 shows the number of sacks of Coromandel/Thames mussels landed annually and the number of boats working the beds. During this period, two to four boats worked the beds full-time, with others working casually. Though effort and catches fluctuated the yield from the fishery steadily increased to a maximum of 40,910 sacks,

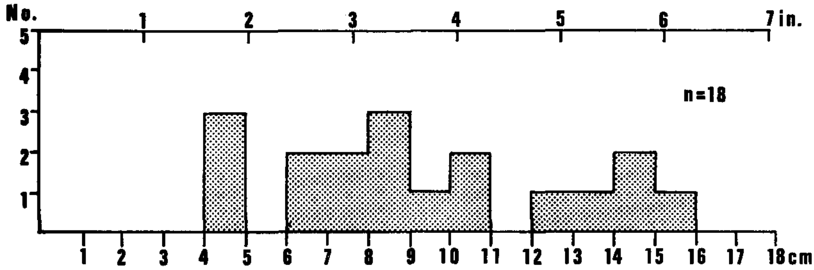

FIG. 10—Length frequency distribution of mussels cultivated off Ponui Island, grown January 1965 – January 1968.

equivalent to 15 million mussels, in 1961. Thereafter, the boats spent increasingly more time dredging but the yield fell in spite of this; by the end of 1966 full-time operations had ceased.

The fishermen made little effort to safeguard the stocks. There is no minimum size for mussels and few fishermen took the trouble to cull out the smaller mussels (<10 cm long) at sea, where they might have a slender chance of reattaching themselves.

EXPERIMENTAL CULTIVATION

Soon after beginning dredging in 1963, the firm of McFarlane's Fisheries realised the need to cultivate mussels to keep the industry alive. In early January 1965, they moored a 9 × 9 ft pontoon in Homestead Bay, Ponui Island (*see* Fig. 2), close below which were suspended 230 green bundles of manuka (*Leptospermum scoparium*) brushwood. By late February 1965 there had been a settlement of mussels, which then averaged 0.5-cm in length in a maximum time of 2 months. By May 1965 a second settlement had appeared on the brushwood, there being an average of 50 mussels to each bundle. By this time only 125 bundles of brushwood remained, the others having worked loose and been lost; the remaining bundles were removed and tied on top of an iron framework, which was then set in 10 fathoms of water. In January 1968, 3 years after initial settlement, samples of the cultivated mussels removed from the frame gave the length frequency distribution shown in Fig. 10; the larger mussels were as big as any found by previous dredging (*see* Fig. 6). The polymodal distribution of lengths indicated the presence of several age-groups. Although some mussels near the centre of the iron framework were overcome by sinking into the mud, the experiment still yielded about 2,500 mussels more than 7.6 cm long.

After removal of the first brushwood, several fresh bundles were attached to the pontoon. In mid-July 1965, there was no sign of settlement since May; specimens from the pontoon averaged 5 cm long for a maximum period of growth of less than 6 months. One year later (July 1966) a sample of larger specimens from the pontoon were between 9.0–14.0 cm long. This indicates that these animals are capable of growing to commercial size in 18 months.

DISCUSSION

In the past, successful dredging around the Auckland area depended on finding new mussel beds when the current beds were exhausted. When beds round Coromandel and the eastern shore line of the Firth of Thames became depleted, attention turned to the southern and western areas, then to Ponui Island, and finally, when all beds were exhausted, to random searching over the whole area until regular landings ceased. Dredging takes all mussels, both young and old, since they are bound together by byssus. Even if young mussels are separated and returned to the water, they are unlikely to survive for long unless they land on a firm substrate to which they can attach. On the muddy bottom of the Firth of Thames, the rate of fishing was probably far in excess of what could be sustained. Where dredging is impossible, close to rocky shores, there may still be enough mussels to provide a breeding stock, but these are now being taken in increasing number by skin divers.

The rapid rates of growth and early maturity (before reaching 7 cm long—Mr C. C. Brittain, pers. comm.) appear to favour quick regeneration of the beds; settlement on buoys shows that there are enough larvae in the water. The beds have not been replenished, however, presumably because of some other factor.

Probably, there have always been mussel populations on rocky outcrops in the Firth. As the surrounding land was cleared of native bush, further surfaces suitable for settlement may have become available on timber and brushwood carried down river and deposited on the bottom of the Firth. If substantial mussel beds were formed thus, further clearing of the land could have caused greater deposition of silt and successive oversettlements would have been needed to keep the beds above the rising silt. Paul (1966) has described such a relationship between the shellfish beds, silting, and land use in Ohiwa Harbour, Bay of Plenty. In the Firth, dredging probably removed the mussels and with them, much of the firmly embedded shell to which they were attached; this left an unstable muddy substrate no longer suitable for attachment. Empty mussel shells returned as cultch could renew the settlement surface, but heavier shell, such as oyster, would probably be more suitable because it is heavier and less easily moved by currents; mussel spat were found on oyster shells in a mud oyster patch during the 1963 survey (*see* Fig. 6.). Burrowing shellfish could provide a hard substrate to which mussel might attach, e.g., cockles, noted by Kreger (1940) but I saw no direct evidence of this.

The patches of dead mussel shell found in the surveys may have been caused by disease or predation (no evidence for either), or by smothering with mud and shell disturbed by intensive dredging. Off Matingarahi Point, areas containing high-density mussels in 1961 by 1962 contained mainly empty shell. Less than 1% of dredged mussels are broken by the dredge; thus, patches of dead mussels probably are caused by the disturbance of dredging.

To cultivate mussels, settlement surfaces more suitable and permanent than the present bed of the Firth are needed. The small-scale commercial cultivation already attempted from a pontoon suggests several possibilities. Mussels are cultivated on rafts extensively in Spain (Waugh 1968). Although the New Zealand species and environment may differ, the results so far suggest that further experiments in raft culture should be made. Waugh quotes the average Spanish production per raft/year as 55 metric tons of mussels; the average weight of New Zealand mussels is 150 lb per sack. Thus a single raft could produce an equivalent of about 808 sacks/year, or about $\frac{1}{50}$ of the peak catch of 40,910 sacks in 1961.

CONCLUSIONS

Intensive dredging over the past decade caused severe depletion of mussel beds in the Firth of Thames. Natural regeneration of the beds appears to be unlikely or protracted. In the rocky areas, where dredging is impracticable, there is still a reserve of mature mussels, and settlement occurs on suitable surfaces. Growth is rapid and artificial cultivation appears to be practicable.

ACKNOWLEDGMENTS

Thanks to the crew of r.v. *Ikatere,* who collected the samples, and to the management of the Auckland-Coromandel Mussel Company and McFarlane's Fisheries, for access to their records and much practical co-operation in the field. Special thanks to Mr G. D. Waugh, Director of the Fisheries Research Division, Wellington, and to Mr L. J. Paul, Fisheries Research Division, Wellington, for much constructive comment and practical assistance in the preparation of the manuscript.

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