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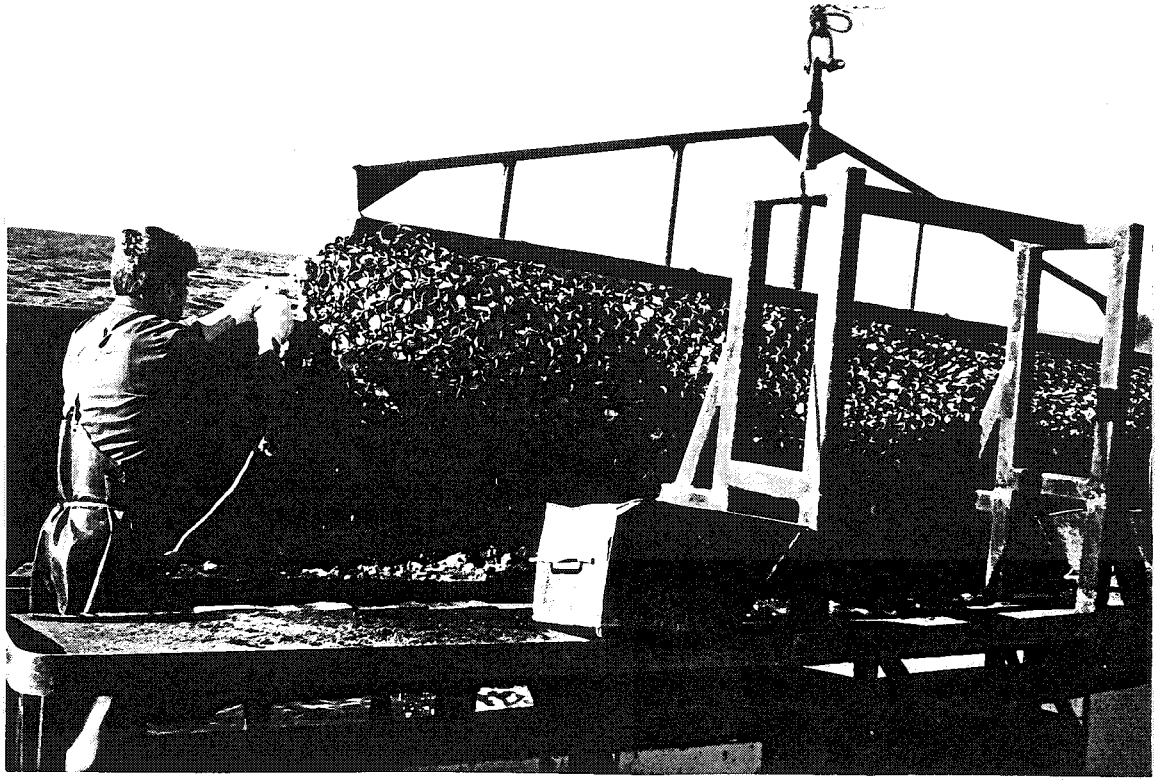

NIWA Technical Report 45
ISSN 1174-2631
1998

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Published by NIWA
Wellington
1998

Inquiries to:
Publication Services, NIWA,
PO Box 14-901, Wellington, New Zealand

ISSN 1174-2631
ISBN 0-478-08464-1

Citation: Cranfield, H. J., Michael, K. P., & Doonan, I. J. 1998:
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NIWA Technical Report 45. 18 p.

Cover photograph by Dave Fisher

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Contents

Abstract

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The size of the Foveaux Strait oyster population was estimated in October 1997, continuing the series of biannual assessments to monitor its recovery after an epizootic caused by *Bonamia*. The recruited oyster population (58 mm or more long) numbered 630 million, the immediate pre-recruits (50–57 mm long) numbered 689 million, and small oysters (10–49 mm long) numbered 859 million. The populations of recruits and small oysters were not significantly different from those of the previous survey in 1995. The numbers of immediate pre-recruits was significantly greater than in 1995. Recruitment may have been lower in the past 2 years than in the immediate post-*Bonamia* period. The commercially exploitable population (in patches of oysters at densities greater than 400 per survey tow) was 254 million oysters.

Introduction

Between 1986 and 1992 mortality from bonamiasis reduced the Foveaux Strait oyster population to 9% of its pre-disease level (Doonan *et al.* 1994). As there was a very high chance that recruitment could fail at such a low population size (Allen 1979), the Minister of Fisheries closed Foveaux Strait to commercial oyster fishing in 1993 to allow the population to rebuild (Cranfield *et al.* 1993). The oyster population was to be surveyed regularly using a stratified random design as the most economic method of monitoring total population size. The variability inherent in dredge surveys meant that changes in population size after one year would not be statistically significant and so surveys were done at two yearly intervals. A comparison of the results of surveys in 1993 and 1995 showed that the population was rebuilding (Doonan & Cranfield 1992, Cranfield *et al.* 1993, 1996). Here we report the results of the October 1997 survey which was carried out well after the possibility of seasonal mortality caused by *Bonamia* sp. (Hine 1991).

In 1995, the oyster industry and the Ministry of Fisheries developed a draft plan for managing the oyster fishery (Anon. 1995) which included a decision rule to reopen the fishery that required the population in the area surveyed in 1975–76 (Allen & Cranfield 1979 Doonan *et al.* 1994) to be at least 40% of the population estimated in 1975–76. In 1995, the oyster population had reached this size and the fishery was reopened. The management plan also suggested that yields estimated for this fishery should be based on the size of the population actually fished, i.e., those areas in Foveaux Strait in which oyster density could support commercially viable fishing (estimated by Cranfield *et al.* (1991) to be over 400 recruited oysters per standard survey tow). Based on this principle, the sustainable yield was estimated in 1995 and used to set quota in 1996 and 1997. The goals of the 1997 survey were to estimate the size of the total oyster population in Foveaux Strait, the size of the population in the area surveyed in 1975–76, and the size of the oyster population in areas with densities over 400 oysters per standard survey tow.

Methods

The survey was designed to estimate the absolute population size in Foveaux Strait of recruited oysters (over 58 mm long) with a target *c.v.* of 20%. Data were also collected on numbers of immediate pre-recruit (50–57 mm) and small (10–49 mm) oysters. To ensure the comparability of estimates of population size with previous surveys, the area surveyed in 1997 included all areas and strata surveyed in 1975, 1993, and 1995.

The 1997 area was defined by the outside grid boundary of the 1993 survey, in which most stations were at the intersections of a 1 n. mile (1.85 km) grid. The area in which the 1993 population was estimated therefore extended 0.5 n. mile (0.92 km) outside the boundary defined by the grid lines. The 1995 and 1997 random surveys were done within the boundary defined by the 1993 survey grid (Figure 1), but their total area was 22% less than that of the 1993 survey. The area of the 1975 survey was largely included within the 1993 survey area, but also incorporated a small segment to the east (*see* Figure 1). A small area (stratum 5, 13.1 km^2) between Fife and Zero Rocks was added to incorporate an area fished by commercial vessels in 1997 (Figure 2).

The survey followed a stratified random design with two phases (Francis 1984) and took 5 days between 29 September and 5 October 1997. Towing and sampling procedures were kept as close as possible to those of the 1990, 1992, 1993, and 1995 surveys (*see* Cranfield *et al.* 1993, 1996).

Stratification

A stratified random sampling design for the dredge survey in October 1997 was developed from oyster densities estimated in the October 1995 survey (Cranfield *et al.* 1996) and catch data. The October 1995 densities were contoured at 200 and 400 recruited oysters per tow. Bootstrap sampling of the 1995 survey data showed that using three levels of density resulted in almost the same *c.v.* for the population estimate as using five levels. Boundaries around high density strata were expanded to guard against high catches in low density areas. The design developed 11 strata covering three levels of recruited oyster density (over 400, 200–400, and less than 200 oysters per tow; Table 1).

Station selection

The number of phase 1 stations in each stratum was determined on the basis of stratum area and the expected oyster density within it, except that each stratum was assigned at least three stations. Of the 106 survey stations used to estimate population size, 25% (27 stations) were allocated in phase 2. Phase 2 stations were allocated on the basis of the expected gain in precision, using the method of Francis (1984). Stations were randomly positioned using a routine in the S statistical package (Becker *et al.* 1989). Stations were separated by at least 0.4 n. mile in all strata to avoid spatial correlation of catches.

An additional 17 stations were allocated in a grid around high density patches of oysters to define their extent. These data were not used in estimating the population size (*see* Table 1).

Sampling methods

Two commercial oyster vessels, *Torea* (skipper Terry Dixon) and *Toiler* (skipper Rex Ryan) and their crews were chartered to carry out the survey. These skippers were involved in previous surveys and were experienced with the procedures and standards required. NIWA staff supervised the navigation and sampling, and recorded vessel position and catch data. Eight-channel GPS sets were used to maximise precision of navigation. The vessel steamed to each station position using GPS, shot the dredge (a standard commercial dredge, 3.35 m wide), and recorded the start position when the towing warp became tight after the winch brake had been applied. Tow length was controlled to 0.2 n. mile (370 m) using the distance elapsed and GPS alarm features. End of tow position was recorded from the GPS at the point the winch began retrieving the dredge.

The dredge catch was landed unwashed (to ensure there was minimal loss of undersized oysters dropping through the dredge rings) and the percentage fullness of the dredge estimated. Live oysters were sorted into three size classes: recruits, over 58 mm long; immediate pre-recruits, 50–57 mm; and small oysters, 10–49 mm (length measured along the anterio-posterior axis parallel to the hinge line). Size could be checked by the failure of the oyster to pass through a 58 or a 50 mm diameter ring. The smallest size at which small oysters could be counted reliably was 10 mm.

Clocks, the articulated shells of dead oysters with the ligament intact, were sorted into recruit and immediate pre-recruit sizes, and into two categories, new and old. The shell of new clocks is clean and without fouling on the interior surfaces: These are shells of oysters that have died since the seasonal settlement of fouling organisms (i.e., since the previous summer and so within the 6 month period before the survey). Old clocks are covered in fouling organisms on external and internal surfaces and are shells of oysters that have died more than 6 months previously. As the ligament of oysters breaks down over a 3 year period, old clocks have died between 6 months and 3 years ago and the number of all clocks therefore reflects mortality over this 3 year period (Cranfield *et al.* 1991).

Population estimates

We estimated the absolute population size of recruited oysters using the estimate of the mean efficiency of dredges used in 1990, 0.164 (95% confidence intervals, 0.13–0.22, Doonan *et al.* 1994) from

$$\text{Total population size} = \frac{\sum y_i \, area_i}{d}$$

where d is the estimated dredge efficiency, i indexes strata, y_i is the mean oyster density in stratum i, $area_i$ is the area of stratum I, and

$$y_i = \frac{\sum x_{ij}}{n_i}$$

where x_{ij} is oyster density (per m^2)

To estimate the variance of the absolute population estimate, we bootstrapped from the error distributions of the estimate of d and the estimated relative population size ($\Sigma y_i area_i$), both assumed to be normally distributed. Only the error in the relative population size is required when we compare population estimates between dredge surveys as the error in dredge efficiency cancels out.

The objective of the survey was to estimate the total population with the lowest *c.v.* possible. The design did not optimise estimation of the distribution of oysters or the distribution and numbers of oysters in areas above the threshold of commercial density.

Distribution of oysters

The catch data in previous surveys were contoured using the S statistical package (Becker *et al.*1989) with the Epanechnikov weighting function and a 2.0 n. mile bandwidth. The density of oysters of all size groups in 1993 and 1995 was contoured at 200 and 400 oysters per standard research tow. Percentage fullness of dredges was contoured at 25% and 40%. The 1997 survey had few stations, and even with the addition of 17 stations defining areas of high oyster density, the number of stations was too small to allow oyster density to be contoured.

We could not, therefore, establish whether the distribution of oysters in Foveaux Strait had changed between the 1995 and 1997 surveys. Plots of the distribution of survey stations where 400 or more oysters of each size group were caught in the 1995 and 1997 surveys are presented (Figures 3–8). Too few new and old clocks were taken in 1997 to be able to contour these data with any confidence.

Results

Station positions and stratum boundaries are shown in Figure 2 and population size for each size group by stratum is given in Table 2.

Population size

The absolute population of recruited oysters in Foveaux Strait in 1997 was estimated to be 630 million (95% confidence interval, 395–899 million). The absolute population size of recruited oysters in the 1975–76 area in 1997 was 352 million (95% confidence interval, 239–465 million).

The recruited population within the area where oyster density was at or above 400 oysters per tow in the 1997 survey area was estimated to be 254 million oysters (95% confidence interval, 77–449 million).

If fishers could dredge all these populations and reduce oyster density in them to the threshold density of commercial viability (400 oysters per survey tow), it is estimated that they would take 109 million oysters (95% confidence interval, 29–198 million) from the area of commercial density.

Distribution

The survey data suggest that the highest densities of recruited oysters (over 58 mm) in October 1997 were in central and western Foveaux Strait (Figure 3).

Discussion

Comparison of total oyster population in 1993, 1995, and 1997

Absolute population size estimates and 95% confidence intervals for three size groups of oysters from the 1993, 1995, and 1997 surveys are shown in Table 3.

In rechecking the 1995 survey data we found an error in computing some stratum areas. The re-estimated numbers of oysters of all sizes in the 1995 population are shown in Table 3 and are slightly lower than those reported by Cranfield *et al.* (1996). The number of recruited oysters in 1997 is not significantly different from those in 1995 ($t = 0.56$, $P = 0.58$, 145 df). The numbers of pre-recruits increased significantly (2.4 times) between surveys ($t = 4.75$, $P < 0.0001$, 145 df), but although the numbers of small oysters increased 1.4 times, the increase was not significant ($t = 1.62$, $P = 0.11$, 145 df).

There has been no mortality from bonamiasis over the summer of 1995–96 (Cranfield *et al.* 1995) and fishers have not reported any significant mortality over the previous 2 years. We expected that the recruited oyster population in Foveaux Strait would have increased between 1995 and 1997 by an amount similar to its increase between 1993 and 1995, but the population has remained at the same size. There have been significant increases in the pre-recruit population over the same period, suggesting that changes in dredge efficiency are unlikely to be the cause. Nevertheless, the oyster industry suggested that rougher weather conditions during the 1997 survey could have reduced dredge efficiency and resulted in a lower catch of recruited oysters, and that the estimate of the 1995 population could have been affected by dredge saturation.

Weather conditions

The weather conditions during the 1995 and 1997 surveys were compared to see if they were likely to have influenced dredge sampling efficiency. The sea conditions and wind speeds during the 1997 survey were not as calm as for the 1995 survey (Table 4). The median sea condition in 1995 was a light breeze (4–6 knots) with wavelets 0.2 m high. The median sea condition in 1997 was a moderate breeze (11–16 knots) with small waves 1.0 m high. The distance between crests of these waves is less than the length of the oyster vessel, so it was not pitching during towing and therefore not lifting the dredge off the seafloor. Fishers dredging in similar weather conditions have not noticed a drop in their catch rate. The weather conditions fall within the range of those experienced during the 1990 survey (Beaufort scale 1–7, median 3, Doonan & Cranfield 1992). The mean dredge efficiency used here to estimate absolute population size was estimated from the 1990 data. If moderate sea conditions affect dredge behaviour at all (an effect that must be below that detectable by fishers), the different weather in 1995 and 1997 might have biased the 1995 absolute estimate slightly upwards and the 1997 absolute estimate slightly downwards.

Dredge saturation

The fishing industry were concerned that during the 1995 survey dredges might have become saturated with benthic epifauna that had overgrown the seafloor during the 3 years with no fishing. If dredges had become saturated before the end of tow during the 1995 survey, the population size in

that year would have been underestimated (the opposite change to that we are seeking to explain). The percentage fullness of all dredge shots in 1995 and 1997 (Table 5) was comparable. Dredges did not become saturated during either survey, so saturation could not have affected estimation of the population size in either year.

Changes in sorting dredge catches

Dredge surveys of Foveaux Strait oysters between 1990 and 1997 have used commercial oyster vessels crewed by commercial fishers. The current minimum legal size of oysters is 58 mm in length (defined as an oyster that will not pass through a 58 mm ID ring), but in the 1997 oyster season, commercial fishers increased the size to which they sorted the catch to 62 mm. Each fisher sorting the catch was provided with 58 mm and 50 mm ID rings to check sizes of recruited and immediate pre-recruit oysters. As fishers sort oysters largely by eye and rarely check against size rings, some recruited oysters (less than 62 mm but larger than 58 mm) were included with the immediate pre-recruits. Quality assurance checking reduced, but did not eliminate, this bias. The effectiveness of the sorting of the same crews was checked during a limited survey in late January 1998. The results suggested that 12% of the oysters sorted as immediate pre-recruits were recruit sized. Hence the recruited population estimated in 1997 was likely to be 12% too small and the immediate pre-recruit population 12% too large.

Changes in size of the recruited population in the 1975–76 survey area

The population estimates of recruits in the area surveyed in 1975–76 are shown in Table 6.

The current population in the area surveyed in 1975–76 is 31% (95% confidence interval 20–41%) of the population estimated in 1975–76. This is below the 40% level (but still within the 95% confidence interval) used by the Ministry of Fisheries in 1995 as a threshold level for re-opening the fishery in 1996.

Distribution of oysters in Foveaux Strait

The 1997 survey was designed to give an absolute estimate of population size with a target *c.v.* of 20% and not a detailed distribution of oysters. The post-*Bonamia* oyster population consists of scattered small patches of high density occurring in areas of a generally low background density (even within high density strata). Because oyster density changed greatly over short distances, oyster distribution was not readily defined by a random survey with a minimum number of stations. We therefore cannot compare changes in oyster distribution between the 1995 and 1997 surveys with any confidence.

The high densities of recruited oysters found in the 1995 survey (Figure 4) were not apparent in the 1997 survey (Figure 3) in southern and eastern Foveaux Strait. The number and size of high density patches of pre-recruit (50–57 mm) and small (10–49 mm) oysters have increased throughout the Strait between the 1995 and 1997 surveys, but their distribution is very patchy (Figures 5–8). Although the distribution of oysters cannot be mapped with any precision from the randomly spread samples in the surveys of 1995 and 1997, some of the data (e.g., the population in the 1975–76 area, Table 6) suggested that the population in eastern Foveaux Strait could have declined substantially between 1995 and 1997. The population of recruits and immediate pre-recruits east and west of longitude 168° 19' E was estimated from the 1995 and 1997 survey data. In 1995, 19% of the recruited population was in eastern Foveaux Strait and in 1997 15%. In 1995, 31% of the immediate pre-recruit

population was in eastern Foveaux Strait and in 1997 36%. These differences would be even smaller with correction of bias in the 1997 data and do not show any major shifts in the distribution of oysters between the surveys.

In 1975, 91% of the population was in patches of commercial density (defined in oyster surveys as 400 or more oysters per standard survey tow and equivalent to a commercial catch rate in the fishery of 6–8 sacks per hour) (Allen & Cranfield 1979). In 1997, 40% of the population in the fishery area was in patches above this 400 oysters per tow threshold. In 1995 more of the population was in patches of higher density, and those patches above the 400 oysters per tow threshold contained 52% of the population.

Conclusion

The estimated sizes of the recruited population of oysters in Foveaux Strait in 1995 and 1997 were not different. If the 1997 estimate is corrected for possible bias, the 12% higher population estimate is still not significantly different from that of 1995. A simple extrapolation of the 1992, 1993, and 1995 population estimates indicates that recruitment should have been large enough to detect a significant population increase between 1995 and 1997. As this did not happen, it suggests that recruitment is more variable than anticipated, and that 1993 and 1995 were good recruitment years relative to 1996 and 1997.

Acknowledgments

This survey was carried out for the Ministry of Fisheries under contract OYS9701.

We thank David Fisher and Brian Sanders for supervising the survey and recording the data, Milton Roderique for organising the logistics of the survey, Terry Dixon and Rex Ryan (skippers) and the crews of *Torea* and *Toiler*, and Tony Campbell, Stuart Bragg, Richard Ryan, Geoffery Woods, Richard Bryce, Peta Mareangareu, and Duncan Ryan for the enthusiastic and efficient way they carried out the survey. We thank Alistair Dunn and Neil Andrew for constructive comments on the manuscript.

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Table 1: **Stratum number, predicted density of stratum from 1995 survey data, stratum area, numbers of phase 1 and phase 2 stations, and whether the area in the stratum was included in surveys in 1975–76, 1993, and 1995, and number of additional grid stations sampled to define the limits of dense patches**

1997 stratum number	1995 Density oysters per tow	Area (km^2)	Area surveyed previously			No. of stns		No. of grid stns
			1975–76	1993	1995	Phase 1	Phase 2	
1	< 200	257.1	✓	✓	✓	5	14	7
2	< 200	39.7	✓	✓	✓	3		
3	< 200	253.6		✓	✓	5	13	10
4	≥ 400	18.2		✓	✓	10		
5	≥ 400	13.1				7		
6	200–400	45.0	✓	✓	✓	5		
7	≥ 400	18.7	✓	✓	✓	10		
8	200–400	27.0		✓	✓	5		
9	≥ 400	24.5	✓	✓	✓	13		
10	≥ 400	16.8				9		
11	≥ 400	12.7		✓	✓	7		

Table 2: **Estimates of absolute recruited oyster density, population size, and *c.v.* of the three size groups of oysters in the 11 strata surveyed in 1997**

Stratum no.	Oyster density (per m^2)	Population size (millions)					
		≥ 58 mm		50–57 mm		10–49 mm	
		Number	*c.v.*	Number	*c.v.*	Number	*c.v.*
1	0.89	228.62	23.0	398.45	20.9	501.38	19.5
2	0.23	9.23	52.7	16.57	53.2	26.20	50.0
3	0.72	182.94	36.6	134.66	33.7	177.70	34.9
4	0.77	13.94	29.8	10.29	32.7	12.07	32.1
5	0.08	1.08	97.0	0.94	97.7	0.62	89.7
6	0.65	29.17	49.3	36.79	77.3	27.93	69.7
7	2.60	48.70	31.1	27.99	29.7	28.65	27.3
8	1.39	37.49	31.3	17.18	25.8	27.53	30.3
9	1.49	36.39	31.1	24.50	48.6	32.73	40.5
10	1.56	26.22	32.9	15.75	28.2	17.04	27.6
11	1.28	16.30	54.3	6.31	44.3	7.12	30.5

Table 3: **Estimates of absolute population size (millions) of recruits (≥ 58 mm long), immediate pre-recruits (50–57 mm long), and small oysters (10–49 mm long) in Foveaux Strait in the 1995 survey area in 1993, 1995, and 1997. 95% confidence intervals estimated from bootstrapped distributions in parentheses**

Oyster size (mm)	1993	1995	1997
≥ 58	283 (178–402)	639 (448–949)	630 (395–899)
50–57	273 (171–390)	285 (196–418)	689 (432–991)
10–49	443 (282–630)	522 (252–855)	859 (547–1223)

Table 4: **Percentage frequency of sea state as defined by the Beaufort scale of wind force for each survey tow in the 1995 and 1997 surveys**

Beaufort scale	Wind speed (knots)	1995	1997
0	< 1	7.8	0
1	1–3	34.4	0
2	4–6	26.6	4.1
3	7–10	26.0	30.1
4	11–16	5.2	58.5
5	17–21	0	5.7
6	22–27	0	1.6
No. of tows		154	123*
Median Beaufort scale	2	4	

* Includes grid stations sampled over same period

Table 5: **The frequency of percent fullness of dredges landed in the 1995 and 1997 Foveaux Strait oyster surveys. A dredge fullness of 80% indicates saturation has occurred and the tow underestimates the density of oysters in the area swept. The fullest dredge bag in 1995 was 70% full and in 1997, 75% full**

Dredge fullness (%)	1995	1997
0–24	37.3	50.0
25–49	44.4	27.5
50–74	18.3	20.8
75–100	0	1.7
No. of tows	154	120*
Median dredge fullness	30	20

* Includes grid stations sampled over same period, data missing for 3 stations

Table 6: **Estimates of absolute oyster numbers in the 1975–76 area, 95% confidence interval (from the *t*-distribution) and survey *c.v.***

Survey	Recruits (millions)	95% Confidence interval	*c.v.*(%)	Reference
1975–76	1140	800–1500	4	Doonan *et al.* (1994)
1990	378	287–469	12	Cranfield *et al.* (1991)
1992	110	90–130	9	Doonan & Cranfield (1992)
1993	180	101–259	22	Cranfield *et al.* (1993)
1995	404	312–579	15	Cranfield *et al.* (1996)
1997	352	239–465	16	This document

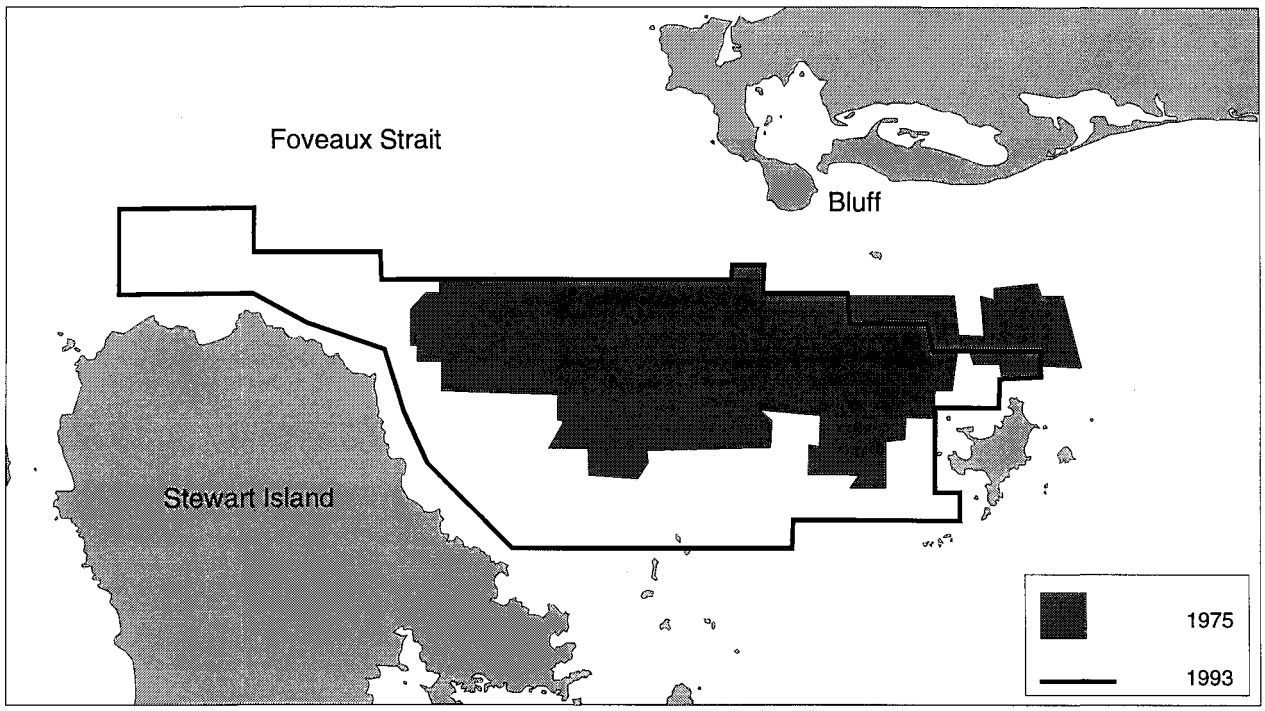

Figure 1: Foveaux Strait oyster survey 1995, boundaries of the 1975 (shaded) and 1993 (heavy outline) survey areas.

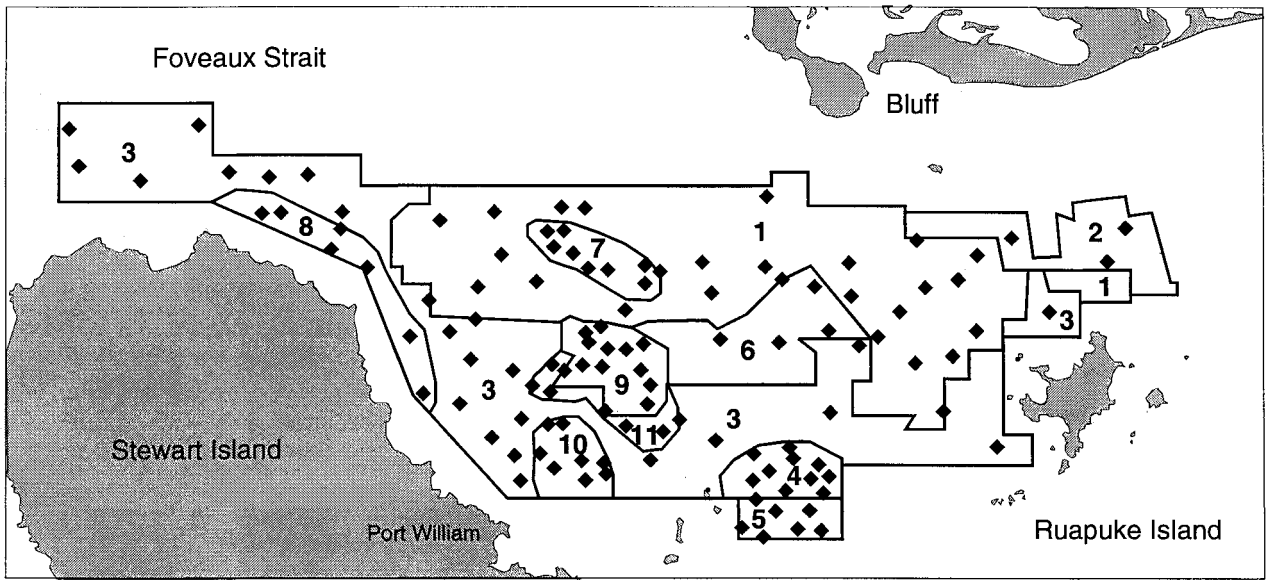

Figure 2: Strata and tow positions for the Foveaux Strait oyster dredge survey, October 1997. Strata 1, 2, 6, 7, and 9 cover the 1975 survey area. Stratum 5 was added to the 1995 survey area in 1997 to include the area fished in the 1996 and 1997 fishing years.

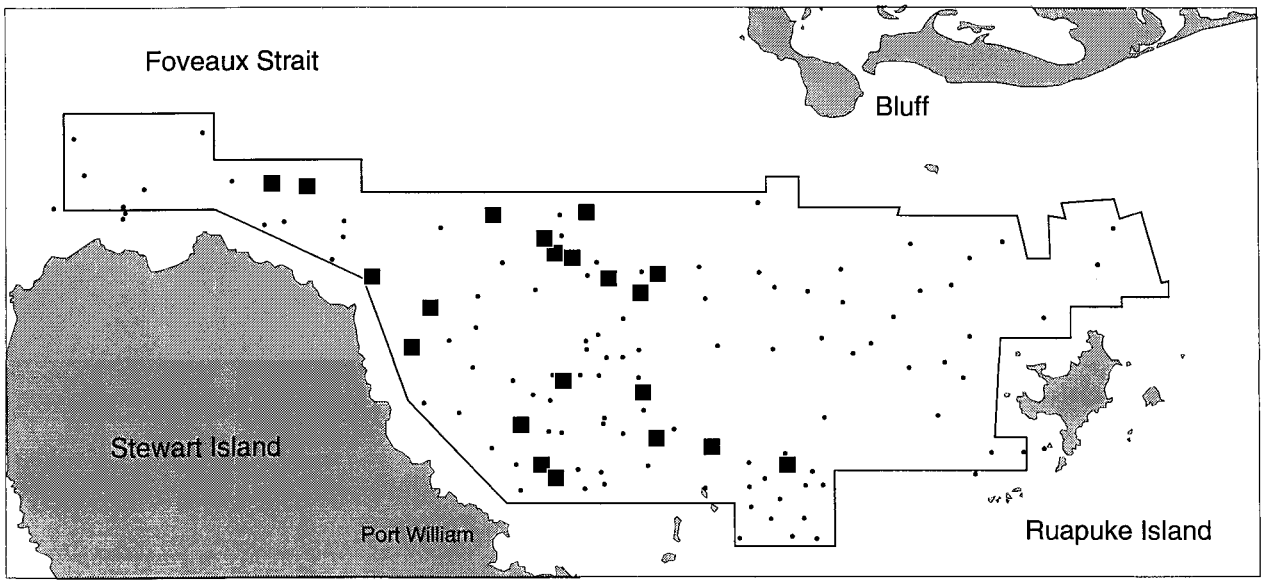

Figure 3: Stations sampled (small dots) in the Foveaux Strait oyster survey, October 1997 and stations where catches of ≥ 400 recruited oysters (≥ 58 mm in length) per tow were caught (filled squares).

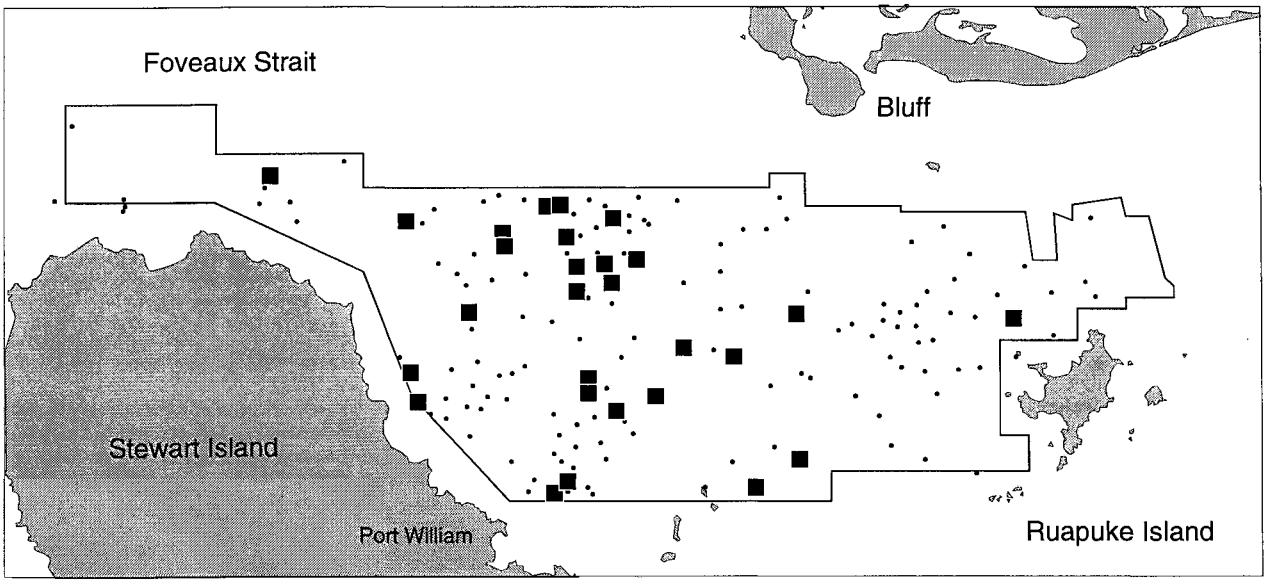

Figure 4: Stations sampled (small dots) in the Foveaux Strait oyster survey, October 1995 and stations where catches of ≥ 400 recruited oysters (≥ 58 mm in length) per tow were caught (filled squares).

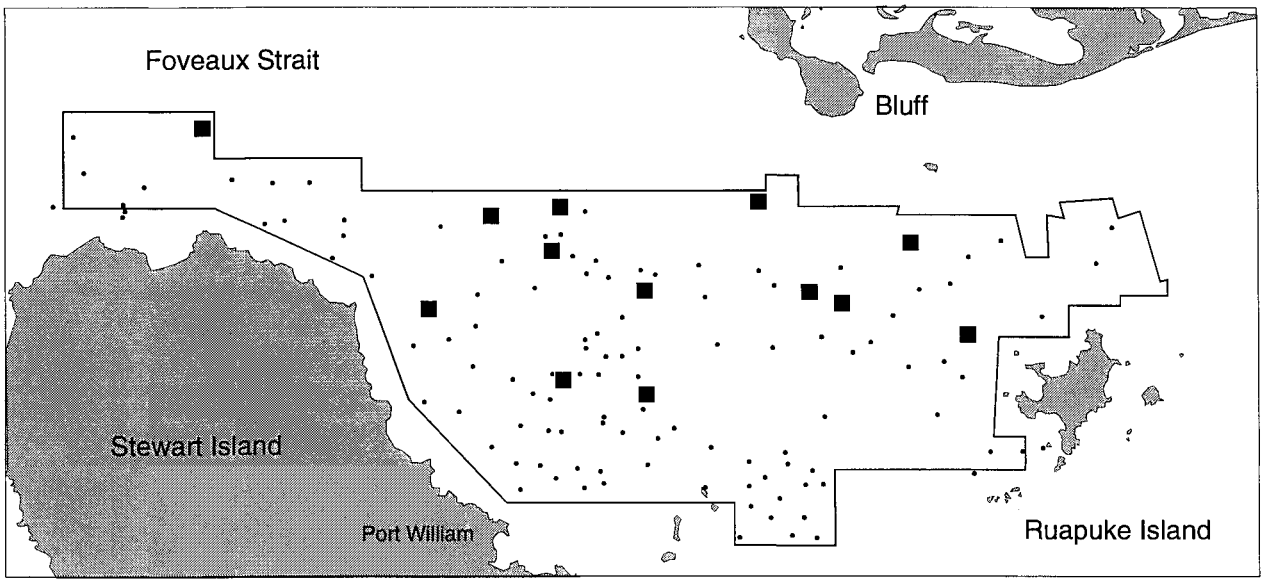

Figure 5: Stations sampled (small dots) in the Foveaux Strait oyster survey, October 1997 and stations where catches of ≥ 400 immediate pre-recruit oysters (50–57 mm in length) per tow were caught (filled squares).

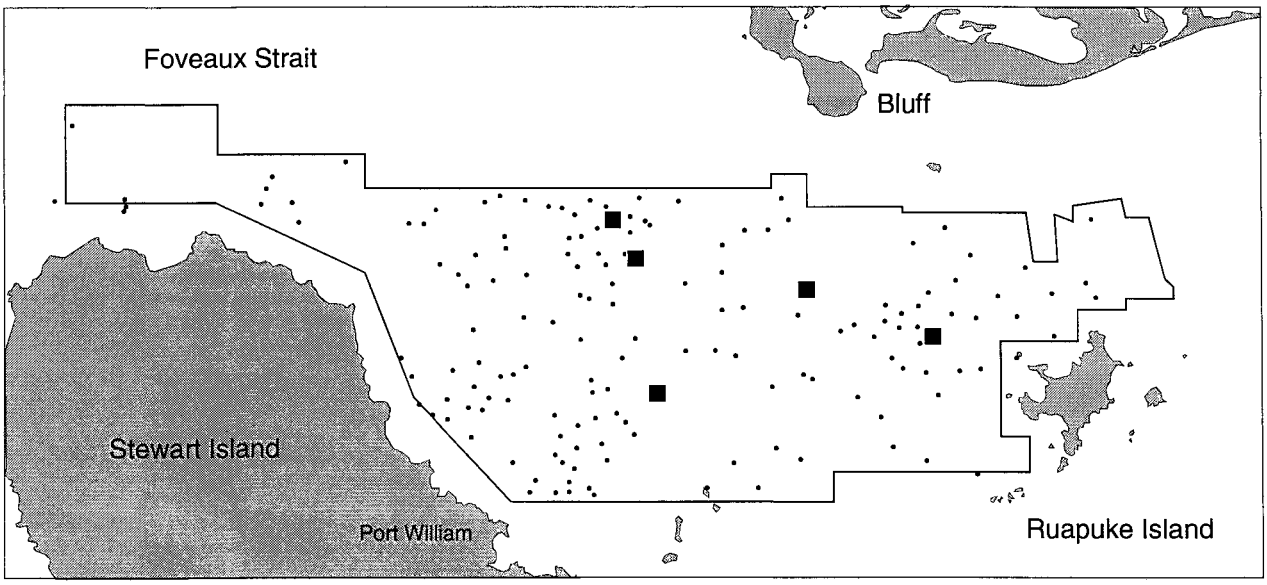

Figure 6: Stations sampled (small dots) in the Foveaux Strait oyster survey, October 1995 and stations where catches of ≥ 400 immediate pre-recruit oysters (50–57 mm in length) per tow were caught (filled squares).

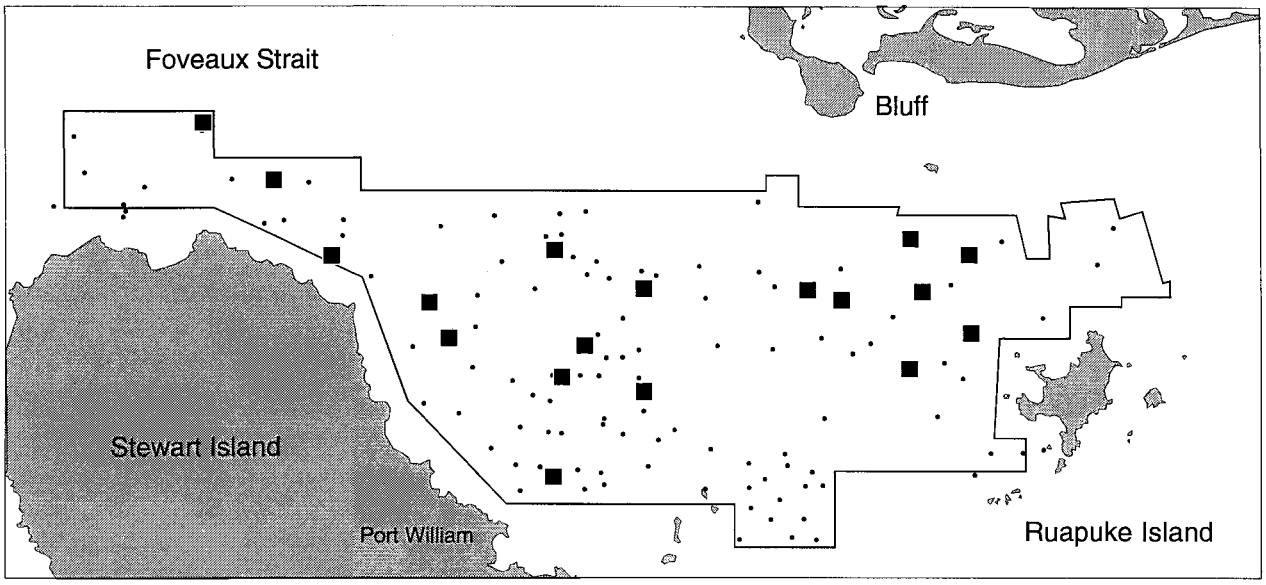

Figure 7: Stations sampled (small dots) in the Foveaux Strait oyster survey, October 1997 and stations where catches of ≥ 400 small pre-recruit oysters (10–49 mm in length) per tow were caught (filled squares).

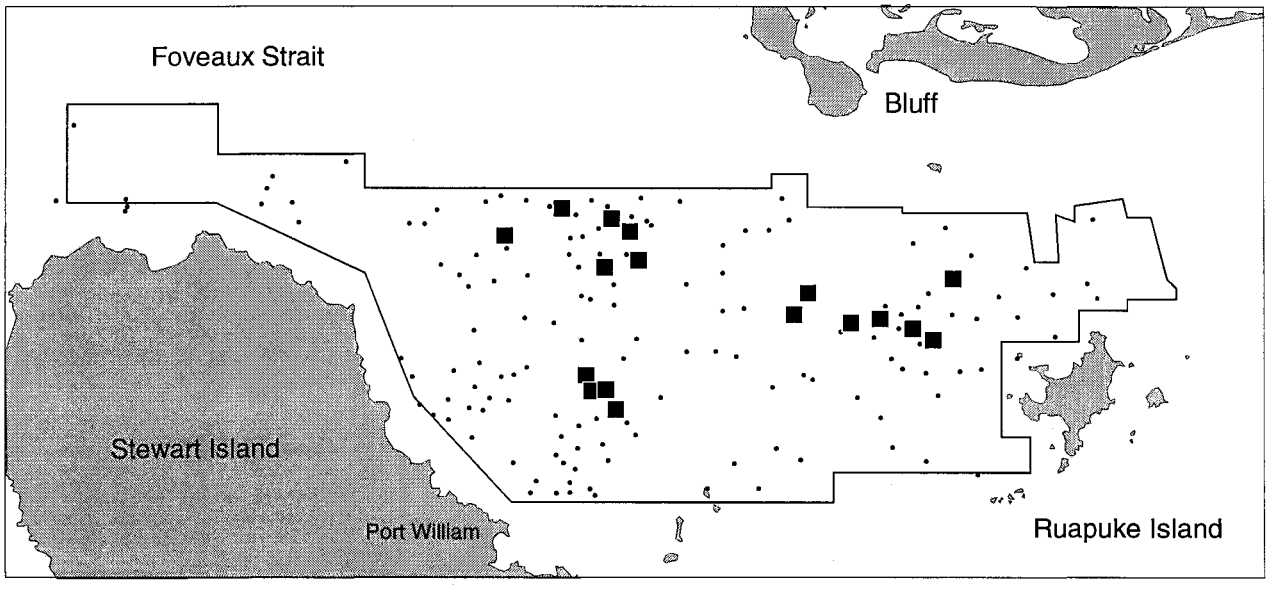

Figure 8: Stations sampled (small dots) in the Foveaux Strait oyster survey, October 1995 and stations where catches of ≥ 400 small pre-recruit oysters (10–49 mm in length) per tow were caught (filled squares).