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Foveaux Strait oyster (*Tiostrea chilensis*) assessment, 1997

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This series documents the scientific basis for stock assessments and fisheries management advice in New Zealand. It addresses the issues of the day in the current legislative context and the time frames required. The documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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1. EXECUTIVE SUMMARY

The population of recruited oysters in Foveaux Strait in 1997 was not significantly different from that in 1995, but the population of immediate pre-recruits (50–57 mm long) in 1997 was 2.4 times larger than that in 1995 (highly significantly different), and the population of smaller pre-recruits (10–49 mm long) was 1.4 times larger than that in 1995 (not significantly different).

In 1997, the population of recruited oysters in the area commercially fished in 1975 (largely in eastern Foveaux Strait) was 31% of that present in 1975, a small decrease from 1995 when it was 35% of the 1975 population.

A CAY was estimated for the oyster population in areas where densities were greater than 400 oysters per standard survey tow (the commercially exploited population). The CAY was 20.3 million oysters (95% CI, 4–38 million).

The stratified random dredge survey used to estimate population size efficiently did not give a good picture of how the distribution of oysters is changing in Foveaux Strait as the population rebuilds, but does suggest that oyster distribution is still limited and densities are very low in eastern Foveaux Strait.

2. INTRODUCTION

The Foveaux Strait oyster population was devastated by a *Bonamia* sp. epizootic between 1986 and 1992. The population of recruited oysters in Foveaux Strait was estimated to have been 1140 million before the epizootic in 1985 (Doonan *et al.* 1994) and as the disease spread through the population oyster numbers were reduced to 771 million by July 1990 (Cranfield *et al.* 1991), and 319 million by February 1992, by which time infection had reached the periphery of oyster distribution (Doonan & Cranfield 1992). In 1992, the population in the area surveyed in 1975 was less than 10% of that present in 1975 and recruitment was considered to be at risk (Doonan *et al.* 1994). The fishery was partially closed to fishing in 1992 and fully closed in 1993 to allow the population to rebuild.

Changes in the distribution of *Bonamia* sp. throughout Foveaux Strait between 1990 and 1995 indicate that prevalence and intensity of infection by *Bonamia* sp. had waned over this period (Cranfield *et al.* 1995) and disease was unlikely to cause much extra mortality of oysters. The size of the oyster population estimated in 1992 and 1993 suggested that oyster numbers were increasing (Cranfield *et al.* 1993), and by 1995 the population had reached a size large enough to sustain some commercial fishing without slowing recovery of the fishery (Cranfield *et al.* 1996). The Minister of Fisheries reopened the fishery in 1996 with a quota of 14.95 million oysters.

2.1 Overview

The oyster population has been fished for two years with the quota of 14.95 million oysters and was surveyed again in October 1997 to assess whether it had continued to recover at this low harvest rate. This document updates the stock assessment of the oyster population in Foveaux Strait and examines the population recovery using data from this survey.

2.2 Description of the fishery

The fishery was described in detail by Doonan & Cranfield (1992). The bounds of the fishery area in Foveaux Strait and the statistical areas of the fishery are shown in Figure 1.

2.3 Literature review

Past work was reviewed by Cranfield *et al.* (1991, 1995, 1996), Doonan & Cranfield (1992), Cranfield *et al.* (1993), and Doonan *et al.* (1994).

Investigations of *Bonamia* sp. since the last review are discussed in Section 4.4.

3. REVIEW OF THE FISHERY

3.1 TACCs, catch, landings, and effort data

Landings of oysters and the TAC of the Foveaux Strait fishery from 1963 to 1997 are summarised in the Dredge Oyster Working Group Report (Annala *et al.* 1998). Fishing effort has been managed as a licensed fishery for 23 vessels since 1979 and the TAC has been divided evenly between all vessels. Changes in landings and catch rates of the fishery resulting from *Bonamia* sp. mortality and TACs changed in response to this are shown in Table 1.

The fishery was closed in 1993 and, after three years, the population had rebuilt sufficiently for the Minister of Fisheries to reopen the fishery in 1996 with a catch limit of 14.95 million oysters (equivalent to 19 315 sacks). In 1996 this limit was converted to weight using a conversion factor of 801 oysters per sack, derived from reported landings under the Bluff Oyster Enhancement Company special permit. This conversion gave a catch quota of 1475 t for 1996. The mean number of oysters per sack landed in 1996 was less than 801 so that the quota specified by weight was filled before 14.95 million oysters were landed. The number of sacks landed as well as the number of oysters they contained was tabulated from the 1996 CELR data and the conversion factor of 774 oysters per sack estimated (the same figure was derived from landings of the Bluff Oyster Enhancement Company under their special permit between 1993 and 1996, Cranfield *et al.* 1996). Using this conversion rate, the quota for 1997 was 1525 t (Table 2). This conversion rate has been used throughout this present report.

In April 1997 individual quotas were granted and quota holders permitted to fish their entire quota on one vessel. At the same time, the Crown purchased 20% of the available quota from existing quota holders and transferred it to the Waitangi Fisheries Commission. This quota was leased by various fishers in 1997. The number of vessels in the fishery dropped to 15 in 1997. The oyster fishery entered the Quota Management System in 1998.

3.2 Other Information

3.2.1 Special permit landings

The Bluff Oyster Enhancement Company (now the Bluff Oyster Management Company Ltd) has been granted a special permit each year since 1992 to catch oysters during the breeding season and trial the enhancement of the oyster population using spat settled on oyster shell (Table 3).

3.2.2 Other sources of mortality from fishing

Since 1968 heavy, double-bit, double ring-bag dredges have been used to harvest oysters. When first introduced, these dredges weighed 410 kg but modifications in 1984 increased their weight to 530 kg so they are three and a half times heavier than the single-bit, single-ring bag dredges employed between 1913 and 1968. Fishing with these heavy dredges damages oysters and causes incidental mortality (Table 4) (Cranfield *et al.* Unpublished results).

Incidental mortality of oysters from dredging with light (320 kg) and heavy (530 kg) double-bit, double-ring bag dredges was compared experimentally in March 1997 (Cranfield & Michael 1987). The oyster population dredged had not been fished for the previous three years of fishery closure and as tows were not coincident, oysters in the experiment had had only a single encounter with the dredge. Dead oysters were counted at the end of the experiment seven days after dredging. They were recorded in three groups. (1), oysters that had encountered the dredge and been left behind on the seafloor in the dredge track (mean dredge efficiency was 18%, (Doonan *et al.* 1994) so these oysters could give rise to the greater proportion of incidental mortality); (2), oysters landed on the vessel in the dredge after a tow and after the dredge contents had been washed by dunking at the surface; and (3), those oysters that had filtered through the dredge bag on the seafloor or during washing (Table 5).

Mortality was inversely proportional to the size of oysters damaged and lighter dredges damaged and killed fewer oysters. Recruited oysters (over 58 mm in length) appeared to be quite robust (1–2% mortality with the heavier dredge) and few were damaged, but spat (less than 10 mm in length) were very fragile and many were killed especially by the heavy commercial dredge and mortality ranged from 19% to 36% in the experiment. Incidental mortality from dredging has the potential to reduce subsequent recruitment in heavily fished stocks, but such mortality is unlikely to be important in reducing numbers of recruited oysters.

The mortality demonstrated experimentally here has not been scaled to the intensity of dredging of oyster beds (where each oyster might encounter dredges many times each season) or the size of the fishery, so its importance cannot be assessed. However, indirect mortality from the dredges in use from 1968 to 1975 (weighing 410 kg) has implicitly been considered in the assumptions concerning the equilibrium exploitation rate estimated for 1975 (*see* Section 4.5.1). Indirect mortality from dredges is likely to have increased after the introduction of heavier (530 kg) dredges in 1984.

3.3 Recreational, traditional, and Maori fisheries

3.3.1 Recreational fishery

Although two recreational fishing surveys have been conducted by MAF and the Ministry of Fisheries (Southern region 1991–92 and national survey 1996 (Teirney *et al.* 1997, Bradford 1998)), the catch of oysters cannot be reliably quantified from them because of the few respondents who reported catches of oysters in their diaries. A recreational fishery takes small quantities of oysters along the Stewart Island coast and is prized by divers from Stewart Island, Southland, and Otago. Local fishers also dredge small quantities of oysters (as a recreational catch) in deeper water using improvised small dredges. Recreational fishers may take 50 oysters per day during the open season. Individual commercial oyster fishers land 50 oysters each day during the fishing season as an amateur catch. The Southland Recreational Marine Fishers Association estimated the annual recreational catch of oysters in Foveaux Strait in 1995 to be about 500 sacks (equivalent to 387 000 oysters). The reliability of this estimate is unknown.

3.3.2 Traditional and Maori fishery

No estimates of customary catch are available. Ninety-two sacks of oysters (equivalent to 71 200 oysters) were permitted to be taken on formal hui/tangi permits granted by the Invercargill office of the Ministry of Fisheries in the 1996/97 fishing year. Customary fishers consider that this figure does not reflect the true customary harvest and is too low (Allan Frazer, MFish, pers. comm.).

3.3.3 Illegal catch

The Ministry of Fisheries estimated a further 100 sacks (equivalent to 77 400 oysters) were taken illegally in the 1996/97 fishing year (Steve Logie, MFish, pers. Comm.). The reliability of this estimate is unknown.

4. RESEARCH

4.1 Stock Structure

The oyster population in Foveaux Strait consists of a number of discrete small dense patches generally separated by extensive areas of barren ground and oyster-bearing ground that covered some 1200 km^2 of Foveaux Strait in 1962 (Stead 1971). In 1975 the fishery exploited only 374 km^2 of the oyster bearing ground and 91% of the total oyster population in this area was located in about 50 small dense patches that together covered only 12 km^2 of the seafloor (Allen 1979). Throughout the years, high catches of oysters have been confined to the same locations suggesting that these localised patches are stable entities. Between 1986 and 1992, mortality from *Bonamia* sp. progressively destroyed most of these dense patches. The surveys between 1990 and 1995 have sampled on a wider scale (1–2 nautical mile spacing between stations and frequently a greater distance in the stratified random surveys) than the 1975 survey (0.33 nautical mile spacing) and are not able to resolve small dense patches. These surveys have, however, delimited the areas of higher density in which the small dense patches are found. The later surveys of the fished area (by then almost twice the area fished in 1975) have been analysed to delineate the higher density areas where mean density was above 400 oysters per survey tow (equivalent to 6–8 sacks per hour of commercial fishing). Table 4 shows how the percentage of the population in areas above a density of 400 oysters per survey tow has changed.

The recovery of localised populations has not been uniform. Dense areas are still absent in eastern Foveaux Strait (A, B5, & C5) and in those western areas most heavily affected by *Bonamia* sp. (G8, G9 & H), where dense patches were common before the epizootic.

4.2 Resource surveys

A dredge survey mapped oyster density in 1960–62, and the population was estimated from a dive calibration of these densities. The population size was estimated again in 1974 and 1975 using a mark-recapture experiment (Cranfield & Allen 1979) involving the commercial fleet and covering the entire commercial fishery of that time (the commercially fished area has expanded since). The population estimates from the mark-recapture experiment were thought likely to be biased upwards (Cranfield & Allen 1979). The efficiency of the small dredge used by a research vessel to survey the oyster population in 1975 and 1976 was poorly estimated at that time and the population estimate from that survey was too inaccurate for use in management. The efficiency of that survey dredge was better estimated during the surveys of 1990 and this new estimate of efficiency for the dredge was used to re-estimate the oyster population in 1975–76 to give a more accurate estimate which is comparable to recent dredge surveys (Doonan *et al.* 1994).

The absolute population size was estimated in 1990 using a stratified random dive survey. The efficiency of the small survey dredge and of commercial dredges was estimated by comparing oyster density in the same areas using these dredges with the density from the dive survey. In 1992 and 1993 the population was estimated from grid pattern dredge surveys. The population was estimated from stratified random surveys in March and October 1995, and again in October 1997. These population estimates (1990–97) used the 1990 estimate of dredge efficiency.

4.3 Population estimates

Table 6 gives the population estimates from the post-1960 surveys.

The similarity of the estimates between 1960 and 1975 has been interpreted by the Working Group as suggesting that the population was in equilibrium at the existing fishing mortality rate before the Shellfish *Bonamia* outbreak (fishers' reports of oyster mortality suggest the epidemic began in 1985). The population declined rapidly to a low point in 1992 from which it has increased.

4.3.1 Estimation of reference population in 1975 survey area

By 1975, the oyster population of Foveaux Strait had been fished for over 80 years and was less than the virgin population size. As the size of the virgin population is unknown and is difficult to estimate, the 1975 population has been used as a reference population. The area surveyed in 1975–76 has been included as a distinct stratum within the area of all subsequent surveys and the population within this area in the surveys between 1990 and 1997 has been computed to show how this reference population has changed (Table 7).

By 1992 the oyster population had been reduced below 10% of the 1975 level and by 1995 had recovered to 35% of the 1975 level, but had dropped to 31% in 1997. The decrease in this population from 1995 to 1997 is not statistically significant (Appendix 1). The 1997 population is below 40% of the 1975 population, the level suggested by the Shellfish Working Group in 1995 as a decision rule for re-opening the fishery (Cranfield *et al.* 1996). However, the areas now fished have changed markedly since 1975, so the Working Group considered it more appropriate to consider the population size of the fished areas when assessing the likely effect of current levels of fishing.

4.3.2 Estimates of recruitment between 1993 and 1997

The populations of immediate pre-recruit oysters (those between 50 and 57 mm long) and the smaller pre-recruit oysters (those between 10 and 49 mm long) were estimated during the surveys of 1993, 1995, and 1997 (Table 7). Immediate pre-recruits were probably totally selected by the dredge. Unless they were attached to larger oysters, smaller pre-recruits could readily pass through the rings of the dredge so their numbers are probably underestimated.

Mortality from *Bonamia* sp. ceased in 1992, and the recruited oyster population increased by a mean 100 million oysters annually between March 1992 and March 1995 and 178 million oysters annually between October 1993 and October 1995. The increase is consistent with about half the immediate pre-recruits recruiting each of these years (which is also consistent with the expected mean annual height increment of this size group, *see* Cranfield *et al.* (1993). The numbers of immediate pre-recruits in 1995 suggested that recruitment over the next two years would continue at the same rate.

However, the recruited population in 1997 appears to be the same size as in 1995 and it was important to understand what had caused this. The pre-recruit population (which had remained constant between 1993 and 1995) followed the opposite trend and increased greatly between 1995 and 1997. Numbers of immediate pre-recruits in 1997 were more than twice those of 1995 (highly significant, Appendix 1) and numbers of smaller pre-recruit were one and a half times greater than those in 1995 (not significant, Appendix 1) and it was also important to understand the causes of this conflicting change.

Variation in sorting procedures discussed in Appendix 1 (the results of the October 1997 population survey) may account for some bias in the results and we conclude that the recruited population estimated in 1997 was likely to be 12% too small and the immediate pre-recruit population 12% too large. Other factors that might have affected dredge efficiency between surveys are examined in Appendix 1 but the Working Group found no compelling evidence that they were important and concluded that oyster recruitment was more variable than anticipated.

4.3.3 Estimation of population in patches above 400 oysters per survey tow

The number of oysters in areas where densities were greater than 400 oysters per standard survey tow (the population likely to be fished commercially the following year) was 254 million in 1997. The number of oysters above the threshold of 400 oysters per standard survey tow (the number of oysters available to the fishery before density is reduced below the threshold level) was 109 million. In 1995 these populations were 331 million and 147 million respectively.

4.4 *Bonamia* sp. studies

The mean prevalence of infection by *Bonamia* sp. in recruited oysters has declined from 21% in 1990 to 8% in 1992 and to 4.5% in 1995 (Cranfield *et al.* 1995). Intensity of infection (and the likelihood of infection resulting in death of oysters, (Hine 1991)) has also declined in a similar way over this period. In 1995, there was little evidence of recent mortality to relate to prevalence of infection, and infection was widespread at low levels throughout Foveaux Strait with no clear pattern. As infection and development of bonamiasis is dependent on density of oysters, sampling for *Bonamia* sp. in February 1998 focused on the densest patches of oysters where infection was most likely to recur. Oysters were sampled from the six densest patches found in the October 1997 survey. Fifty oysters were taken from a central station on a dense patch and four stations 0.5 nautical mile to the north, east, south, and west. Only 3 of the 1500 oysters examined were infected and the intensity of infection in these oysters was so low as to be barely detectable with the heart imprint method used. Infection by *Bonamia* sp. is continuing to wane. Although there was evidence that considerable numbers of oysters had died recently at three stations in the same general area, the mortality was not due to infection by *Bonamia* sp. and no other pathogens were detected in histological examination of samples from these stations (Cranfield *et al.* Unpublished results).

4.5 Yield estimates

4.5.1 Estimation of Maximum Constant Yield (MCY)

An estimate of B_0 is not available. MCY could be estimated should the population size rebuild to the pre-epizootic level. By the 1960s, the oyster population of Foveaux Strait had been fished for 80 years and the fishery was fully developed. The oyster population had been stable between 1965 and 1975 and appeared to be in equilibrium with the mean annual harvest of 115 000 sacks through this period. The size of the oyster population was estimated in 1976 and the associated fishing mortality for that year's catch of 115 000 sacks was estimated to be 0.078 (rounded to 0.08). This was assumed to equate to a sustainable exploitation rate. The population in 1975–76 was probably at equilibrium with the existing fishing mortality rate and the population estimate for those years (the only pre-epizootic estimate) is therefore an estimate of B_{av}. Method 2 (Annala *et al.* 1998) was used to estimate MCY

$$\text{MCY} = 0.5 * F_{0.1} * B_{av}$$

with the estimate of $M = 0.1$ (*see* Allen 1979) substituted for $F_{0.1}$,

$$\text{MCY} = 0.5 * 0.1 * 1140 \text{ million oysters}$$
$$= 57 \text{ million oysters}$$

The Working Group discounted this estimate by 0.69 (the proportion that the population is currently below B_{av}.(Table 6)).

$$\text{MCY} = 17.7 \text{ million oysters}$$

These estimates of MCY may not be relevant to this population as catastrophic declines in population size can occur, but have not been considered in the model.

4.5.2 Estimation of Current Annual Yield (CAY)

CAY was estimated using Method 1 (Annala *et al.* 1998) where most fishing mortality occurs over a short period at the beginning of the year.

$$\text{CAY} = (1-e^{-Fref})B_{beg}$$

B_{beg} is the recruited population level at the beginning of the fishing year. The population estimate of 630 million was used as an estimate of B_{beg}. The use of this figure from the October 1997 survey for a fishery beginning in June 1998 assumes that natural mortality over the intervening period will be balanced by recruitment. The sustainable exploitation rate, $(1-e^{-Fref})$ was estimated as 0.08 from 1975 data (Doonan & Cranfield 1992), so:

$$\text{CAY} = 0.08 * 630 \text{ million oysters}$$
$$= 50 \text{ million oysters (95\% confidence interval 24–80 million oysters)}$$

The level of risk to the stock by harvesting the population at the estimated CAY cannot be determined.

5. FACTORS MODIFYING YIELD ESTIMATES

5.1 Concentration of fishing on only a few populations

Oyster fishers tend to concentrate on populations giving the highest catch rates and cease fishing these when the catch rate drops below a level that is commercially viable (Allen 1979). Yield for the fishery can be estimated for that portion of the population that is above commercial densities and therefore likely to be fished. Because of the extreme localisation of settlement, the unfished, low-density populations may not contribute much to recruitment of fished populations.

Here the assumption was made that the threshold for commercial fishing is a density above 400 oysters per standard survey tow. The CAY for this portion of the oyster population (254 million oysters, 95% confidence interval 77–449 million) is:

$$\mathbf{CAY}_{\mathbf{400\ oysters/survey\text{-}tow}} = 0.08 * 254 \text{ million oysters}$$
$$= 20.3 \text{ million (95\% confidence interval, 4–38 million)}$$

The level of risk to the stock by harvesting this yield cannot be determined.

5.2 Continuing mortality from *Bonamia* sp.

Very few shells of recently dead oysters were found during the survey of the 1997 population so mortality from *Bonamia* sp. in the last year is unlikely to have been important. The low prevalence and intensity of infection found in the March 1995 *Bonamia sp.* survey (Cranfield *et al.* 1995) made it impossible to estimate mortality caused by *Bonamia* sp. by that time. Now that the epizootic is over, natural mortality of oysters is considered to have returned to pre-epizootic levels, assumed to be less than 0.1 (*see* Cranfield *et al.* 1996).

5.3 Recruitment overfishing

Stock size and recruitment are frequently unrelated in shellfish fisheries but a number of life history traits indicate that this may not be true for *T. chilensis*. This species produces large eggs, has a low fecundity, and only a low percentage of the population in Foveaux Strait breeds each year (Cranfield & Allen 1977). Hence oyster populations produce few larvae. Larvae are incubated and generally released as pediveligers ready to settle, which they do within minutes of release and larvae disperse only a few metres from the parent (Cranfield 1968, 1979). Although a very small percentage of larvae may be released at an earlier stage of development and spend some time in the plankton (Cranfield & Michael 1989), each localised oyster population is largely self-recruiting. Most spat that survive settle on live oysters. This recruitment pattern is atypical of commercially fished bivalves, adults of which generally produce millions of larvae that have a moderately long planktonic life and that generally disperse widely before settling.

A simulation model of the fishery including the biological information indicated that recruitment would fail should the population be reduced below $10\%B_0$ (Allen 1979). The oyster population in 1992 was less than 10% of B_{1975} and was therefore probably less than 10% B_0. In spite of this low biomass level, in 1995 the population appeared to be rebuilding (to 39% of B_{1975}) after only 3 years with no fishing. This oyster population apparently has the capacity to rebuild quickly in the absence of fishing, even at low biomass levels. The population has however not rebuilt uniformly throughout Foveaux Strait, and the oyster density is still very low in some localities, especially to the east (in statistical areas B5, C5, & A), and recruitment may have failed at the local level. The low oyster density found in eastern Foveaux Strait may continue to result in poor recruitment and could slow the recovery of oyster density and the redevelopment of dense patches in this area.

Fishing of dense patches in the past may have reduced oyster density so low that the patches have never recovered. Dense patches of oysters along the Stewart Island coast (in southern S7) fished heavily in the 1860s (Hunter 1906) were reduced to low densities at that time, and are almost barren of oysters to the present day. A larger dense patch, the East bed (in the northern parts of B5 and A), was fished heavily from 1888 to the 1950s (Hunter 1906, Robjohns 1979) when it was reduced to low densities and is also barren of oysters today. On the other hand, mortality from *Bonamia* sp. probably reduced oyster density around the focus of the original infection in the central western Foveaux Strait below the threshold level Allen suggested would result in recruitment failure (Cranfield *et al.* 1991), but by 1997, oyster density had rebuilt here to commercial densities.

Based on the increase in population size since 1992 and the recent observed levels of pre-recruits, the Working Group concluded that the low biomass may not have had much effect on recruitment.

5.4 Indirect fishing mortality

A small scale experimental study suggested dredging caused little indirect mortality to recruited oysters and this was confirmed by the very few freshly dead oysters found in heavily fished areas in the 1997 survey. However, mortality of small pre-recruit oysters is likely to be higher with the currently used heavy dredges than with the lighter dredges used in 1975 (*see* Section 3.2.2).

6. STATUS OF THE STOCKS

The status of the oyster population is uncertain but it is most likely to be below B_{MSY}. B_0 and B_{MSY} are hard to estimate because of the long history of undocumented exploitation. The adult population (the breeding population includes immediate pre-recruits as well recruits) may be between 15 and 20% B_0.The current exploitation rate (at 15 million oysters) is low in relation to the current surplus production (based on the number of immediate pre-recruits) and should allow the biomass to continue to increase. Current catch levels are unlikely to be having a measurable effect on the rate of rebuilding.

The results of the two most recent surveys are hard to interpret and the surveys may not be giving us a good picture of all that is going on in the population. The breeding population of oysters (including immediate pre-recruits and recruits) increased between 1992 and 1997, yet the recruited population size in 1997 did not increase from the size estimated by the 1995 survey. Measurement error (*see* Appendix 1) has affected these estimates but the similarity of the population size in 1995 and 1997 may be mainly due to interannual variation in recruitment.

7. ACKNOWLEDGMENTS

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Table 1: Reported oyster catch, total allocated catch, individual vessel allocation, and the average catch rate in calendar years 1986–95

Year	Reported catch (sacks)	Total allocated catch (sacks)	Individual vessel allocation (sacks)	Mean catch rate (sacks per hour)
1986	77 880	115 000	5 000	10.5
1987	61 544	64 400	2 800	10.9
1988	87 607	92 000	4 000	10.0
1989	85 025	115 000	4 000	10.7
1990	46 114	46 000	2 000	6.4
1991	54 000	46 000	2 000	5.8
1992*	5 821	18 400	800	3.4
1993		**0		
1994		**0		
1995		**0		

* exploratory commercial fishing in the periphery of oyster distribution.
** commercial fishery closed

Table 2: Reported landings, catch limit, quota for the Foveaux Strait dredge oyster fishery from 1996 to 1997. Landings and catch limits reported in numbers and weight. CPUE converted to sacks/hour (774 oysters per sack) to compare with earlier data. n.a. = not available

Year	Reported Landings		Catch limit		CPUE
	Number (millions)	weight(t)	Number (millions)	weight (t)	(sacks/hour)
1996	13.41	1475	14.95	1475	5.9
1997	n.a.	n.a.	14.95	1525	6.8*

* preliminary value based on partial data

Table 3: Reported oyster catch of vessels fishing under special permits for Bluff Oyster Enhancement Company 1992–97. Fishing took place over the summer breeding season (November-February) rather than the winter season (March-August) of commercial fishing. In 1996–97 the permit catch was specified in numbers of oysters rather than sacks

Summer	Reported catch (sacks or number)	Permit allocation (sacks or number)
1992–93	3 141	4 000
1993–94	3 986	4 000
1994–95	3 918	4 000
1995–96	1 199	1 200
1996–97	0.20 million oysters	0.88 million oysters

Table 4: Indirect fishing mortality of oysters after a single encounter with a light (320 kg) double ring bag double bit dredge and a heavy standard (530 kg) dredge on the seafloor, of oysters captured by the dredges washed and landed, and of oysters that filtered out of the dredges during fishing or washing. Mortality shown as percentage of oysters that died within a week of the experiment

	Light dredge			Heavy Dredges		
	Spat (≤10 mm)	Juveniles (11-57 mm)	Adults (≥58 mm)	Spat 10 mm)	(Juveniles (≤11-57 mm)	Adults (≥58 mm)
Uncaught oysters that encountered dredge on seafloor	11	6	1	19	7	2
Oysters from landed dredge	23	2	+	36	6	+
Oysters that filtered through dredge bag	25	9	*	26	11	*

+ These recruited oysters would normally have been landed. Any subsequent mortality of these oysters was therefore not relevant.

* Recruited oysters are too large to pass through the dredge bag rings and are all retained in the dredge during dredging and washing.

Table 5: Percentage of the oyster population in areas above a density of 400 oysters per survey tow (equivalent to 6–8 sacks per hour in commercial dredging) in the area surveyed. Standard errors in parentheses. The comparative figure for 1975 in the 1975 area was 91%

Survey	1990	1992	1993	1995	1997
Percentage	56 (3)	11 (2)	26 (3)	52 (4)	40 (5)
Number of stations	116	370	177	154	107

Table 6: Population size estimates (millions) of recruited oysters (greater than or equal to 58 mm length) in Foveaux Strait. Pre-1990 estimates are from Cranfield *et al.* (1991); 1990 and 1992 estimates are from Doonan & Cranfield (1992); 1993 from Cranfield *et al.* (1993); March 1995 (Cranfield *et al.* 1995), and October 1995 from Cranfield *et al.* (1996); October 1997 from Cranfield *et al.* (Unpublish. results). SR, stratified random survey design, MR, mark-recapture survey method, Total cv includes error in dredge efficiency. -, no data; na, not applicable

Year	Month	Survey design	Survey method		Area (km^2)	No. stations	Population size	Sampling cv	Total cv
1960-62	-	grid	dive		377	35	1400	-	na
1974	-	grid	MR		374	-	1800	20	na
1975	-	grid	MR		374	-	1500	11	na
1975-76	-	grid	dredge	*1*	374	929	1140	4	15
1990	July	grid	dredge	*2*	1116	262	771	14	na
1990	October	SR	dredge	*1*	646	116	– *3*	11	na
1990	October	SR	dive		646	83	607	13	na
1992	March	grid	dredge	*2*	1229	370	319	10	18
1993	October	grid	dredge	*2*	875	177	372	14	21
1995	March	SR	dredge	*2*	680	50	543	26	30
1995	October	SR	dredge	*2*	680	154	639 *4*	12	19
1997	October	SR	dredge	*2*	693	107	630	14	21

1 1.2 m wide replica of commercial dredge towed by research vessels
2 3.35 m wide commercial dredge towed by commercial oyster vessels
3 Survey calibrated from dive survey
4 Figure modified from that published in 1996, *see* Appendix 1

Table 7: Population size estimates (millions) of legal-sized oysters (greater than 58 mm in length), within the area of Foveaux Strait surveyed in 1975–76 (374 km^2), in 1975–76, 1990, 1992, 1993, 1995 and 1997.

Year	Population size		Population size as a percentage of 1975	No. of stations	Sampling cv (%)
1975–76	1140		100	929	4
1990 (July)	378		33	141	12
1992 (March)	101		9	126	9
1993 (Oct)	180		16	57	22
1995 (Oct)	404	*1*	35	97	15
1997 (Oct)	352		31	50	16

Figure modified from that published in 1996, *see* Appendix A.

Table 8: Population size estimates of oysters (millions) within the area of Foveaux Strait surveyed in 1995 (680 km^2), in 1992, 1993, two surveys in 1995, and 1997. Recruited oysters (greater than or equal to 58 mm in length), immediate pre-recruit oysters (50–57 mm in length) and small pre-recruits (10–49 mm in length). 95% confidence intervals in parentheses includes error in dredge efficiency 1993–1997. -, no pre-recruit data in 1992

Year	Recruited oysters	Percentage of 1992	Immediate pre-recruits	Small pre-recruits
1992 (March)	238 (143–352)	100	-	-
1993 (Oct)	283 (178–402)	119	273 (171–390)	443 (282–630)
1995 (March)	543 (254–878)	228	377 (177–612)	370 (187–582)
1995 (Oct) *1*	639 (448–949)	268	285 (196–418)	522 (252–855)
1997 (Oct)	630 (395–899)	264	689 (432–991)	859 (547–1223)

1 Figure modified from those previously published, *see* Appendix A.

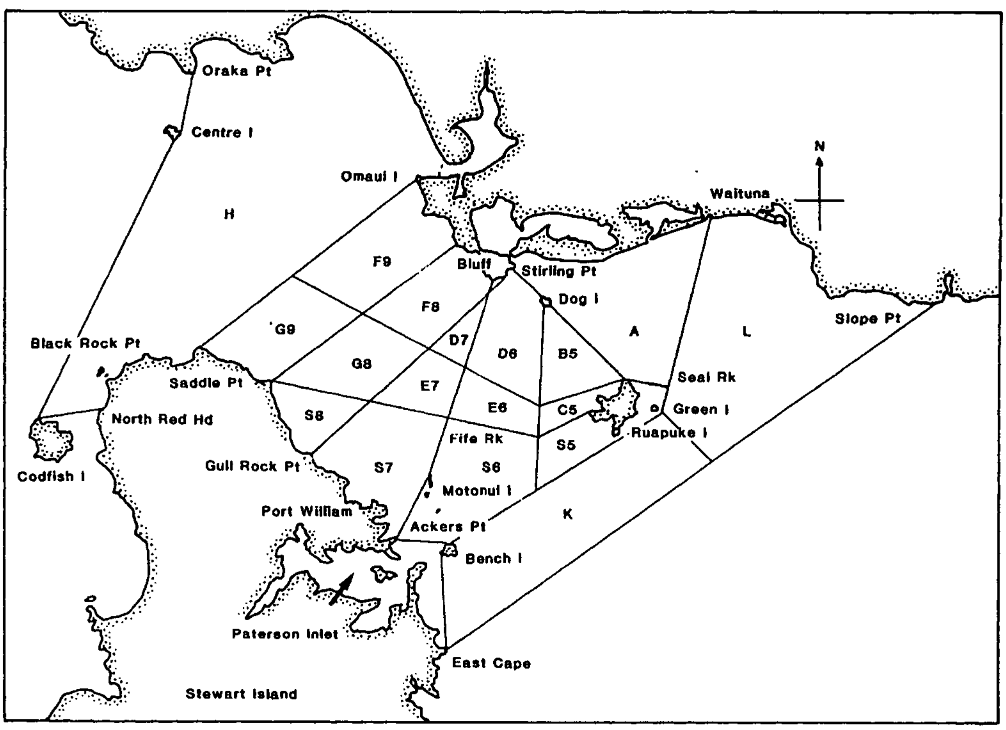

Figure 1: Boundaries of the oyster fishery and statistical areas for landing returns in Foveaux Strait

Appendix 1

Stratified random survey of Foveaux Strait oysters in October 1997 using commercial oyster vessel.

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 of the oyster population 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 in the absence of fishing mortality (Cranfield *et al.*, 1993). From 1992, the size of the oyster population was estimated to monitor recovery regularly. Dredge surveys that followed a stratified random design was the most economic method of monitoring total population size. The variability inherent in dredge surveys meant that likely changes in population size after 1 year were unlikely to be statistically significant and so surveys were done at 2 yearly intervals. A comparison of previous surveys in 1992, 1993 and 1995 showed that the population was rebuilding (Doonan & Cranfield 1992, Cranfield *et al.* 1993, 1996). In this document we report the results of the 1997 survey. This survey was carried out in October, well after the period of the seasonal mortality of *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). This plan included a decision rule to re-open the fishery when the population in the area surveyed in 1975–76 (Allen & Cranfield 1979, Doonan *et al.* 1994) had increased to at least 40% of the 1975–76 population. 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 greater than 400 recruited oysters per standard survey tow). Based on this principle, the sustainable yield for this population was estimated in 1995 and used to set quota for the 1996 and 1997 oyster seasons. 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, the size of the recruited oyster population in areas above densities of 400 oysters per standard survey tow and to estimate the size of the population of immediate pre-recruit (50–57 mm long) and small oysters (10–49 mm long).

METHODS

The survey was designed to estimate the absolute population size in Foveaux Strait of recruited oysters (greater or equal to 58 mm long) with a target *c.v.* of 20%. Data were also collected on numbers of immediate pre-recruit oysters (50–57 mm) and small oysters (10–49 mm). 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 nautical mile grid (1.85 km). The area in which the 1993 population was estimated therefore extended 0.5 nautical mile (0.92 km) outside the boundary defined by the grid lines. The 1995 and 1997 surveys were random surveys done within the boundary defined by the 1993 survey grid (Figure A1), but their total area was 22% lower than that of the 1993 survey. The area of the 1975 survey was largely included within the 1993 survey area but also incorporates a small segment to the east (Figure A1): A small area (stratum 5, 13.1 km^2) between Fife and Zero Rocks was added to incorporate a new area fished by the commercial vessels in 1997 (Figure A2).

The survey followed a stratified random design with two phases (Francis 1984). 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) and took 5 days between 29 September and 5 October 1997.

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 available catch data. Estimates of oyster density in the October 1995 survey (Cranfield *et al.* 1996) were contoured (at 200 and 400 recruited oysters per tow) and used to define strata for sampling in October 1997. Bootstrap sampling 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 (greater than 400, 200–400, and less than 200 oysters per standard survey tow, Table A1).

Station selection

The number of first-phase stations for 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 the second phase. Second-phase 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 nautical mile in all strata to avoid spatial auto-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 (Table A1).

Sampling methods

Two commercial oyster vessels and their crews were chartered to carry out the survey, *Torea,* skippered by Terry Dixon, and *Toiler,* skippered by Rex Ryan. These skippers have been 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. Each vessel steamed to each station position using GPS, shot the dredge (a standard 530 kg 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 nautical 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 true percentage fullness of the dredge could be estimated. Live oysters were sorted into three size classes: recruits, equal to or greater than 58 mm long; immediate pre-recruits, 50–57 mm; and small oysters, 10–49 mm (length is 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 clocks. The shell of new clocks was clean and without fouling on the interior surfaces. These clocks are shells of oysters that have died since the seasonal settlement of fouling organisms (i.e., since last summer and so within the 6 month period before the survey). Old clocks were covered in fouling organisms on external and internal surfaces. These clocks are shells of oysters that have died more than 6 months ago. As the ligament of oysters breaks down over a 3 year period, old clocks have died between 6 months and 3 years ago (Cranfield *et al.* 1991). 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 mean efficiency of dredges used in 1990, 0.164 (95% confidence intervals 0.13-0.22, Doonan *et al.* (1994), where

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

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

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

x_{ij} = oyster density (m^2)

To estimate variance of the absolute population estimate, we bootstrapped from the error distributions of the estimate of d and of the estimated relative population size (i.e., $\sum y_i$ $area_i$ term), 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 a *c.v.* of 20% and the stratified random survey design was chosen to optimise sampling. The design did not optimise for the estimation of the distribution of oysters or the distribution or numbers of oysters in areas of the population above the threshold of commercial density.

Distribution of oysters

The catch data from previous surveys were contoured using the S statistical package (Becker *et al.* 1989) with the Epanechnikov weighting function and a 2.0 nautical mile bandwidth. The density of oysters of all size groups in 1995 and 1993 was contoured at 200 and 400 oysters per standard survey tow. Percentage fullness of dredges was contoured at 25% and 40%. The 1997 survey had a relatively small number of 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 accurately 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 more than 400 oysters of each size group were caught in the 1995 and 1997 surveys are presented. Too few new and old clocks were caught 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 in Table 2.

Population size

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

Size of population in areas of commercial density

The recruited population within the area where oyster density was at or above 400 oysters per standard survey 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 standard survey tow), it is estimated that they would take 109 million (95% confidence interval 29-198 million) oysters from the area of commercial density.

Distribution

The survey data suggests the highest densities of recruited oysters (greater or equal to 58 mm) in October 1997 were in central and western Foveaux Strait (Figure A3).

DISCUSSION

Comparison of total population of oysters in Foveaux Strait in 1992, 1993, 1995, and 1997

Absolute population size estimates and 95% confidence intervals for 3 size groups of oysters, from the 1993, 1995, and 1997 surveys are shown in Table A3.

The 1995 survey data were re-checked this year and we found an error in computing the area of some strata. The numbers of oysters of all sizes re-estimated for the 1995 population shown in Table A3 are slightly less than those reported in Cranfield *et al.* (1996). The number of recruited oysters in 1997 was not significantly different from those in 1995 ($t = 0.56$, $P = 0.58$, 145 df). The numbers of pre-recruits have significantly increased between surveys (increase x 2.4, $t = 4.75$, $P < 0.0001$, 145 df) and although the numbers of small oysters have increased between surveys, this was not significant (increase x 1.4, $t = 1.62$, $P = 0.11$, 145 df).

Bonamiasis was not seen in the survey of March 1995 nor was there any sign of oyster mortality in the survey of October 1995 (Cranfield *et al.* 1995, 1996). Furthermore, fishers have not reported localised mortality of oysters anywhere in the fishery since these surveys so it appears that all mortality from disease has ceased. We therefore 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. However, we found that the population has remained at about 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 have caused us to catch more of population of small oysters and less of the population of large oysters. Nevertheless, the oyster industry suggested that rougher weather conditions during the 1997 survey had reduced dredge efficiency and had resulted in a lower catch of recruited oysters. They also suggested that the estimate of the 1995 population could have been reduced by dredge saturation in that year (the first dredging after 3 years of closure of the fishery with the re-growth of epifauna on the seafloor giving the potential for larger dredge catches and possible saturation) and that this underestimate was the cause of the failure to detect differences between the recruited populations of 1995 and 1997. These factors are examined below.

Weather conditions

We have compared the weather conditions of the 1995 and 1997 surveys to see if weather was likely to have influenced dredge efficiency enough to have altered sampling efficiency. The sea conditions and wind speeds during the 1997 survey were not as calm as for the 1995 survey (Table A4). 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 out of contact with the seafloor. Fishers dredging in similar weather conditions have not noticed a drop in their catch rate (Terry Dixon, pers comm). 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 sea floor during the 3 years with no fishing. Should dredges have 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 is shown in Table A5 and demonstrates that they are comparable in both surveys. Dredges did not become saturated during either survey and so saturation could not have effected estimation of the population size in either year.

Changed size of oysters sorted from dredge catches

Dredge surveys of the oyster population of Foveaux Strait between 1990 and 1997 have used commercial oyster vessels staffed 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). However, in the 1997 oyster season, commercial oyster fishers increased the size to which they sorted the catch to 62 mm in length. 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 by NIWA supervisory staff reduced this bias but did not eliminate it. The effectiveness of oyster sorting of the same crew was checked during a limited survey later that summer, in late January 1998. This survey was carried out by one of the same vessels with the same crew used in the population survey and followed the same dredging procedures. 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. A change of this magnitude does not alter the significance of the changes in population size tested statistically.

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

The population estimates of recruits in the area surveyed in 1975–76 are shown in Table A6. The decrease in this population from 1995 to 1997 is not statistically significant ($t = 0.56$, $P = 0.58$, 145 df).

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 throughout Foveaux Strait

The 1997 survey was designed to give an absolute estimate of population size with a target *c.v.* of 20% and not to estimate the distribution of oysters precisely. The post-epizootic 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 quickly over short distances, oyster distribution was not readily defined by a random survey with a minimum number of stations. We therefore can not compare changes in oyster distribution between the 1995 and 1997 surveys with any confidence.

The high densities in the southern central and eastern areas in the 1995 (Figure A4) survey were not apparent in the 1997 survey (*see* Figure A3). The number and size of high density patches of immediate pre-recruit (50–57 mm) and small pre-recruit (10–49 mm) oysters have increased throughout Foveaux Strait between the 1995 and 1997 surveys, but their distribution is very patchy (Figures A5–A8). Although the distribution of oysters cannot be mapped with any precision from the randomly spread samples in the stratified random surveys of 1995 and 1997, some of the data (e.g., the population in the 1975–76 area, Table A6) 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 15% in 1997. In 1995 31% of the immediate pre-recruit population was in eastern Foveaux Strait and 36% in 1997. These differences in distribution between the two surveys 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 with 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 1995, 52% and in 1997, 40% of the population in the fishery area was in patches above this threshold.

Conclusion

The estimated size of the recruited population of oysters in Foveaux Strait in 1995 and 1997 were not different. Even if we corrected the 1997 estimate for its possible bias, the 12% higher population estimate would still not be significantly different from that of 1995. A simple extrapolation of the 1992, 1993, and 1995 population estimates indicate that recruitment should have been large enough for a significant population increase between 1995 and 1997 to be detected. 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.

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Table A1: October 1997 survey, stratum number, predicted density of stratum from 1995 survey data, stratum area, numbers of first and second phase 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 oys/tow	Area (km^2)*	Area surveyed previously 1975–76	1993	1995	No. of stn 1st phase	No. of stn 2nd phase	No. of stn grid
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		

* variation from drawing contour boundaries has resulted in a 3% error in total area surveyed.

Table A2: Estimates of absolute recruited oyster density, population size, and survey *c.v.* of the three size groups of oysters, in each of the 11 strata surveyed in Foveaux Strait in 1997

Stratum No.	Oyster density (oys/m^2)	Population size (millions) ≥58 mm Number	*c.v.*	50–57 mm Number	*c.v.*	10–49 mm 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 A3: 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 1993 survey area in 1993, 1995 and 1997. 95% confidence intervals estimated from bootstrapped distributions are in brackets

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

Table A4: 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 along with the stratified random stations sampled over same period

Table A5: 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 largest catch in 1995 filled 70% of the dredge bag; the largest catch in 1997 filled 75% of the dredge bag

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 along with stratified random stations sampled over same period (data missing for 3 stations)

Table A6: Estimates of absolute oyster numbers in the 1975–76 area, 95% confidence interval (from the *t*-distribution), survey *c.v*, and reference from which the data are taken

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

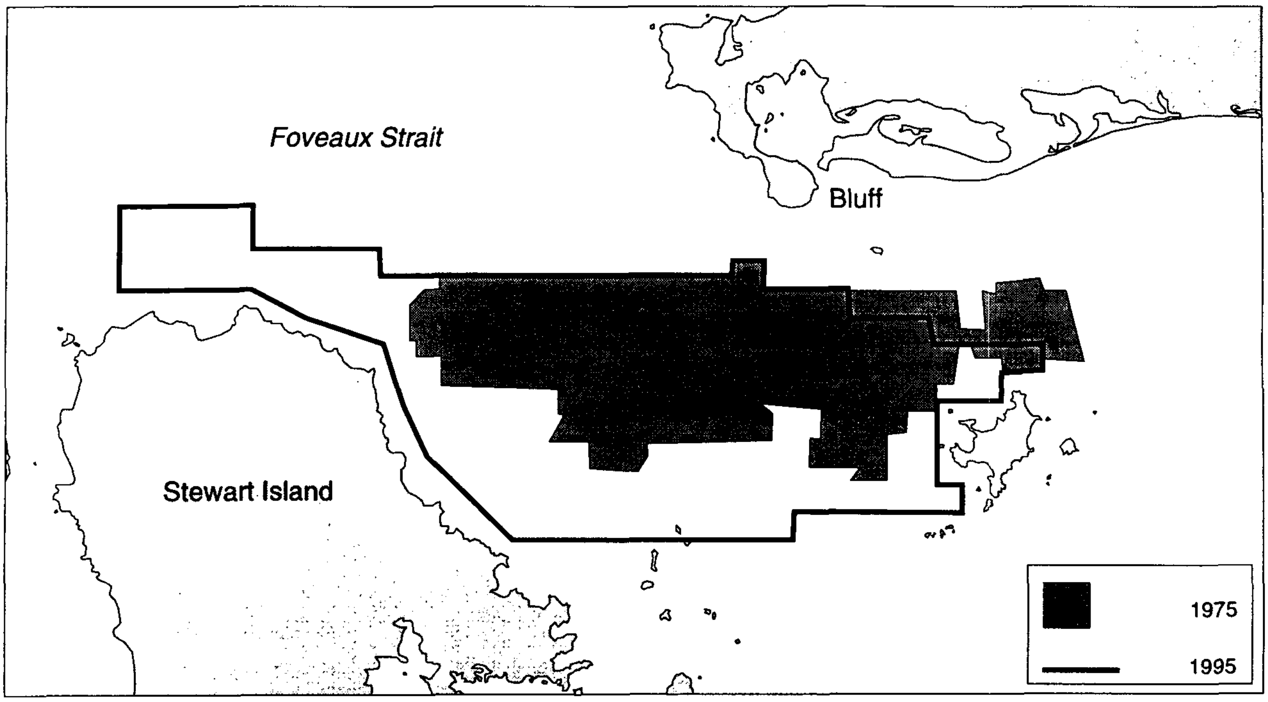

Figure A1: Foveaux Strait oyster survey 1995, boundaries of the 1975 (shaded) and 1995 (heavy outline) survey areas.

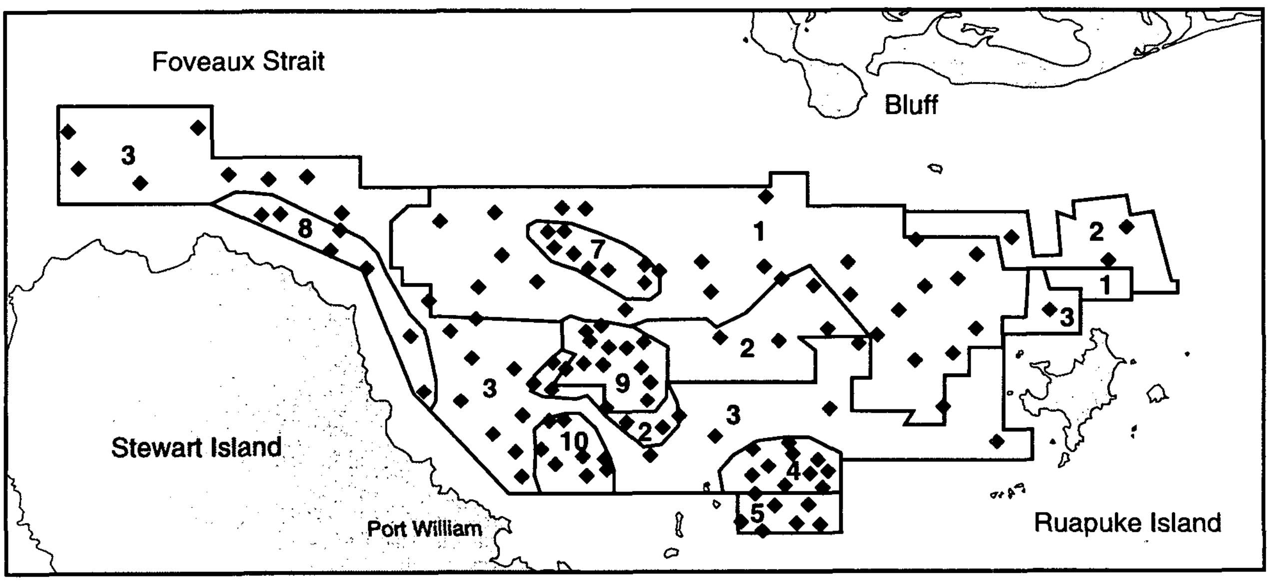

Figure A2: Strata and tow positions for the Foveaux Strait oyster dredge survey, October 1997. Strata 1, 2, 6, 7, and 9 cover the 1975 survey area. Stratum 5 and added to the 1995 survey in 1997 to include the area fished in the 1996 and 1997 fishing years.

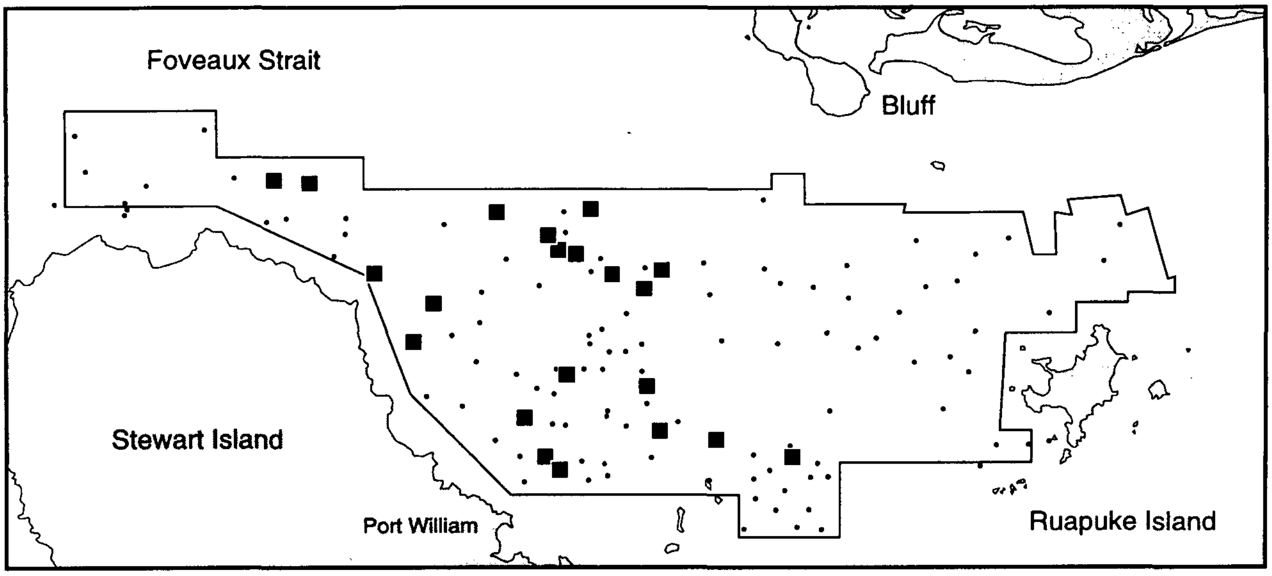

Figure A3: Stations sampled (small dots) in the Foveaux Strait oyster survey, October 1997, and stations where catches of ≥ 400 recruited oysters (≥ 58 mm in length) per tow were caught (filled squares).

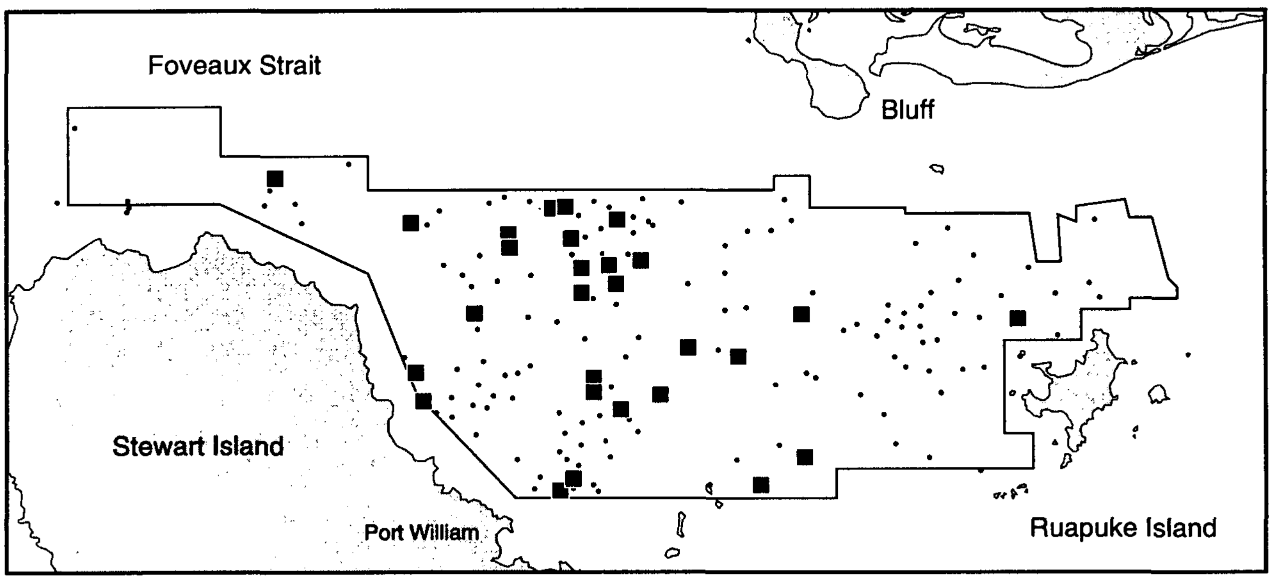

Figure A4: Stations sampled (small dots) in the Foveaux Strait oyster survey, October 1995, and stations where catches of ≥ 400 recruited oysters (≥ 58 mm in length) per tow were caught (filled squares).

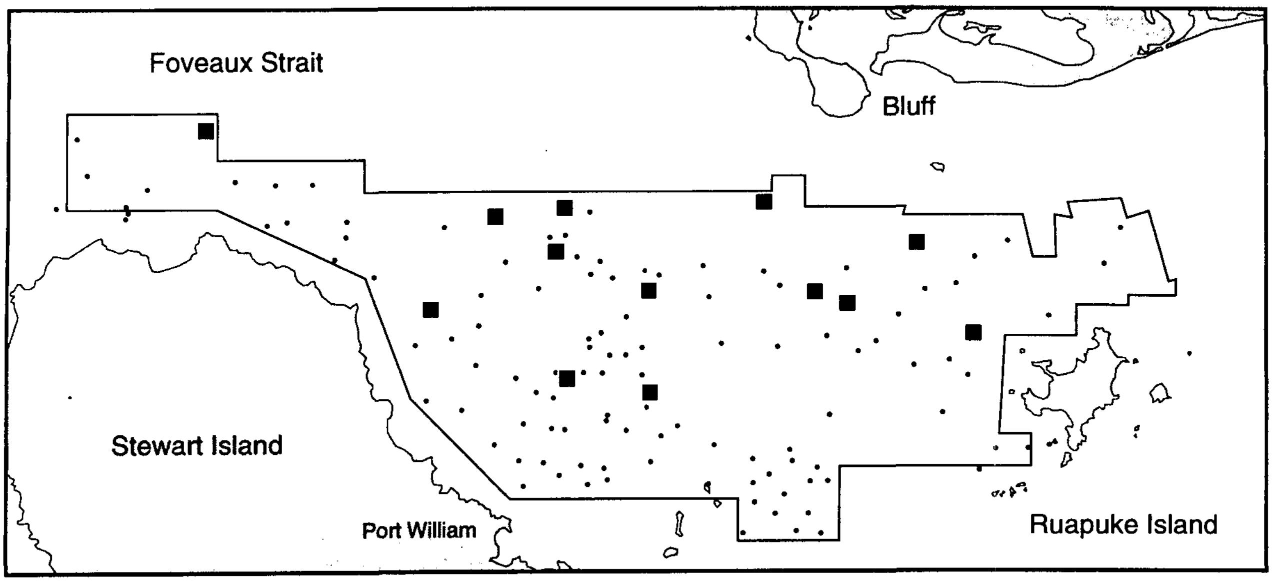

Figure A5: Stations sampled (small dots) in the Foveaux Strait oyster survey, October 1997, and stations where catches of ≥ 400 immediate pre-recruit oysters (50–57 mm in length) per tow were caught (filled squares).

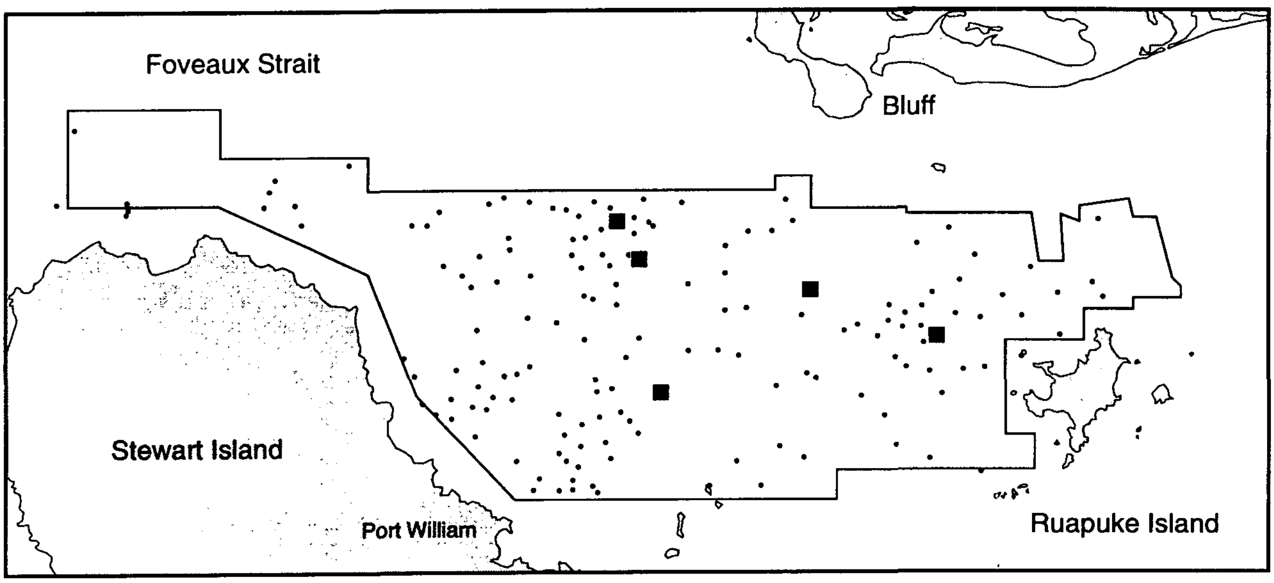

Figure A6: Stations sampled (small dots) in the Foveaux Strait oyster survey, October 1995, and stations where catches of ≥ 400 immediate pre-recruit oysters (50–57 mm in length) per tow were caught (filled squares).

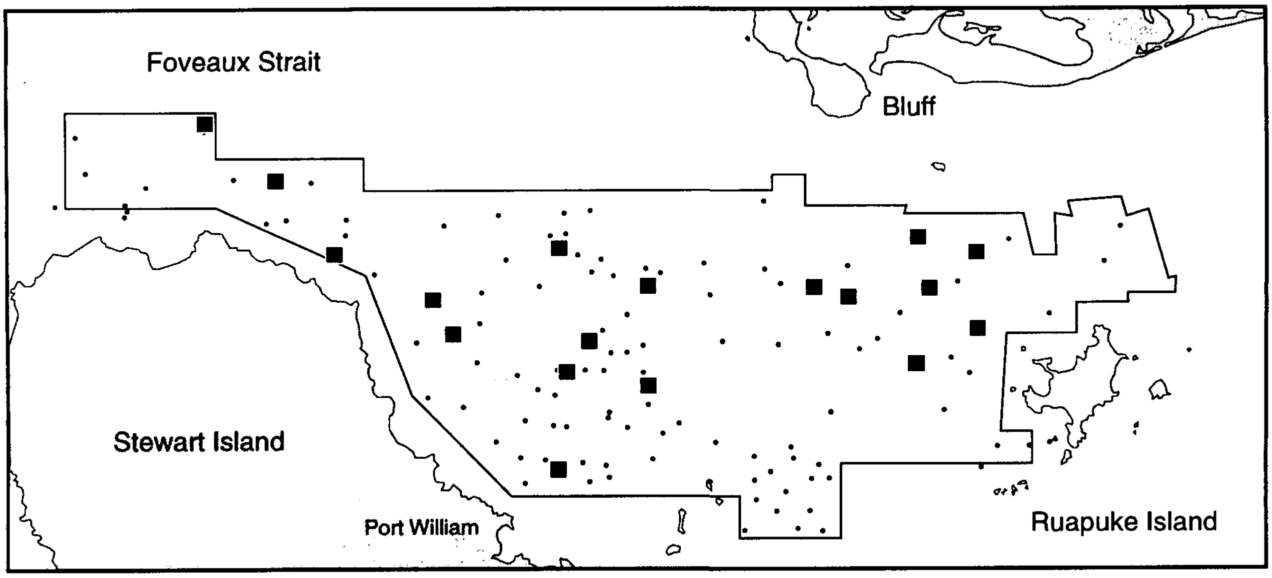

Figure A7: Stations sampled (small dots) in the Foveaux Strait oyster survey, October 1997, and stations where catches of ≥ 400 small pre-recruit oysters (10–49 mm in length) per tow were caught (filled squares).

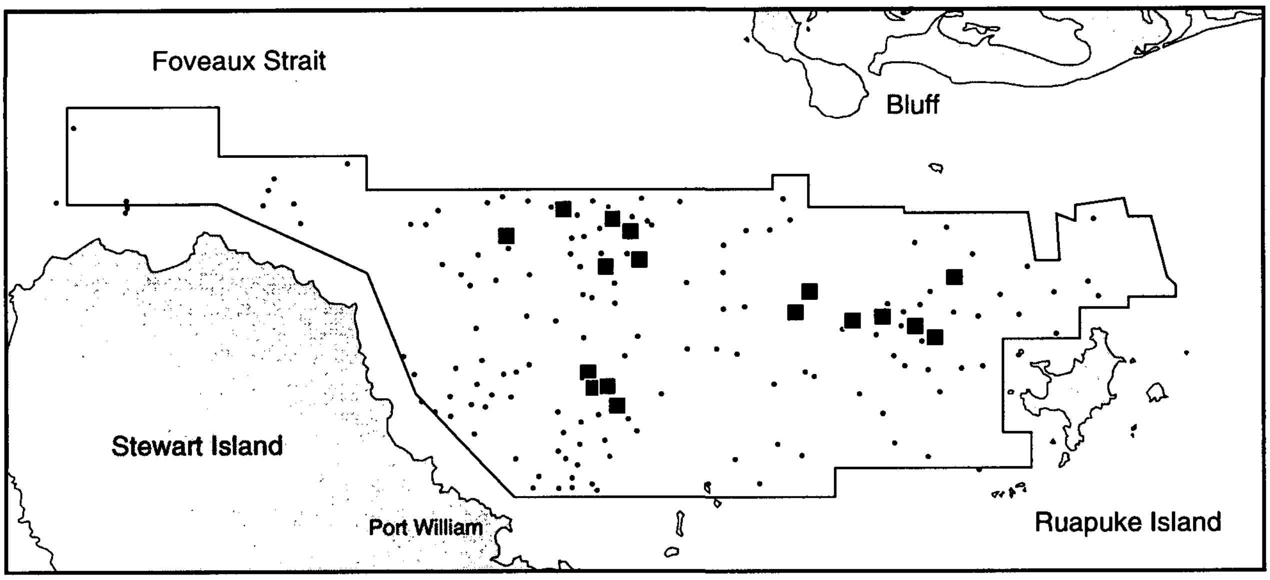

Figure A8: Stations sampled (small dots) in the Foveaux Strait oyster survey, October 1995, and stations where catches of ≥ 400 small pre-recruit oysters (10–49 mm in length) per tow were caught (filled squares).