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Foxeaux Strait oyster (*Tiostrea chilensis*) assessment, 1995

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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 in 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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***New Zealand Fisheries Assessment Research Document 96/19.* 25 p.**

1. EXECUTIVE SUMMARY

Mortality from infection by *Bonamia* sp. between 1986 and 1992 reduced the oyster population of Foveaux Strait, estimated to have been 1140 million in 1985, to 319 million in 1992. By 1992 the population in the area surveyed in 1975 was estimated to be less than 10% of that present in 1975 and the fishery was closed in 1993 to allow it to rebuild. The population may have increased slightly in 1993, and was re-surveyed in 1995 to monitor further changes.

The estimated population size in October 1995 was 696 million oysters. This was 2.9 times the size of the population in the same area in 1992, although the population in the 1975 survey area in 1995 was still only 39% of that present in 1975.

The numbers of immediate pre-recruits in 1995 were similar to those in 1993. The numbers of small pre-recruits in 1995 were also similar to those in 1993. Therefore, in the absence of fishing, the population can be expected to increase.

A Current Annual Yield (CAY) of 49.4 million oysters was estimated for the total population. As 53% of the population was in patches with densities above 400 oysters per tow (the threshold of commercial density in 1990) slightly more than half of this population will be fished. The life history of this species results in recruitment of localised populations being independent of each other and larvae from the lower density populations will not contribute to recruitment of the areas of commercial density. The CAY for the commercial population alone has been estimated at 26.3 million oysters.

2. INTRODUCTION

The population of takeable oysters in Foveaux Strait was estimated to have been 1140 million in 1985 (Doonan *et al.* 1994). An epidemic of the protistan parasite *Bonamia* sp. probably began in 1985 and was diagnosed from samples taken after locally high oyster mortalities in 1986 (Dinamani *et al.* 1987). The infection and subsequent mortality spread through the population in the following years (Cranfield *et al.* 1995) reducing the population 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. in Foveaux Strait between 1990 and 1995 indicate that the prevalence and intensity of infection had waned (Cranfield *et al.* 1995) and that mortality of oysters in the future is unlikely to be as great as it has been in the immediate past. The size of the oyster population estimated in 1992 and 1993 suggested that the population was increasing, though the increase was not statistically significant (Cranfield *et al.* 1993). The population was surveyed again in 1995 after all chance of seasonal mortality from disease was past (*see* Hine 1991a) to monitor further changes.

2.1 Overview

This document updates the stock assessment of the oyster population in Foveaux Strait using data from a population survey in 1995.

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. The fishery has been closed since 1993.

2.3 Literature review

Past work was reviewed by Cranfield *et al.* (1991), Doonan & Cranfield (1992), and Cranfield *et al.* (1993). Since then, Doonan *et al.* (1994) have compared population estimates from 1990 to 1993 with dredge surveys in 1975–76. The 1975 population estimate was derived from a mark-recapture survey (Cranfield & Allen 1979). However, with an estimate of the efficiency of the 1975 dredge (used again in a survey in 1990), the 1975–76 dredge survey provides an unbiased and more precise estimate of the oyster population in those years. This estimate was 23% smaller than that from the mark-recapture experiment (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 Catch and catch rate

There has been no commercial fishing since the last review of the fishery. Until the fishery closure, landings were controlled by an annual catch allocated equally among the 23 vessels participating in the controlled fishery. Before 1986, individual vessel allocation was 5000 sacks (sampling between 1993 and 1996 found the mean number of oysters per sack was 774), but this allocation was changed several times after that (Table 1). The landings and catch rates of limited fishing under a special permit between 1992 and 1996 are shown in Table 2.

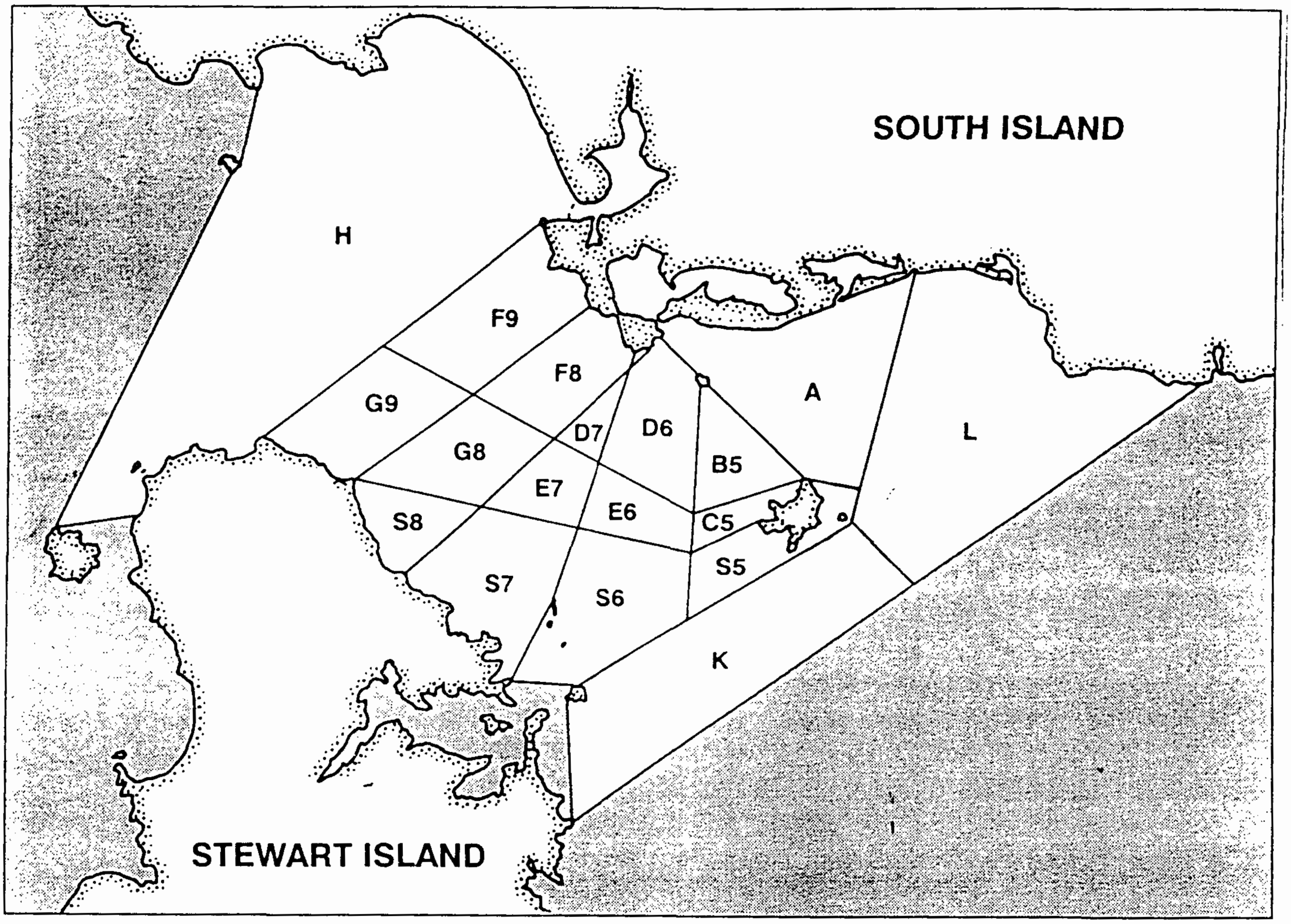


Figure 1: Boundary of the Foveaux Strait licensed oyster fishery, showing the statistical areas for catch and effort returns.

Table 1: Oyster catch, total allocated catch, individual vessel allocation, and the average catch rate in calendar years 1986–92

Year	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

* Exploratory commercial fishing on the periphery of oyster distribution.

Table 2: Oyster catch and average catch rate of vessels fishing under special permit for the Bluff Oyster Enhancement Company in 1992-96. Fishing occurred over the summer breeding season (November-February) rather than in the winter season (March-August) of commercial fishing

	Catch (sacks)	Permit allocation (sacks)	Mean catch rate (sacks per hour)
1992–93	3 141	4 000	5.0
1993–94	3 986	4 000	4.1
1994–95	3 869	4 000	5.5
1995–96	1 199	1 200	not available

3.2 Maori and recreational fishing

Recreational catches cannot be quantified from previous surveys of recreational fishing. 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 waters using small improvised dredges. The Southland Recreational Marine Fishers Association estimate the recreational catch of oysters in Foveaux Strait to be about 387 500 oysters annually (equivalent to 500 sacks). In the 1995 calendar year 44 authorisations were notified to the Invercargill office of the Ministry of Fisheries to take oysters from Foveaux Strait for the purposes of hui, tangi, or other traditional non-commercial use. These authorisations totalled 58 800 oysters (equivalent to 76 sacks). The Invercargill office of the Ministry of Fisheries estimate a further 42 000 oysters (equivalent to 54 sacks) were taken illegally over the same period.

4. RESEARCH

4.1 Stock Structure

The population of oysters in Foveaux Strait in 1975 consisted of a number of discrete, small, dense patches generally separated by extensive areas of barren ground (Allen 1979, Cranfield & Allen 1979). Oyster-bearing ground covered some 1200 km^2 of Foveaux Strait. In 1975, 91% of the total oyster population was located in 50 small dense patches that together covered only some 12 km^2 of the seafloor. Throughout the years, high catches of oysters have been confined to the same locations, suggesting that these localised patches of oysters have remained stable in position over the history of the fishery. Recruitment, growth, and mortality of oysters was considered to vary largely independently between these populations (Allen, 1979). Between 1986 and 1992, mortality from *Bonamia* sp. progressively destroyed most of the dense patches of oysters. The surveys between 1990 and 1995 have sampled on a wider scale (1–2 n. mile spacing between stations) than the 1975–76 survey (0.3 n. mile spacing) and are not able to resolve small dense patches. The later surveys can resolve the higher density areas where mean density was above a commercially viable level of 400 oysters per survey tow (equivalent to 6–8 sacks per hour in commercial fishing). The dense patches occurred in these areas of commercial density. Table 3 shows how the percentage of the population in the commercial area has changed since 1975–76.

Table 3: Percentage of the oyster population in areas above the commercially viable density of 400 oysters per tow (equivalent to 6-8 sacks per hour in commercial dredging)

Survey	1975	1990	1992	1993	1995
Percentage	91	56	11	26	53

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

4.2 Resource surveys

Resource surveys were conducted between 1960 and 1962, between 1974 and 1976, 1975, 1990 (Cranfield *et al.* 1991), 1992 (Doonan & Cranfield 1992), 1993 Cranfield *et al.* (1993), in March 1995 (Cranfield *et al.* 1995), and in October 1995 (Appendix 1).

4.3 Population size estimates

Estimates of population size are given in Table 4.

Table 4: Population size estimates (millions) of legal-sized oysters (≥ 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);), in March 1995 (Cranfield *et al.* 1995), and in October 1995 from Appendix 1. 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. of stations	Population size	Sampling cv	Total cv
1960–62	-	grid	dive	377	35	1 400	-	na
1974	-	grid	MR	374	-	1 800	20	na
1975	-	grid	MR	374	-	1 500	11	na
1975–76	-	grid	dredge*	374	929	1 140	4	15
1990	July	grid	dredge†	1116	262	771	14	na
1990	October	SR	dredge*	646	116	607	11	na
1990	October	SR	dive	646	83	607	13	na
1992	March	grid	dredge†	1229	370	319	10	18
1993	October	grid	dredge†	875	177	372	14	21
1995	March	SR	dredge†	680	50	543	26	30
1995	October	SR	dredge†	680	154	696	12	19

* 1.2 m wide replica of commercial dredge towed by research vessels.
† 3.35 m wide commercial dredge towed by commercial oyster vessels.

The oyster population was reduced to its lowest level in 1992 and has since recovered. The population in 1995 had rebuilt to a size similar to that in 1990. The distribution of oysters in 1990 and 1995 is however very different (cf. Appendix Figures 3 and 7, Cranfield *et al.* (1991)). The areas surveyed have differed between 1990-1995, and to follow changes in the oyster population since 1990 more precisely we have computed the populations within the 1995 boundary (Table 5).

Table 5: Estimates of oyster population (millions) within the area of Foveaux Strait surveyed in 1995 (680 km^2), 1990, 1992, 1993, and two surveys in 1995. Legal-sized oysters (≥ 58 mm in length), immediate pre-recruit oysters (50–57 mm) and small pre-recruits (10–49 mm). 95% confidence intervals in brackets includes error in dredge efficiency 1992–1995, and sampling error alone in 1990. - no pre-recruit data gathered in 1990 or 1992

	Legal-sized oysters	Percentage of 1992	Immediate recruits	Small pre-recruits
1990(July)	697 (584–823)	293	-	-
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)	696 (448–949)	292	312 (196–418)	559 (252–855)

By 1975, the oyster population of Foveaux Strait had been fished commercially for 89 years and was probably less than the virgin population. The population in 1975–76 was likely to be in equilibrium with the fishing effort, which had remained the same over the previous decade (Doonan *et al.* 1994), and the population, which was estimated precisely in 1975–76, has been used as a reference point. The area surveyed in 1975–76 was smaller than the 1995 survey area and covered more of the eastern part of Foveaux Strait (*see* Appendix Figure 1); we have computed the population within this area in the surveys of 1990–95 to show how this reference population has changed over this period (Table 6).

Table 6: Estimates of population (millions) of legal-sized oysters (≥ 58 mm in length), within the area of Foveaux Strait surveyed in 1975–76 (374 km²), in 1990, 1992, 1993, and 1995 compared with the population estimate of 1975–76

	Population size	Percentage of 1975	No. of stations	Sampling cv
1975-76	1 140	100.0	929	4
1990(July)	378	33.2	141	12
1992(March)	101	8.9	126	9
1993(Oct)	180	15.7	57	22
1995(Oct)	445	39.0	97	15

By 1992, the oyster population had been reduced below 10% of the 1975–76 level, and by 1995, it had recovered to 39% of the 1975–76 level.

4.4 *Bonamia* sp. studies

The life history of *Bonamia* sp. and the pathology of infection in oysters were described and discussed by Hine (1991a, 1991b) and Hine & Wesney (1992). Studies of the parasite between 1992 and 1995 have focused on functional ultrastructure of the parasite (Hine 1992, Hine & Wesney 1994a, 1994b). Although the Foveaux Strait oyster fishery has experienced significant mortalities in the past, none of these events has been as widespread or catastrophic as the 1986 epizootic. *Bonamia* sp. has been identified in tissue of Foveaux Strait oysters fixed in 1964, and the parasite appears to be enzootic and widespread in New Zealand (Hine & Jones 1994). Hine & Jones (1994) also established that prevalence of infection by *Bonamia* sp. was similar in all size groups of oysters. Life history studies suggest that *Bonamia* sp. may be virally infected, and that the virus kills all parasites present in oysters at the end of winter (between June and September).

The distribution of prevalence and intensity of infection by *Bonamia* sp. in oysters throughout Foveaux Strait in 1995 was surveyed in the period when *Bonamia* sp. is most readily detected (February-March, Hine 1991a). Mean prevalence of infection by *Bonamia* sp. in takeable 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 1991a, Hine & Thorne, in press)) has also declined in a similar way over this period. In 1995, prevalence of infection was not directly related to oyster density or recent mortality, and low-level infection was widespread throughout Foveaux Strait.

4.5 Yield estimates

4.5.1 Estimation of Maximum Constant Yield (MCY)

An estimate of B_0 is not available. By the 1960s the oyster population of Foveaux Strait had been fished for over 70 years and the fishery was fully exploited. The population in 1975–76 was believed to be in equilibrium with the yield (see earlier) and hence, by definition, the population estimate of these years (the only pre-*Bonamia* estimate) is an estimate of B_{av}. MCY is therefore estimated by Method 2 in Annala (1995):

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

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

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

This estimate of *MCY* applies to the oyster population at its pre-*Bonamia* infection size.

4.5.2 Estimation of Current Annual Yield (*CAY*)

CAY was estimated from Method 1 in Annala (1995) as most fishing mortality occurs over a short period at the beginning of the year:

$$CAY = (1-e^{-F_{ref}})B_{beg}$$

B_{beg} is the recruited population level at the beginning of the fishing year; F_{ref} is the level of (instantaneous) fishing mortality that, if applied every year, would, within an acceptable level of risk, maximise the average catch from the fishery. The population estimate of 696 million (95% confidence interval of 448–949 million) was used as an estimate of B_{beg}. The use of this figure from the October 1995 survey for a fishery starting later than February 1996 assumes that natural mortality over the intervening period will be balanced by recruitment. The estimated exploitation rate in 1975–76 was 0.078, which was adjusted by the factor of 0.91 to account for the 9% of the exploitable population lying outside the area fished in 1975–76 (Cranfield *et al.* 1991) resulting in an estimate of 0.071[1]. The oyster population had sustained a mean harvest of 115 000 sacks for the previous decade and was in equilibrium with this level of exploitation. This yield appears to be sustainable and, therefore, we take it to be an estimate of $(1-e^{-F_{ref}})$ (Doonan & Cranfield 1992), so:

[1]This estimate of F_{ref} has several sources of uncertainty. We do not know how applicable the numbers of oysters per sack estimated between 1993 and 1996 is to the fishery of 1975–76, especially as there was a systematic change in the relationship with time in the data used. Furthermore, there is some evidence that changes in weight of dredges between 1975 and 1996 has increased incidental mortality of undersized oysters and that the exploitation rate may therefore be too high for the current fishing mortality.

$$CAY = 0.071 * 696 \text{ million oysters}$$
$$= 49.4 \text{ million oysters (95\% confidence interval 31.8–67.4 million oysters)}$$

The level of risk to the stock by harvesting the population at the estimated CAY cannot be determined. This yield is substantially smaller than the average annual population increase over the last 3 years.

5. FACTORS MODIFYING YIELD ESTIMATES

Given the current state of the stock, the CAY estimate needs to be modified by the following factors when determining catch levels.

5.1 Continuing mortality from *Bonamia* sp.

This is unlikely to be important now. At the low prevalence and intensity of infection by *Bonamia* sp. found in March 1995 (Cranfield *et al.* 1995) it is not possible to estimate mortality caused by *Bonamia* sp.; however, it is unlikely to be a major factor. Comparison of the populations of legal-sized oysters and pre-recruits in 1993 and 1995 suggest that oyster mortality is probably close to pre-epizootic estimates of instantaneous natural mortality (less than 0.1, Allen 1979, Cranfield & Allen 1979). Although mortality is currently very low, the epizootic could recur as oyster density rebuilds within dense patches.

5.2 Effect of low population size on recruitment

There is general acceptance in managing finfish stocks that have a clear stock-recruit relationship that stock levels should be kept above 20% B_0 (Beddington & Cooke 1983, Francis 1993, Thompson 1993), a threshold below which recruitment is likely to decline (Beddington & Cooke 1983). Stock size and recruitment are frequently unrelated in shellfisheries, but a number of life history traits indicate that this may not be true for *Tiostrea 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 likely to have been less than 10% B_0. In spite of this low biomass level, the population has been able to rebuild 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). The low oyster density found here may result in poor recruitment locally and could slow the recovery of oyster density and the redevelopment of dense patches.

Fishing of dense patches in the past may have reduced oyster density so low that the patches have never recovered. Thus 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 barren of oysters to this 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.

5.3 Concentration of fishing on only a few populations

Oyster fishers tend to concentrate fishing on populations giving the highest catch rates and will tend to stop fishing these when the catch rate drops below a commercially viable level (Allen 1979). Because of the extreme localisation of settlement, the unfished, low density populations do not contribute to recruitment of fished populations. Hence yield for the fishery can be estimated for that portion of the population that is above commercial densities (371 million oysters) and which will be the only part of the population to form the fishery. The estimated exploitation rate for 1975–76 was again used as an estimate of $(1-e^{-Fref})$.

CAY for the portion of the oyster population that is above commercial densities and will be fished is:

$$CAY_{400\text{ oysters per standard-tow}} = 0.071 * 371 \text{ million oysters}$$
$$= 26.3 \text{ million oysters (95\% confidence interval, 14.5–38.1 million oysters)}$$

The level of risk to the stock by harvesting this yield cannot be determined. This yield is half that estimated for the total population and is substantially less than the annual population increase over the last 3 years.

6. MANAGEMENT IMPLICATIONS

The population of legal-sized oysters continues to increase from the low population level of 1992, but it is still less than 40% B_{1975}. Compared to 1992, a larger proportion of the population is in densities that are commercially viable. Because pre-recruit numbers are the same as those estimated in 1993, the population should continue to increase in the absence of fishing.

7. ACKNOWLEDGMENTS

We thank Allan Frazer, Malcolm Clark, Paul Breen, David Fletcher, and Paul Starr who have critically reviewed this document and suggested constructive changes.

APPENDIX 1 : STRATIFIED RANDOM DREDGE SURVEY OF FOVEAUX STRAIT OYSTERS IN OCTOBER 1995 USING COMMERCIAL OYSTER VESSELS

1. INTRODUCTION

The assessment of the oyster population in Foveaux Strait in 1993 (Cranfield *et al.* 1993) suggested that the population had rebuilt since March 1992, although the increase was not statistically significant. Another survey to monitor the population was planned for October 1995 after all chance of seasonal mortality from *Bonamia* sp. was past (Hine 1991a).

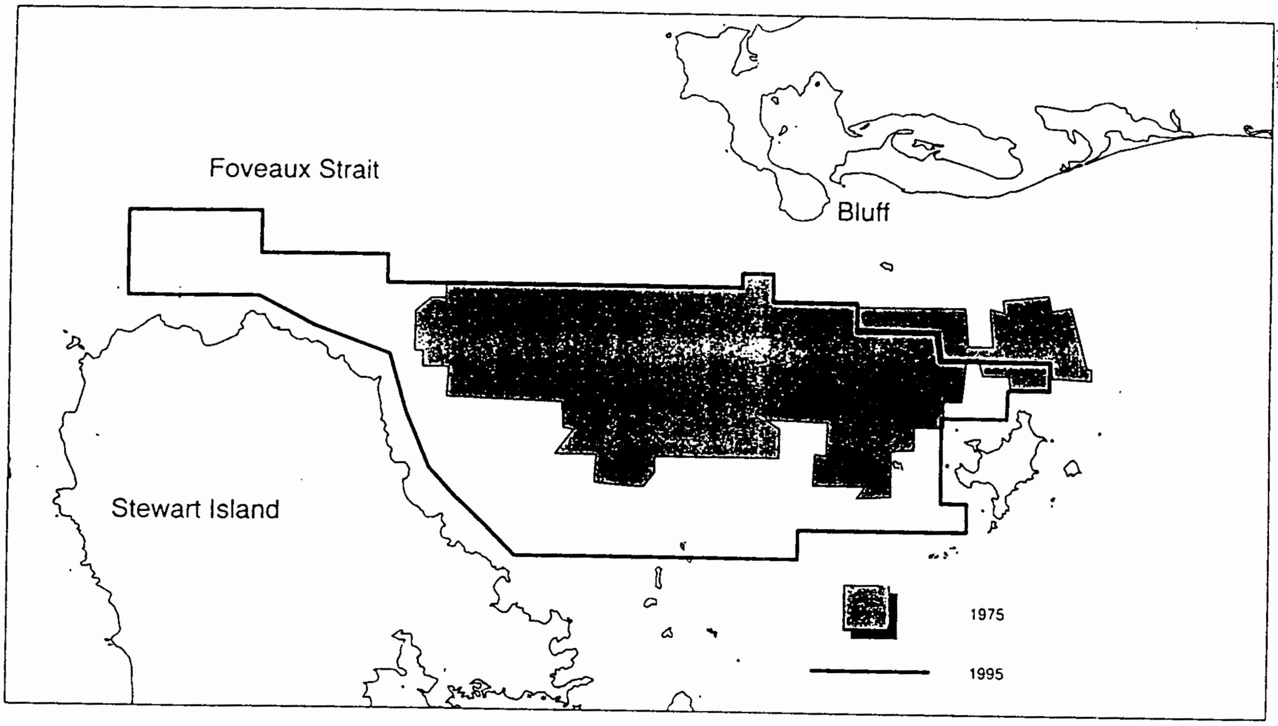
Ministry of Fisheries staff and the oyster industry developed a draft plan for managing the oyster fishery (Anon. 1995) which included a decision rule that before the oyster fishery was re-opened, the oyster population in the area surveyed in 1975–76 should have rebuilt to over 40% of the 1975–76 population. The plan also suggested that yields estimated for this fishery should be based on the size of the population actually fished, i.e., that portion of the oyster population where oyster density could support commercially viable fishing. Thus the goals of the 1995 survey included estimating the size of the oyster population in the area surveyed in 1975–76 and the size of the oyster population in areas above densities of 400 oysters per survey-tow (taken to be the threshold density for commercially viable fishing (*see* Cranfield *et al.* 1991).

During the dredge survey to estimate prevalence of infection by *Bonamia* sp. in Foveaux Strait in March 1995 we occupied 50 stations in the 1993 survey grid area. These allowed us to estimate oyster density and population size (Cranfield *et al.* 1995) and to develop a stratified random design for the dredge survey in October 1995.

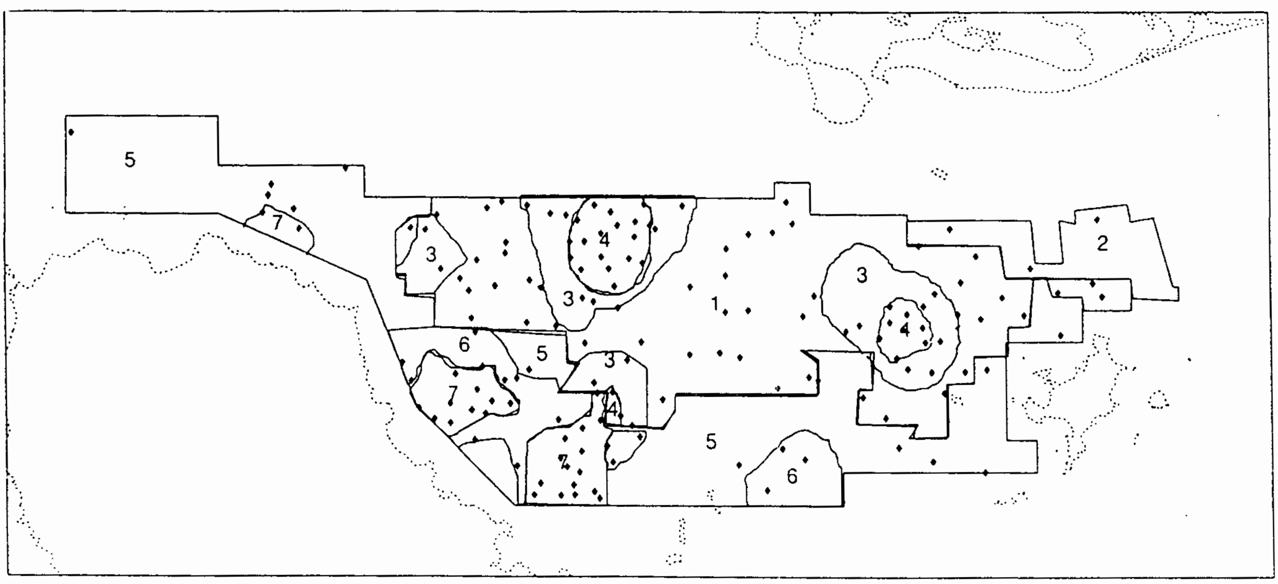
2. METHODS

2.1 Survey

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, and 1993 surveys (*see* Cranfield *et al.* 1993). The 1995 area was defined by the outside grid of the 1993 survey, which was a grid pattern survey with stations at the intersections of a largely 1 n. mile grid. The area from which the 1993 population was estimated therefore extended 0.5 n. mile outside the boundary defined by the grid lines, whereas the 1995 surveys were random surveys and the population was estimated within the boundary defined by the 1993 survey grid lines. The total area covered by the two surveys therefore differs by 22%. The area of the 1975 survey was largely included within the 1993 survey area but also incorporated a small segment to the east (Appendix Figure 1).



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



Appendix Figure 2: Strata and tow positions for Foveaux Strait oyster dredge survey, October 1995. Strata are numbered 1–7; strata 1–4 cover the 1975–76 survey area. Stratum 2 is outside the 1993 survey area. Note that strata are not continuous as they are based on oyster density (see text). Station positions shown by diamonds.

2.1.1 Stratification

Contours of five levels of oyster density determined in the March 1995 survey (Cranfield *et al.* 1995) were used to define strata for sampling in October 1995. We chose three strata (less than 250, 250–749, and over 750 oysters per tow) as bootstrapping sampling of these three resulted in almost the same *c.v.* for the population estimate as bootstrapping sampling all five strata.

The 1975 area cut these three density-based strata and so we ended up with six disjunct strata to sample. A seventh stratum, not included in the area used to estimate the 1995 population, was needed to estimate the population in the 1975 area (Appendix Figures 1, 2 and Appendix Table 1).

Appendix Table 1: Stratum number (Appendix Figure 1) and boundary, stratum area, relationship to the 1975–76 and 1993 survey areas, and numbers of first and second phase stations in the October 1995 survey

Stratum number	Boundary	Area (km^2)	Stratum surveyed previously 1975–76	1993	No. of first-phase stns	No. of second-phase stns
1	< 250	221.53	✔	✔	16	33
2	< 250	39.53	✔		3	0
5	< 250	234.97		✔	5	8
3	250-749	89.43	✔	✔	13	4
6	250-749	55.17		✔	4	9
4	≥ 750	33.19	✔	✔	27	0
7	≥ 750	45.24		✔	32	0

2.1.2 Station selection

The number of first-phase stations for each stratum was determined on the basis of stratum area and the standard deviation of oyster density within it (estimated from the survey of March 1995), except that each stratum was assigned at least three stations. Second-phase stations were allocated on the basis of the expected gain in precision from an additional station using the method of Francis (1984). Stations were randomly selected by the computer program RAND_STN V1.7. Stations were separated by at least 1 n. mile in all strata other than the 750+ strata to avoid spatial correlation of catches and to ensure sufficient spread of stations for contouring. In the 750+ strata, stations had to be closer (separation varied between the disjunct parts of this stratum) to fit the number of samples into their smaller areas. We allocated 100 stations for the first phase of the survey and 50 for the second. Four extra stations were sampled (Appendix Table 1).

2.1.3 Sampling methods

Torea skippered by Milton Roderique and *Monica* skippered by Rex Ryan were chartered to carry out the survey. These skippers have been involved in previous surveys and were thoroughly familiar 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 by crew members into three size classes: recruits, 58 mm or more in length; immediate pre-recruits, 50–57 mm in length; and smaller pre-recruits, 10–49 mm in length. Length is measured along the anterio-posterior axis parallel to the hinge line. Size can be checked by the failure of the oyster to pass through a 58 or a 50 mm diameter ring. The smallest size at which pre-recruits could be counted reliably was 10 mm. Clocks, the articulated shells of dead oysters (i.e., with the ligament intact), were sorted into recruit and immediate pre-recruit sizes, in two categories: new and old clocks. The shells of new clocks were clean and without fouling on the interior surfaces. They 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 both surfaces, and 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. The number of all clocks is thought to reflect mortality over this 3 year period (Cranfield *et al.* 1991).

2.2 Population Estimates

The population size was estimated for oysters in three size groups: 58 mm or more in length, 50–57 mm, and 10–49 mm. We estimated the absolute population size using the estimate of mean efficiency of dredges used in 1990, 0.164 (95% confidence intervals 0.13–0.22).

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

where d is the estimated dredge efficiency, i indexes strata, and y_i is the mean oyster density in

stratum i and area_i is the area of stratum i and $x_i = \frac{\sum x_{ij}}{n_i}$

Given a minimum commercial density of oysters (x_0), the population above this threshold was calculated by:

$$\text{Commercial population size} = \frac{\sum x_i \, area_i}{d}$$

where x_i is the mean commercial oyster density in stratum i

$$x_{ij} = \begin{cases} 0 & \text{if } y_{ij} < x_0 \\ y_{ij} - x_0 & \text{if } y_{ij} \geq x_0 \end{cases}$$

where j indexes stations in a stratum and y_{ij} is the oyster density.

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., $\sum y_i \ area_i$ for total population and $\sum x_i \ area_i$ for the commercial population), 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 first objective of the survey was to estimate the total population with the lowest *c.v.* possible and the design was chosen to achieve this.

2.3 Survey areas of the past

Not all the area surveyed in 1975 was included in the 1995 population area so an extra stratum was included in the survey (Appendix Figures 1 & 2). We have re-estimated population size in 1993 within the area surveyed in 1995 to compare the populations of 1993 and 1995.

2.4 Contouring

The catch data were contoured using new S statistical package (Becker *et al.* 1989) using the Epanechnikov weighting function and a 2.0 n. mile bandwidth. The density of oysters of all size groups in 1995 and 1993 was contoured at 200 and 400 oysters per tow. Percentage fullness of dredges was contoured at 25% and 40%.

3. RESULTS

The survey took 5 days between 6 and 10 October 1995. Tow positions and stratum boundaries are shown in Appendix Figure 1 and population size for each size group by stratum in Appendix Table 2.

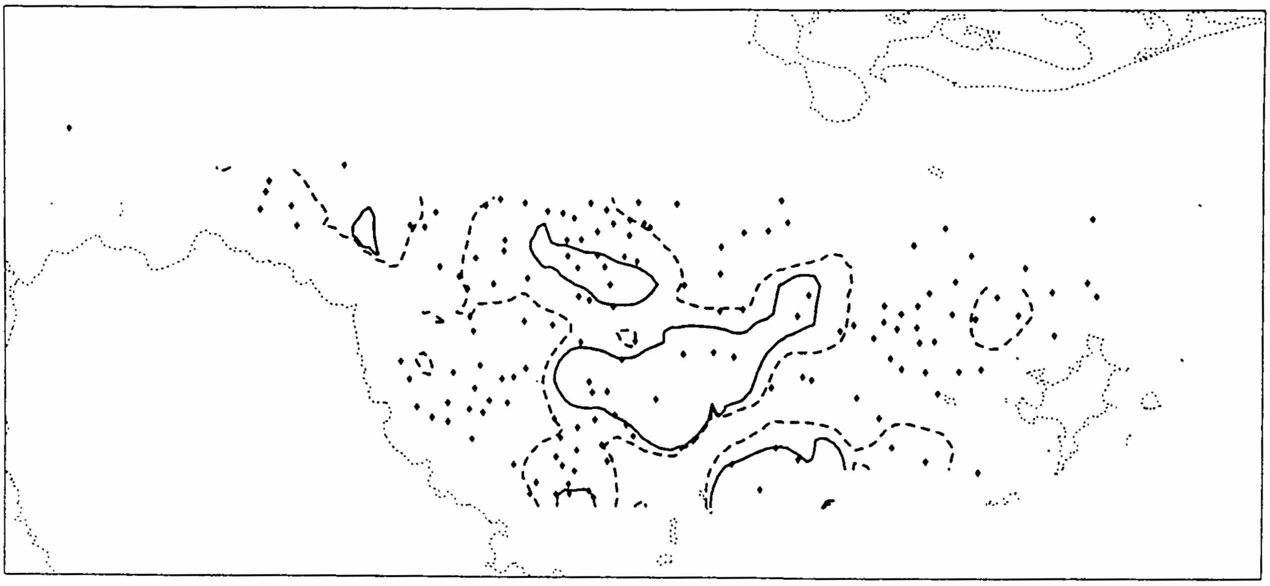
Appendix Table 2: Estimates of oyster density, population size and c.v. of the three size groups of oysters, in each of the 7 strata surveyed in Foveaux Strait in 1995

		Population size (millions)					
Stratum no.	Oyster density	≥58 mm in length		50–57 mm in length		10–49 mm in length	
& boundary	(Nos. per tow)	No.	c.v.	No.	c.v.	No.	c.v.
1 < 250	1.26	280.13	19.6	130.84	18.3	286.89	45.8
2 < 250	1.33	2.55	51.4	6.06	51.7	10.04	49.1
5 < 250	0.63	147.83	30.1	61.07	28.7	90.67	27.8
3 250–749	1.33	119.26	29.1	68.27	26.3	96.36	21.8
6 250–749	0.99	55.05	44.4	11.40	34.4	15.01	30.1
4 ≥ 750	1.28	42.65	15.7	23.36	16.1	42.42	15.0
7 ≥ 750	1.08	48.81	29.6	10.64	21.2	17.50	26.0

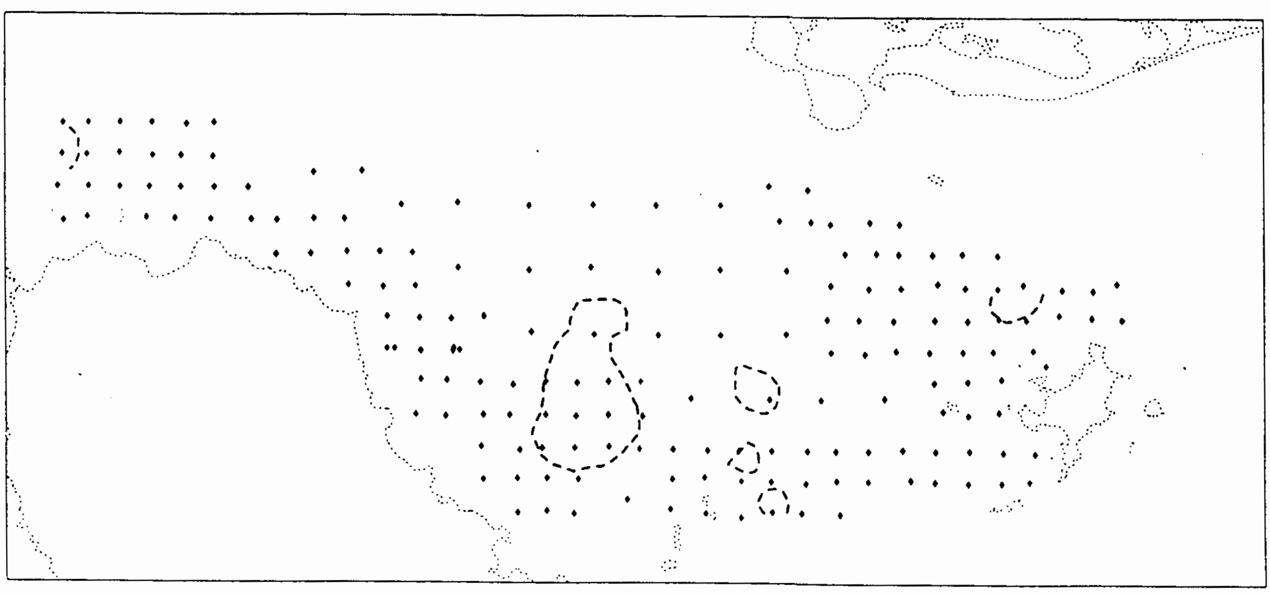
3.1 Distribution

3.1.1 Legal-sized oysters (58 mm and over)

The highest densities of legal-sized oysters were in the centre of Foveaux Strait (Appendix Figure 3), similar to what was found in 1993 (Appendix Figure 4) but at higher density. High densities of oysters along the southern boundary of the survey area suggest that we may have missed the full extent of the 1995 population.



Appendix Figure 3: Contours (200 (dashed line), 400 (solid line) oysters per tow) of legal-sized oysters (≥ 58 mm in length) Foveaux Strait oyster survey October 1995. Station positions shown by diamonds.



Appendix Figure 4: Contours (200 (dashed line) oysters per tow) of legal-sized oysters (≥ 58 mm in length) Foveaux Strait oyster survey October 1993. Station positions shown by diamonds.

3.1.2 Immediate pre-recruits (50–57 mm)

The highest densities of immediate pre-recruit oysters were in the centre of Foveaux Strait, (Appendix Figure 5). The distribution in 1995 shows much higher densities in the centre of Foveaux Strait, but much lower densities in eastern Foveaux Strait, than in 1993 (Appendix Figure 6).

3.1.3 Small pre-recruits (10–49 mm)

The highest densities of small pre-recruits were in the centre of and in eastern Foveaux Strait (Appendix Figure 7) similar to 1993 (Appendix Figure 8) but with higher densities.

3.2 Population size

3.2.1 Comparison of population size in 1975–76 and 1995

The population estimate in 1975–76 was 1140 x 10^6 legal-sized oysters compared to 445 x 10^6 legal-sized oysters in the same area in 1995.

3.2.2 Size of population in areas of commercial density in 1995

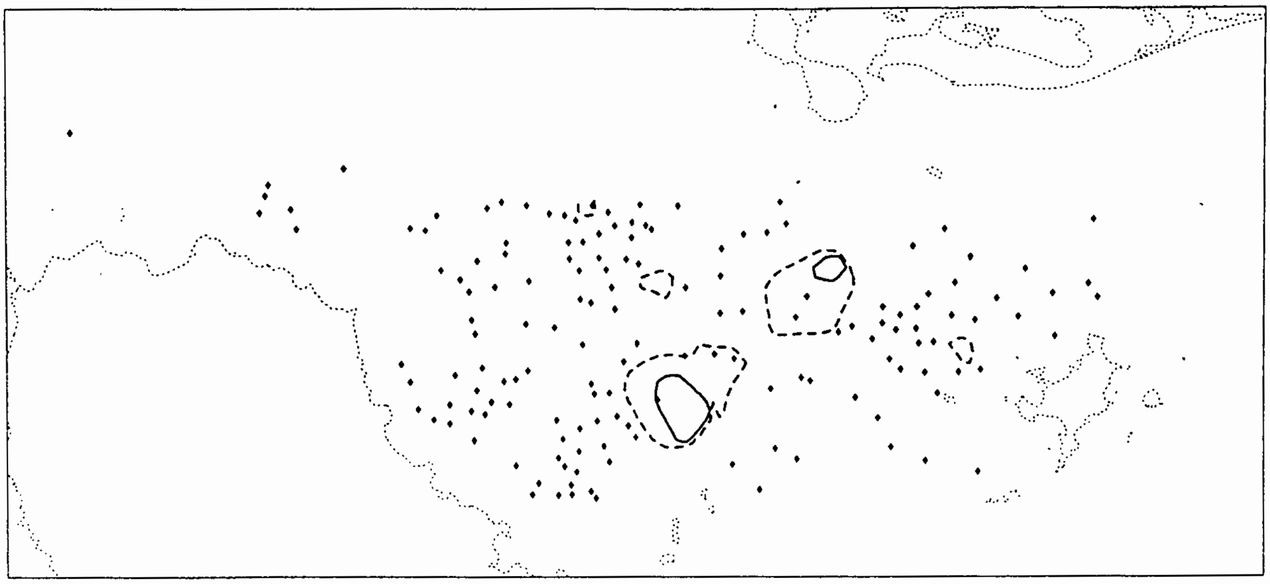
The legal-sized population within the area where oyster density was at or above 400 oysters per tow in the 1995 survey area was estimated to be 371 million oysters (95% CI, 204–537 million).

If fishers could dredge all these populations and reduce oyster density in them to the threshold density of commercial viability (400 oysters per tow), it is estimated that they would take 160 million (95% CI, 55–274 million) oysters from the area of commercial density.

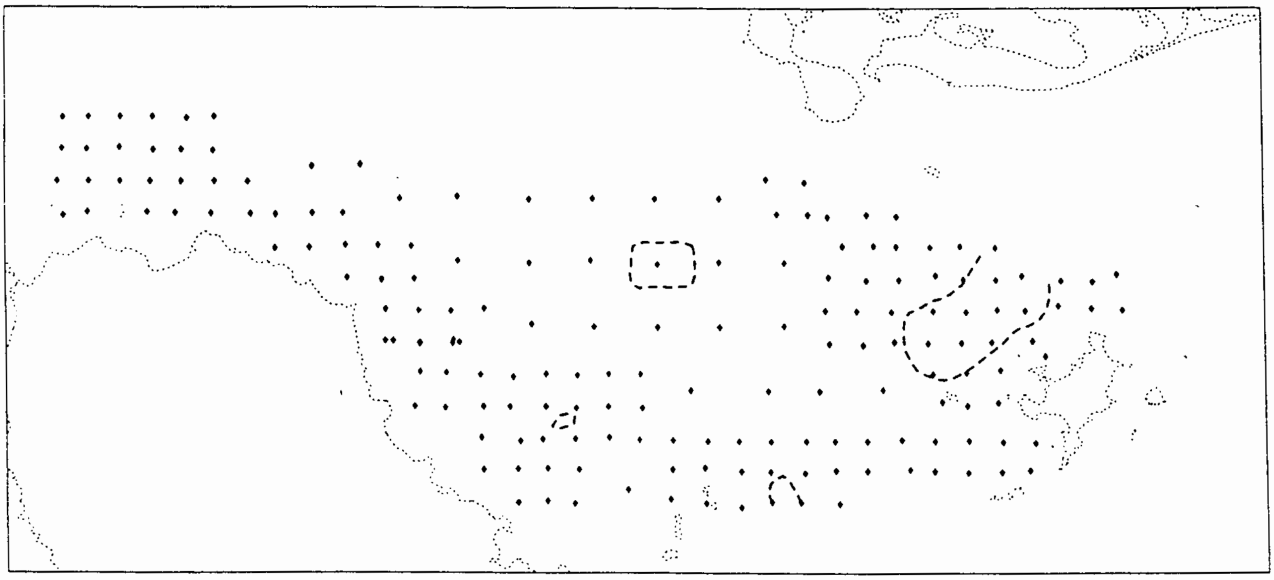
3.2.3 Comparison of population of oysters in 1993 and 1995

Table 3: Population size estimates (millions) of legal-sized oysters (≥ 58 mm in length), immediate pre-recruits (50–57 mm in length), and small pre-recruits (10–49 mm in length) in Foveaux Strait in the 1995 survey area in 1993 and 1995. 95% confidence intervals in parenthesis

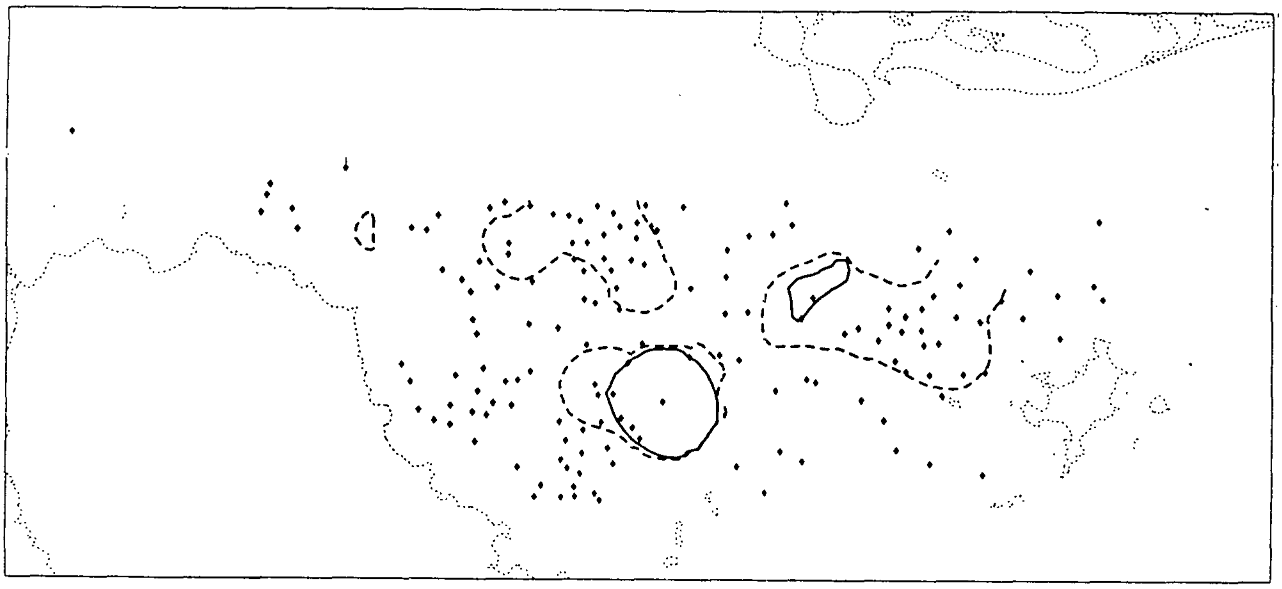
Size (mm long)	1993	1995
≥ 58 mm	283 (178–402)	696 (448–949)
50–57 mm	273 (171–390)	312 (196–418)
10–49 mm	443 (282–630)	559 (252–855)



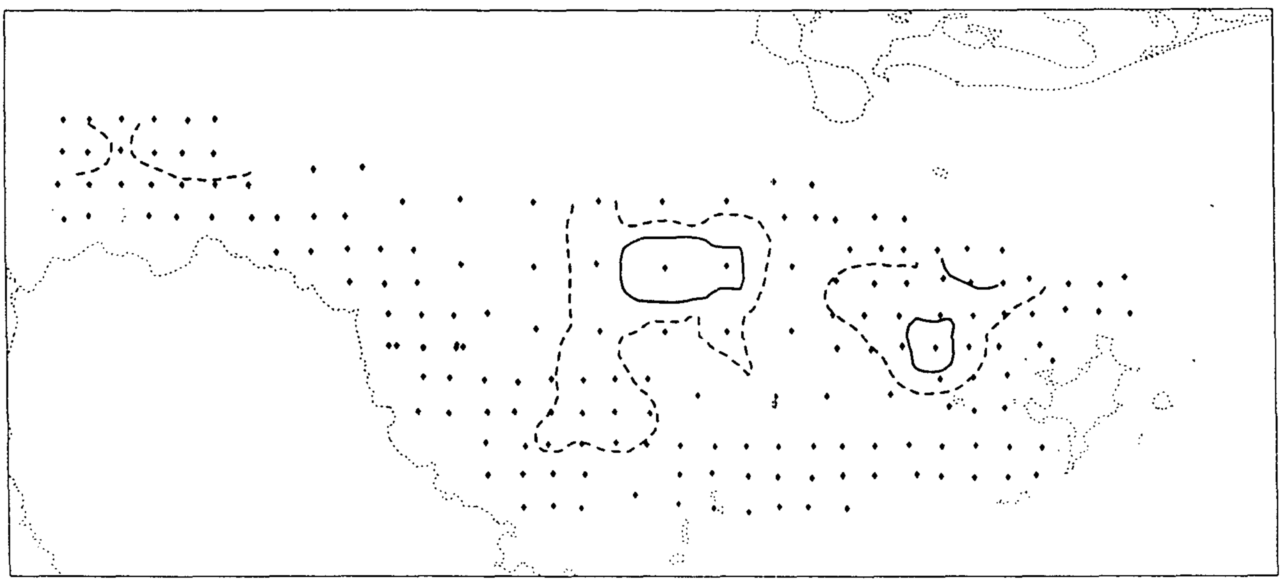
Appendix Figure 5: Contours (200 (dashed line), 400 (solid line) oysters per tow) of immediate pre-recruit oysters (50–57 mm in length) Foveaux Strait oyster survey October 1995. Station positions shown by diamonds.



Appendix Figure 6: Contours (200 (dashed line) oysters per tow) of immediate pre-recruit oysters (50–57 mm in length) Foveaux Strait oyster survey October 1993. Station positions shown by diamonds.



Appendix Figure 7: Contours (200 (dashed line), 400 (solid line) oysters per tow) of small pre-recruit oysters (10–49 mm in length) Foveaux Strait oyster survey October 1995. Station positions shown by diamonds.



Appendix Figure 8: Contours (200 (dashed line), 400 (solid line) oysters per tow) of small pre-recruit oysters (10–49 mm in length) Foveaux Strait oyster survey October 1993. Station positions shown by diamonds.

4. DISCUSSION

4.1. Dredge efficiency

During the planning of the survey there was some concern among members of the oyster industry that the estimate of dredge efficiency from 1990 would not be appropriate in 1995. Although dredges have not changed over this period, the fishery has been closed for 3 years and, in the absence of dredging, epibenthic organisms might have recolonised the seafloor. If the epibenthos had become dense, its catch could saturate dredges before the end of a tow and lower dredge efficiency. Any such major increase in the epibenthos would clearly show in the contents of dredges. We saw no change in dredge contents from previous surveys. A comparison of the fullness of dredges in the 1993 survey (after 1 year of closure) and 1995 (after 3 years of closure) shows some increase in fullness. The median dredge fullness was 15% (range 0–80%) in 1993 and 30% (range 0–70%) in 1995. Contours of dredge fullness (Appendix Figures 9 & 10) suggest that the increased catches of oysters in 1995 have contributed to the slightly fuller dredges in 1995 (cf. Appendix Figures 3 & 9). Dredges never became saturated during the 1995 survey, so the mean efficiency estimated in 1990 should be reliable for 1995. Variation in dredge efficiency at different oyster densities is incorporated in the bootstrapped confidence intervals for population estimates. Although the distribution of oysters is different from that in 1990, mean oyster density is very similar so change in oyster density is unlikely to have had any effect on dredge efficiency (which was estimated in comparisons in 1990).

4.2. Comparison with population in 1975–76

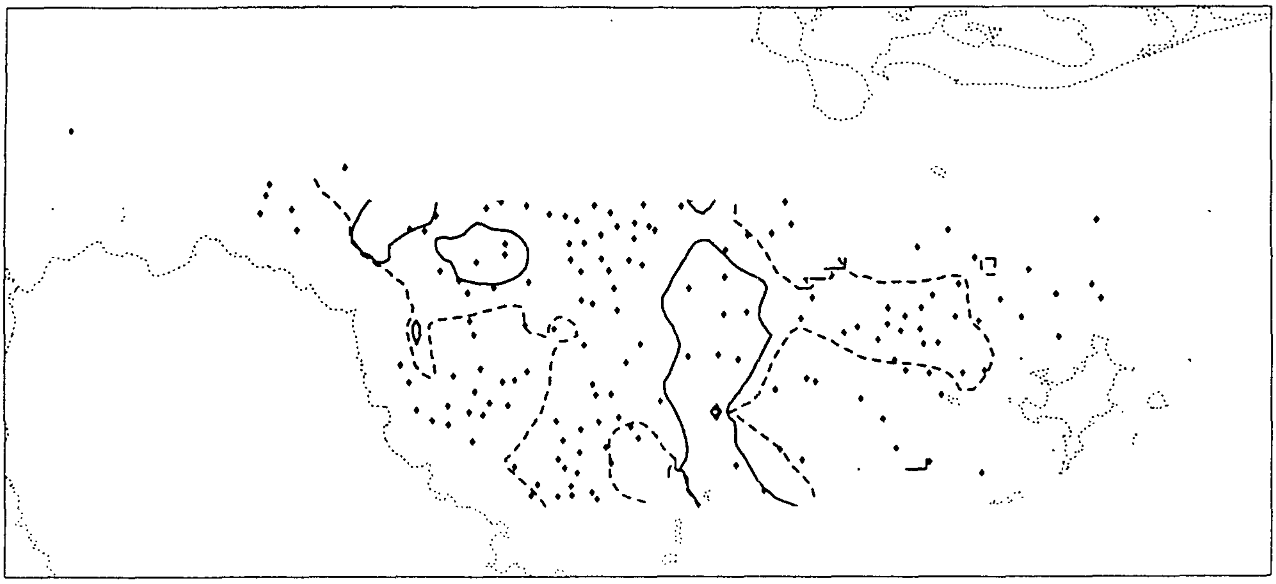
The current population in the area surveyed in 1975–76 is 39% of the population estimated in 1975–76.

4.3 Comparison with population in 1993

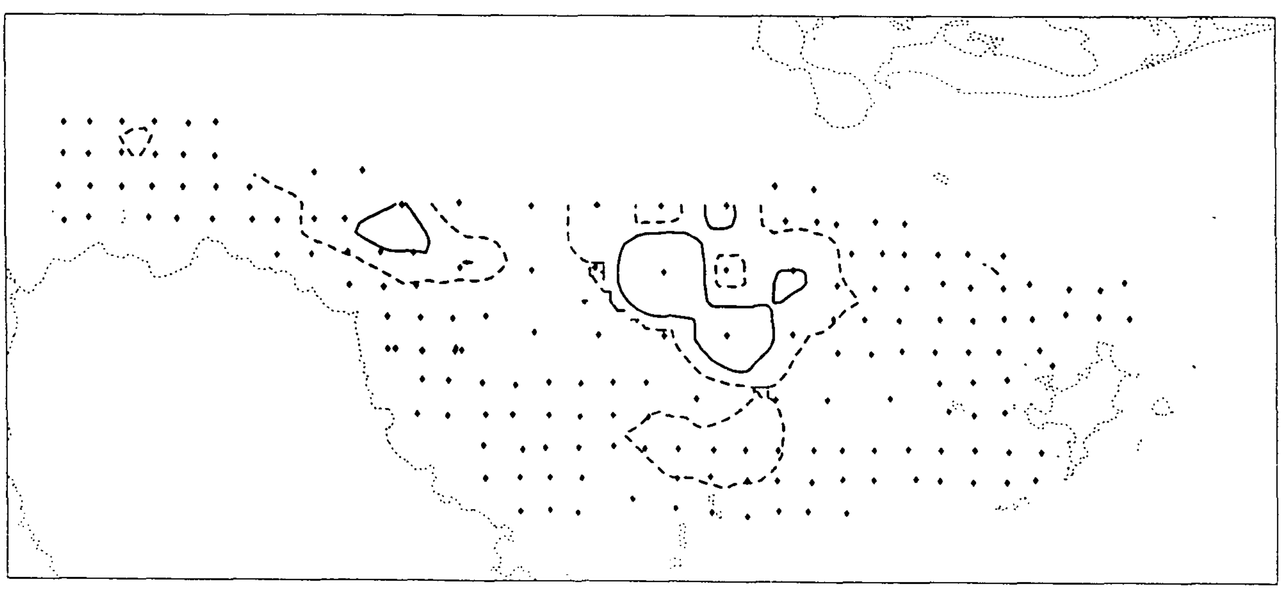
Compared to 1993, the abundance of legal-sized oysters in 1995 has increased about 2.5 times, which is statistically significant ($t = 4.6$, $P = 0.0001$). Numbers of small and immediate pre-recruits have remained the same between years which suggests that recruitment will continue at about the same level in the future.

4.4 Patchiness of commercial densities

In 1975, 91% of the population was in patches above commercial density (defined then as 6–8 sacks per hour and equivalent to 400 oysters per tow here) (Allen & Cranfield 1979). In 1995, 53% of the population was in patches above this 400 oysters per tow threshold more than twice the level found in 1993, but still a much lower proportion than in 1975–76. The numbers of oysters and the concentration of oysters in dense patches is continuing to rebuild towards former levels.



Appendix Figure 9: Contours of dredge fullness (25% (dashed line) and 40% (solid line)) on landing in Foveaux Strait oyster survey October 1995. Station positions shown by diamonds.



Appendix Figure 10: Contours of dredge fullness (25% (dashed line) and 40% (solid line)) on landing in Foveaux Strait oyster survey October 1993. Station positions shown by diamonds.

5. ACKNOWLEDGMENTS

We thank David Fisher and Brian Sanders for supervising the survey and recording the data. We thank Milton Roderique for organising the logistics of the survey in Bluff; we thank Milton Roderique and Rex Ryan skippers, and the crews of *Torea* and *Monica* for the enthusiastic and efficient way they carried out the survey.

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