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Foveaux Strait dredge oyster (*Tiostrea chilensis*) stock assessment, 1999

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EXECUTIVE SUMMARY

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A survey of the Foveaux Strait oyster population in October 1999 estimated the mean absolute population of recruited oysters in the 1055 km^2 area surveyed to be 1461 million (95% confidence interval, 872–2334 million). The area surveyed was 55% larger than the area surveyed in 1995. The mean population in the area surveyed in 1995 had increased from 630 million (395–899 million) in 1997 to 1183 million (721–1874 million) in 1999. The population of pre-recruit and small oysters, within the area surveyed in 1995, has about doubled since 1995. The point estimates of the proportion of recruited oysters within the area surveyed in 1975–1976 have increased from 31% in 1997 to about 44% in 1999. These changes in population assume dredge efficiency has not increased from 0.166 estimated in 1990, though we have reason to suspect it may have.

Because the distribution of the oyster population and fishing effort has changed markedly since 1975, the Shellfish Working Group recommended that only the oysters within areas designated as commercial by fishers should be used for TACC advice. TACC estimates in previous years used the entire survey area and estimates of the commercial population were calculated as the portion of the whole population over 400 oysters per tow. The TACC for the 2000 fishing year is based on an estimate of the entire population of recruited oysters from the commercial strata alone. Because of this change in method, the commercial population estimates from the 1995 and 1997 surveys can not be directly compared with the 1999 estimates.

The population in the designated commercial areas (strata 1 to 6) was 275 million oysters (184–408 million). Point estimates of commercial population for the 1995 and 1997 surveys, from the entire survey areas, were 254 and 331 million oysters respectively. The population in patches greater than 400 oysters per tow, in the 1999 commercial strata (1–6) was estimated to be 235 million oysters.

Yield estimates for 2000 were based on the entire population of recruited oysters from commercial strata and range from 30 to 44 million oysters (M 0.02 and 0.10 and $F_{0.1}$ of 0.116 and 0.173, respectively).

The estimated mean density of recruited oysters in Foveaux Strait increased between 1992 and 1999. Estimates of oyster density were calculated with a dredge efficiency of 0.166, which may have increased. Any increase in dredge efficiency will produce a significant positive bias in these estimates, overestimating the population. There is no information available on how dredge efficiency has changed since 1990.

Survey data from 1990 to 1999 suggest that dense aggregations of oysters can rebuild over time in areas where there were few oysters previously. There are some signs of rebuilding in western and eastern Foveaux Strait, but more research is required to establish its nature and strength.

1. INTRODUCTION

1.1 History

The Bluff oyster (*Tiostrea chilensis*) has been commercially fished in Foveaux Strait for 130 years. Annual landings of oysters, fishing effort, and the size of the area exploited by fishers steadily *increased* until 1986 (Cranfield et al. 1999a). A *Bonamia* sp. epizootic between 1986 and 1992 devastated the Foveaux Strait oyster population (Doonan et al. 1994). From the initial focus of infection in the western oyster beds, the disease spread through the population to reach the periphery of oyster distribution in 1992 (Doonan & Cranfield 1992). In 1992, the size of the oyster population in the area surveyed in 1975–76 was less than 10% of that present in 1975–76 and recruitment was considered to be at risk (Doonan et al. 1994). The Minister of Fisheries partially closed Foveaux Strait to oyster fishing in 1992, and fully closed it in 1993, to allow the population to rebuild.

By 1995, the prevalence and intensity of infection by *Bonamia* sp. had decreased (Cranfield et al. 1995) and disease was unlikely to cause mortality of oysters. The estimated size of the oyster population 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 (Cranfield et al. 1996). The Minister of Fisheries reopened the fishery in 1996 with a quota of 14.95 million oysters.

The estimated 1995 population of pre-recruit oysters (50–57 mm in length) was 312 million (Cranfield et al. 1996). Most of these oysters were expected to recruit into the fishery within two years. In 1997, the estimated population of recruited oysters (58 mm and over) had decreased from 639 million in 1995 to 630 million (Cranfield et al. 1999b). The apparent failure of the oyster population to increase between 1995 and 1997 may have resulted from three factors. (a) Recruitment varied more between years than expected and as the number of estimated pre-recruit oysters increased from 299 million in 1995 to 689 million in 1997, recruitment failure was suggested as the most probable cause of the population failing to increase (Cranfield et al. 1999b). (b) A downward bias of estimated numbers of recruited oysters due to differences in the way crew sorted oysters in the two surveys. This would have also resulted in an upward bias in numbers of pre-recruits, and their numbers were significantly greater in 1997 than in 1995. (c) Sampling variation. The 1999 survey of the Foveaux Strait investigated these factors. Numbers of pre-recruit oysters and small oysters (10–49 mm) were estimated in surveys of Foveaux Strait in 1993, 1995, and 1997, and the survey of 1999 provided a further estimate from which to compare variability of recruitment.

Before the *Bonamia* sp. epizootic, fishers had a choice of about 50 recognised oyster beds to fish (Cranfield et al. 1999b) and were able to employ an informal rotational harvesting strategy by abandoning beds which did not produce commercially acceptable catch rates. As the number of oyster beds declined during the epizootic and the catch rates accepted as commercially viable dropped across the fishery, fishing became more focused on the remaining oyster beds. In response to this change in strategy, the Ministry of Fisheries and the Bluff Oyster Management Company changed the design for the 1999 Foveaux Strait oyster survey. The new design focused survey effort on fishery areas designated by commercial fishers to contain commercial densities of oysters.

Bluff oyster skippers designated fishery areas that were likely to have commercial densities of oysters in 2000 and the boundaries of the survey area. Commercial areas were designated before the survey, from examination of charts, analyses of 1999 logbooks, their own information, and data from previous surveys. The skippers also designated exploratory areas that were not currently fished, but might provide commercial catches in the future. It was agreed that the TACC for the 2000 fishing year would be based on an estimate of the entire population from the commercial strata alone. In previous years, TACC estimates were based on population estimates using oyster density from tows where 400 or more oysters per tow were caught over the entire survey area.

1.2 Overview

The spread of the *Bonamia* sp. epizootic and its impact on the oyster population of Foveaux Strait was investigated by grid pattern dredge surveys in 1990, 1992, and 1993. By 1993, mortality from *Bonamia* sp. was considered to have ceased and the oyster population had shown signs of rebuilding. Since 1995, stratified random dredge surveys every two years have been used to estimate the absolute population of oysters in Foveaux Strait and monitor recovery. This document updates the stock assessment of the oyster population in Foveaux Strait and examines the population recovery using data from the 1999 survey. The sensitivity of estimates of biomass and yield to the methods of estimating commercial population used in 1999 and 1997 were tested.

This document also presents estimates of growth from the analysis of data from 1979 to 1981 and mortality estimates from the analysis of mark-recapture data from 1974 to 1986.

1.3 Description of the fishery

Oysters have been commercially harvested from Foveaux Strait since the 1860 and since the 1870s, by dredge. In the 130 years of oyster dredging, vessels and dredges have changed considerably (Cranfield et al. 1999a).

Oysters are harvested in a six-month season, 1 March to 31 August. Vessels tow two 550 kg, double bit, steel dredges on steel warps. Each dredge is towed off its own derrick, both on the vessel's port side. The dredges are towed along an elliptical track. Once the dredges are shot the vessel drifts down tide under minimal power turning in to the tide to haul the dredge. The dredge contents are emptied on to culching benches and the oysters sorted and sized by hand. Small oysters and bycatch are returned to the sea. Oysters are landed daily, live in the shell (Cranfield et al. 1999b).

Foveaux Strait oysters have been managed under the Quota Management System (QMS) since 1998.

1.4 Literature review

Distribution and population surveys since 1960 were summarised by Cranfield et al. (1991, 1993, 1996, 1998, and 1999b), Doonan & Cranfield (1992), and Doonan et al. (1994).

The fishery was described in detail by Doonan and Cranfield (1992), Doonan et al. (1994), and Cranfield et al. (1999b). The bounds of the fishery area in Foveaux Strait and the statistical reporting areas for the fishery are shown in Figure 1.

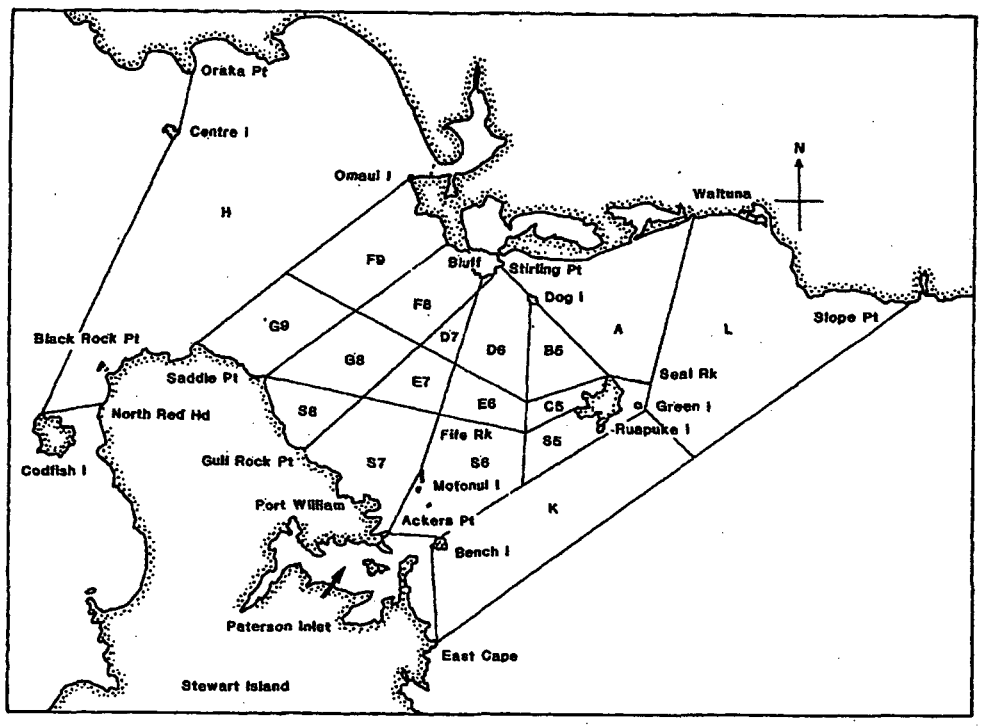

Figure 1: Boundaries of the oyster fishery and statistical areas for landing returns in Foveaux Strait.

The *Bonamia* sp. epizootic ended in 1992 (Cranfield et al. 1993) and the mortality of oysters has been at pre-epizootic levels since (Cranfield et al. 1999b).

Cranfield et al. (1999a) discussed changes in the distribution of epifaunal reefs and oysters during the 130 years of dredging in Foveaux Strait. Oyster beds are associated with epifaunal reefs, and are patchily distributed. An increasing intensity and frequency of fishing disturbance has increased the rate of removal of epifaunal reefs and, probably hasten the commercial extinction of the associated oyster beds.

Cranfield et al. (1997) discussed the results of a small-scale experiment to investigate the incidental mortality of small, pre-recruit, and recruited oysters caused by dredging. Mortality was inversely proportional to size; direct mortality of recruited oysters was low (1–2%), higher in pre-recruit oysters and high (19%) in small oysters. Heavier dredges currently in use in the fishery are likely to cause higher indirect mortality of small and pre-recruit oysters, than lighter dredges used before 1984.

Data on oyster abundance from surveys, catch landing returns, catch effort landing returns, and voluntary fishers logbooks were summarised by Cranfield & Michael (1999).

Dunn et al. (1998a) estimated natural mortality for 1974 to 1986 using data from the tag-recapture experiment of Cranfield & Allen (1979). The weighted average M for all data combined from 1974 to 1986 was 0.042 y^{-1}, but it is unlikely M would have been constant over this time. These data are discussed in more detail in Section 4.3.

Dunn et al. (1998b) modelled growth (diameter) of oysters sampled from four areas and grown in cages at the same site in Foveaux Strait from 1979 to 81. These data are discussed in more detail in Section 4.3.

2. REVIEW OF THE FISHERY

2.1 TACCs, catch, landings, and effort data

The Foveaux Strait oyster fishery, TACCs, and landings of oysters from 1963 to 1997 were summarised in the Dredge Oyster Working Group Report (Annala et al. 1999). The fishery was managed as a controlled fishery with 23 vessel licences since 1979 and fixing a TACC that was divided evenly between all vessels. In April 1997 individual quotas were granted and quota holders permitted to fish their entire quota on one vessel. The number of vessels in the fishery dropped to 15. At the same time, the Crown purchased 20% of the quota from quota holders and transferred it to the Waitangi Fisheries Commission. The oyster fishery entered the Quota Management System in 1998 under the Fisheries (Foveaux Strait Dredge Oyster Fishery) Amendment Act 1998.

The *Bonamia* sp. epizootic began about 1986 and the fishery closed in 1993 to allow the oyster population to recover without fishing. A survey in 1995 estimated the oyster population had rebuilt to a level that would allow limited fishing. Catch limits and reported landings between 1986 and 1999 are presented in Figure 2. Catch limits and reported landings of oysters between 1986 and 1995 when mortality from *Bonamia sp.* progressively reduced the size of the oyster population are shown in Table 1. Catch limits and reported landings of oysters for the post *Bonamia* period when the oyster population was small and rebuilding from 1996 to 1999 are shown in Table 2. When the fishery was reopened in 1996, the catch limit was set by weight instead of the number of sacks. The TACC for 1996 of 14.95 million oysters (equivalent to 19 315 sacks) was converted to weight using a conversion factor of 801 oysters and 79 kg per sack (*see* Cranfield et al. 1999b), which 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. A conversion factor of 774 oysters per sack was estimated from the 1996 CELR data and Bluff Oyster Enhancement Company data (Cranfield et al. 1996). Using this conversion rate, the catch limit for 1997 was 1525 t (Table 2). A conversion factor of 774 oysters per sack is used throughout this report.

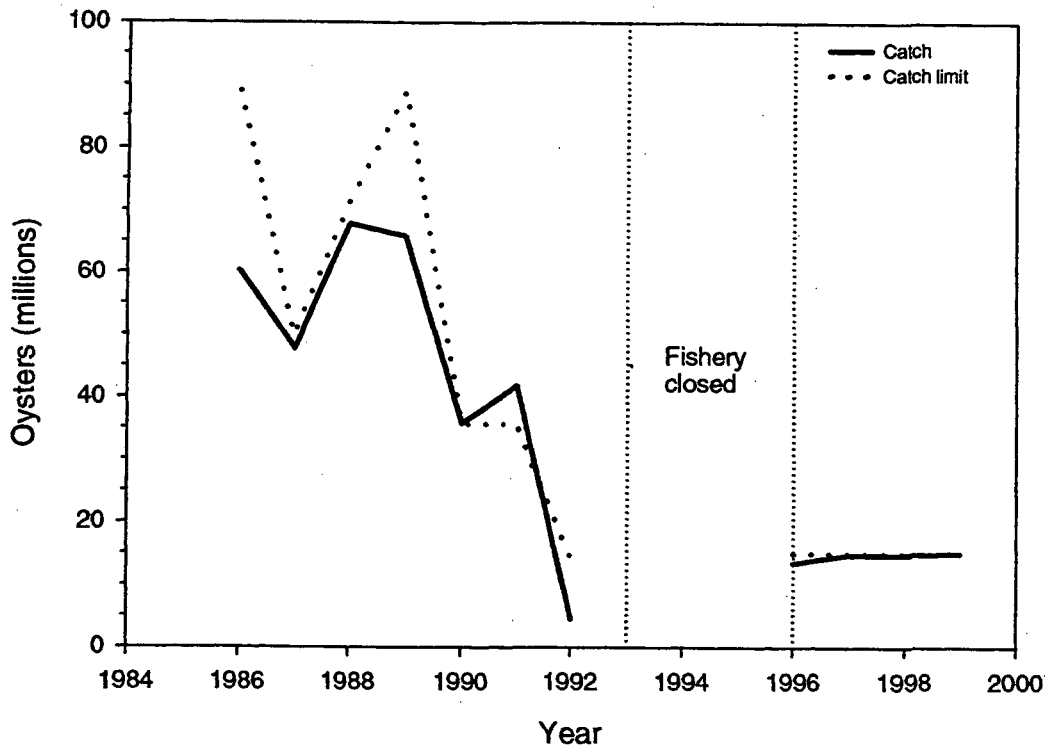

Figure 2: Catch limits and reported landings of oysters from Foveaux Strait between 1986 and 1999. The period 1986–92 shows declining catches as a result of the *Bonamia sp.* epizootic.

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

Year	Reported landings (sacks)	Catch limits (sacks)	Individual vessel Catch limits (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[1]	5 821	18 400	800	3.4
1993	–	0[2]	–	–
1994	–	0[2]	–	–
1995	–	0[2]	–	–

1. Exploratory commercial fishing in the periphery of oyster distribution.
2. Commercial fishery closed

Cranfield & Michael (1999) collated oyster abundance data from the Foveaux Strait fishery, including catch and effort data for the 1996, 1997, and 1998 fishing years (Table 2). Landings data from catch landing returns (CLR) and catch effort landing returns CELR) from the Ministry of Fisheries shows the catch limit of 14.95 million oysters was caught early in both the 1998 and

1999 fishing years. Mean catch per unit effort estimates from the Ministry of Fisheries for the 1998 and 1999 fishing years were similar, at 8.3 and 8.4 sacks per hour receptively.

Table 2: Reported landings, catch limit, quota for the Foveaux Strait dredge oyster fishery from 1996 to 1999. Landings and catch limits reported in numbers and weight. CPUE converted to sacks/hour (774 oysters per sack) to compare with earlier data.

Year	Reported landings (number millions)	Weight (t)	Catch limit (number millions)	Weight (t)		CPUE (sacks/hour)
1996	13.41	1475	14.95	1475	*	5.9
1997	14.82	1513	14.95	1525		7 0
1998	14.85	1515	14.95	1525		8.3
1999	14.94	1525	14.95	1525		8.4

* Catch limit in tonnes estimated using a conversion factor of 801 oysters per sack

2.2 Other information

2.2.1 Special permit landings

The Bluff Oyster Management Company Ltd has been granted a special permit each fishing year since 1992 (except 1998) to catch oysters during the breeding season to trial enhancement using spat settled on oyster shell (Table 3). The permit allocation is over and above the TACC set in each fishing year. Female oysters incubate their larvae from September to February, with the number of oysters incubating late stage larvae peaking in December.

Table 3: Reported oyster catch of vessels fishing under special permits for Bluff Oyster Enhancement Company, 1992–2000. Fishing took place over the summer breeding season (September–February) rather than the winter (March–August) commercial fishing season. From the summer of 1996–97, special permit catches were specified in numbers of oysters rather than sacks.

	Reported landings			Permit catch limit		
	Number (millions)	Number (sacks)	Weight (t)	Number (millions)	Number (sacks)	Weight (t)
1992–93	2.43	3 141	248.14	3.10	4 000	316.00
1993–94	3.09	3 986	314.89	3.10	4 000	316.00
1994–95	3.03	3 918	309.52	3.10	4 000	316.00
1995–96	0.93	1 199	94.72	0.93	1 200	94.8
1996–97	0.2	258	20.38	0.88	1 137	89.82
1997–98	0.72	930	73.47	0.72	930	73.47
1998–99	0	0	0	0	0	0
1999–00	1.00	1 292	102.07	1.00	1 292	102.07

2.2.2 Other sources of mortality from fishing

The mortality of oysters passed over by light (320 kg) and heavy (550 kg) dredges and left on the seabed and those caught by these dredges were compared experimentally in March 1997 (Cranfield and Michael unpublished results). Mortality was inversely proportional to the size of oysters damaged and lighter dredges killed fewer oysters. Adult oysters appeared to be robust (1–2% mortality) and few were damaged, but spat were very fragile and many were killed, particularly by the heavy commercial dredge (up to 36% mortality of spat below 10 cm). Incidental mortality from dredging may reduce subsequent recruitment in heavily fished stocks but is unlikely to be important once oysters are recruited in to the fishery.

2.3 Recreational, traditional, and Maori fisheries

2.3.1 Recreational fishery

Recreational fishers take small quantities of oysters by diving along the Stewart Island coast. Small quantities of oysters are dredged from deeper waters using improvised small dredges. The fisheries regulations allow recreational fishers to take 50 oysters per day during the open season (1 March to 31 August). The Ministry of Fisheries has conducted two surveys of recreational fishing, the South region 1991–92 survey (Teirney et al. 1997) and the 1996 national survey (Bradford 1998). However, only a few local respondents reported catches of oysters in their diaries. Because of the small sample size, the catch of oysters cannot reliably be quantified from these surveys. The only estimate of annual recreational catch was about 390 sacks (equivalent to 387 000 oysters), made by the Southland Recreational Marine Fishers Association in 1995. The reliability of this estimate is not known. The Ministry of Fisheries believes amateur catch is not likely to have increased since (Allen Frazer, pers comm.).

Under the Fisheries (Amateur Fishing) Regulations 1986, commercial fishers may take their daily amateur catch provided it is bagged separately from their commercial catch and labelled. During the 1998 and 1999 oyster seasons, the Ministry of Fisheries estimated commercial oyster fishers landed an additional 140 000 oysters (50 oysters each fisher each day) each season as an amateur catch. The Ministry of Fisheries estimated the total recreational catch to be about 430 000 (500 sacks) per season. The reliability of these estimates of recreational catch is not known.

2.3.2 Traditional and Maori fishery

Reporting of Maori customary harvest is specified in the Fisheries (South Island Customary Fisheries) Regulations 1999. Ngai Tahu administers reporting of customary catch of Foveaux Strait oysters to the Ministry of Fisheries. In 1999, the total reported catch was 246 940 oysters, or about 317 sacks. Estimates of Maori customary harvest for other years are not available.

2.3.3 Illegal catch

The Ministry of Fisheries believes the illegal catch of oysters for the 1998 and 1999 fishing years to be about 10% of the total non-commercial catch, 66 436 oysters (about 85 sacks), but this estimate cannot be verified.

3. RESEARCH

3.1 Stock structure

The Foveaux Strait oyster fishery has been managed as a single stock. However, fishers consider the fishery to comprise genetically different sub-stocks. No information is available on sub-stocks of oysters in Foveaux Strait, but difference in growth rates of oysters from four areas in Foveaux Strait (Dunn et al. 1998b) suggest genetic differences.

Before the *Bonamia* sp. epizootic in 1986, oysters in Foveaux Strait were distributed in a number of widely separated, discrete, small, dense patches considered as stable entities (Cranfield et al. 1999b). In 1975–76, the fishery exploited 374 km^2 of the 1200 km^2 of oyster bearing ground delineated in 1962 by Stead (1971). Ninety one percent of the total oyster population in the 1975–76 survey area was located in about 50 small, dense patches of oysters that together covered only 12 km^2 (Allen 1979). Between 1986 and 1992, mortality from *Bonamia* sp. progressively destroyed most of these high-density patches.

This extensive mortality forced fishers outside the established fishery area (the 1975–76 survey area). A wave of mortality from the epizootic spread through Foveaux Strait destroying patches of oysters rarely fished. By 1992, most high-density patches in the known limits of the oyster fishery in Foveaux Strait had been destroyed (Doonan et al. 1994). Fishers had to fish ahead of the wave of mortality to make commercial catches. In 1993, when the fishery was closed, the established fishery area had more than doubled from that in 1986.

The surveys between 1990 and 1993 used a grid design and sampled on a scale too wide to resolve small dense patches (Cranfield et al. 1999b). Stratified random surveys in 1995, 1997, and 1999 were aimed at estimating absolute population. Although data from these surveys can by used to look at macro scale distribution of oysters, the distribution of sampling is too widely spread to delineate small patches.

The recovery of localised populations has not been uniform. Dense populations of recruited oysters are still absent in eastern Foveaux Strait (oyster fishery statistical areas A, B5, and C5) and in those western areas most heavily affected by *Bonamia* sp. (G8, G9, & H), where dense patches were common before the epizootic (Cranfield *et al.* 1999b). Survey data from 1990 to 1999 suggest that dense aggregations of oysters can rebuild over time in areas where there were few oysters previously. There are some signs of rebuilding in western and eastern Foveaux Strait, but its nature and strength in non-commercial areas remains poorly described.

3.2 Resource surveys

Three estimates of population for Foveaux Strait oysters were made between 1960 and 1976, two dredge surveys and a mark-recapture experiment (Cranfield et al. 1999b). Population estimates and survey designs are given in Table 4. The absolute population was estimated in 1990 using a stratified random dive survey (Doonan & Cranfield 1992). The surveys of 1990–97 used the same procedure to estimate population (*see* population estimates in Appendix A) and an estimate of dredge efficiency of 0.164. In 1990, the efficiency of the small 1.2 m wide survey dredge used for the 1975–1976 survey was re-estimated as 0.15 (standard deviation (0.03) and the efficiency of the 3.35 m wide commercial dredges estimated as 0.18 (0.03). Because the differences in the estimates of dredge efficiency were not statistically significant, the data for both dredges were combined to give a mean

of 0.164. Absolute oyster density estimated from the dive survey was compared with oyster density estimated from dredge catches in the same area (Doonan et al. 1994). The updated estimate of dredge efficiency for the small survey dredge was used to re-estimate the oyster population in 1975–1976 (Doonan et al. 1994). The 1999 population survey used a revised estimate of 0.166, the mean estimated from two dredge surveys and a dive survey in 1990. Population estimates for these surveys are shown in Table 4. Survey design and operational procedures for the 1999 Foveaux Strait oyster population survey are given in Appendix A.

Table 4: Population estimates of recruited oysters (58 mm in length and greater) in Foveaux Strait. Pre-1990 estimates are from Cranfield et al. (1991); 1990 and 1992 estimates Doonan & Cranfield (1992); 1993 Cranfield et al. (1993); March 1995 Cranfield et al. (1995), and October 1995 Cranfield et al. (1996), and October 1997 from Cranfield et al. (1999b). Grid, grid pattern survey; SR, stratified random survey design; MR, mark-recapture survey method. Total *c.v.* includes error in dredge efficiency. –, no data.

Years	Month	Survey design	Survey method	Area (km^2)	No. stations	Population size (millions)	Sampling *c.v.*	Total *c.v.*
1960–62	–	Grid	Dive	377	35	1400	–	–
1974	–	Grid	MR	374	–	1800	0.20	–
1975	–	Grid	MR	374	–	1500	0.11	–
1975–76	–	Grid	Dredge[1]	374	929	1140	0.04	0.15
1990	July	Grid	Dredge[2]	1116	262	771	0.14	–
1990	October	SR	Dredge[1]	646	116	–[3]	0.11	–
1990	October	SR	Dive	646	83	607	0.13	–
1992	March	Grid	Dredge[2]	1229	370	319	0.10	0.18
1993	October	Grid	Dredge[2]	875	177	372	0.14	0.21
1995	March	SR	Dredge[2]	680	50	543	0.26	0.30
1995	October	SR	Dredge[2]	680	154	639	0.12	0.19
1997	October	SR	Dredge[2]	693	107	630	0.14	0.21
1999	October	SR	Dredge[2, 4]	1055	199	1461	0.16	0.26

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. Differential GPS used for navigation and tow length accurate to ± 2 m.

Since the early 1990s, most dredging for oysters has taken place in the central and western beds, which occur on sandier and softer substrates than the eastern beds. This pattern of fishing combined with the reduction in biogenic reef as a result of dredging in the area (Cranfield et al. 1999a) and the diminishing number of clocks (shells of oysters that had died during the *Bonamia* epizootic) are likely to have increased dredge efficiency from 0.166. If dredge efficiency has increased, it is likely to produce a large positive bias in the later estimates of population size.

3.3 Growth and mortality estimates

Mortality of adult oysters is probably low, other than during epizootics. Allen (1979) estimated the instantaneous rate of mortality, M, from a mark-recapture experiment in 1974 and 1975 to be between 0.009 y^{-1} and 0.015 y^{-1}, but thought this was likely to be an underestimate. He used 0.1 y^{-1} in a simulation model of the fishery.

Dunn et al. (1998a) estimated natural mortality from the re-analysis of Allen's (1979) data for 1974–75 and data from 1976 to 1986. Natural mortality was found to increase from 0.017 y^{-1} to 0.188 y^{-1} from 1974 to 1986 for the cohort of oysters released in 1974, and from 0.009 y^{-1} to 0.199 y^{-1} for the cohort of oysters released in 1973. He suggested a point estimate, based on the weighted average instantaneous natural mortality, M, for all data combined for the years from 1974 to 1986, of 0.042 y^{-1}.

Dunn et al. (1998b) modelled length based growth of a sample of oysters collected from four areas and grown in cages at a single site in Foveaux Strait. They used the following model (see model 3 in Dunn et al. (1998b)) to estimate growth as change in diameter (mean of height and length).

$$\Delta l = (L_{\infty_{area}} - l_1)(1-e^{-k_{area+year}(\Delta t+\phi)}) + \varepsilon$$

Where Δl is the change in diameter from an initial measurement l_1, over change in time between successive measurements Δt. The parameters are L_∞ (asymptotic size), k (growth constant), and ϕ (the seasonal growth (amplitude) of the growth curve). ε is a normally distributed noise term with mean zero.

Growth parameters from the study are shown in Table 5.

Table 5: Length-based growth parameters (see model 3 in Dunn et al. (1998b)) for a sample of oysters from four areas and held at a single site in Foveaux Strait, 1979–81. Growth is given as change in diameter.

Parameter values (and 95% confidence intervals)

L_∞	*Area A*	92.2 mm (86.7–97.9)
	Bird I.	76.2 mm (73.5–78.9)
	Lee Bay	77.8 mm (73.4–81.4)
	Saddle	81.0 mm (77.3–84.9)
k	1979	(reference year)
	1980	-0.29 (-0.33– -0.25)
	1981	0.02 (-0.02– 0.06)
	Area A	0.48 (0.41– 0.54)
	Bird I.	0.85 (0.76– 0.94)
	Lee Bay	0.77 (0.68– 0.86)
	Saddle	0.51 (0.50– 0.52)
ϕ		-0.03

Dunn et al. (1998b) found evidence for strong seasonal variation in growth; mean growth over the winter was zero or slightly negative (the latter presumably due to shell abrasion). He found high variability between areas and high seasonal and yearly effects. No estimates of growth overall were made.

3.4 Population estimates

Population estimates from surveys since 1960 are given in Table 4. The similarity of the estimates between 1960 and 1975 has been interpreted by the Shellfish Working Group as suggesting that the population was in equilibrium at the existing fishing mortality rate before the *Bonamia* epizootic (fishers reports suggest the epidemic began in 1985). The population declined rapidly to a low point in 1992 from which it has increased.

3.4.1 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. As the size of the virgin population is unknown and difficult to estimate, the 1975 population has been used as a reference population. The area surveyed in 1975–76 (Figure 3) has been included within the area of all subsequent surveys and the population within this area in the surveys between 1990 and 1999 has been computed to show how this reference population has changed over this period (Table 6).

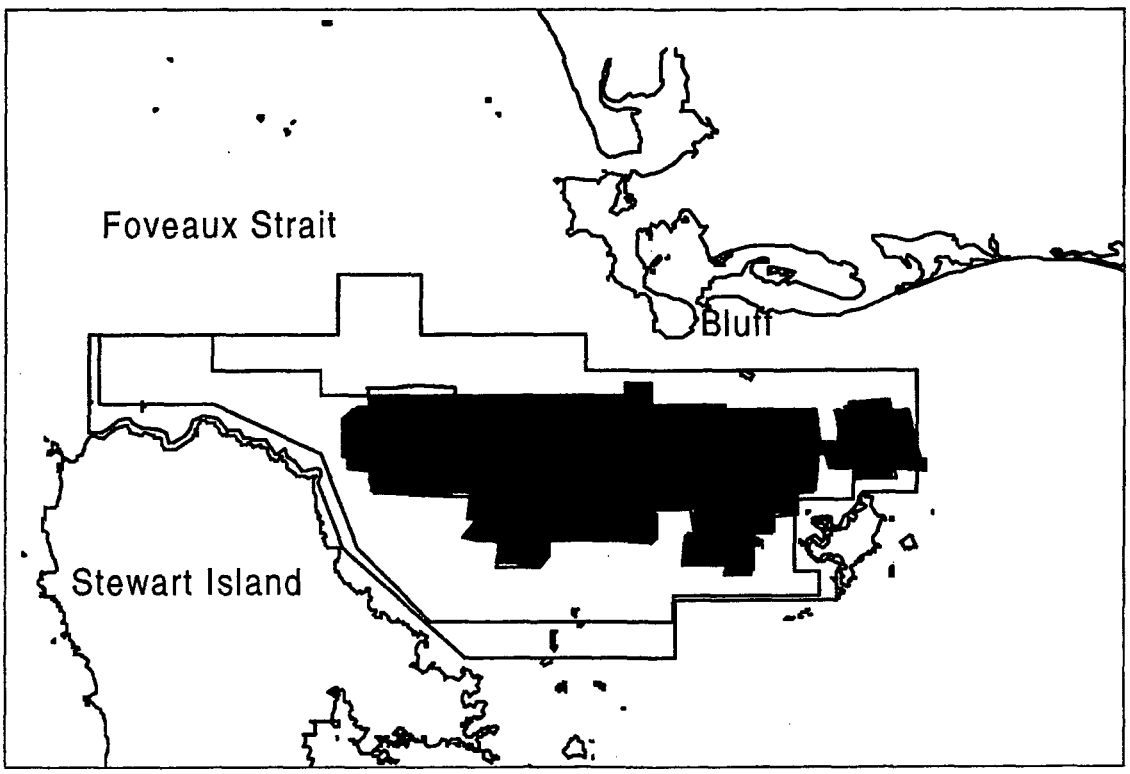

Figure 3: The 374 km^2 area of Foveaux Strait surveyed in 1975–76 (shaded black), the boundary of the area surveyed in 1995 (solid inner line), and the boundary of the area surveyed in 1999 (solid outer line).

Table 6: Population estimates (millions) of recruited oysters (58 mm in length and greater), within the area of Foveaux Strait surveyed in 1975–76 (374 km^2), in 1975–76, 1990, 1992, 1993, 1995, 1997 and 1999; 95% confidence intervals in parentheses include error in dredge efficiency 1993–99.

Year	Population (95% CI)	c.v.	N	% 1975 population
1975–76	1 140 (774–1652)	0.04	929	100
1990 (July)	378 (240–584)	0.12	141	33
1992 (March)	101 (66–151)	0.09	126	9
1993 (October)	180 (92–300)	0.22	57	16
1995 (October)	404 (242–637)	0.15	97	35
1997 (October)	352 (206–562)	0.16	50	31
1999 (October)	502 (301–798)	0.16	73	44

In 1992, the recruited oyster population in the 1975–76 survey area was below 10% of the 1975–76 level and recruitment was considered to be at risk (Doonan et al. 1994). The Minister of Fisheries partially closed the fishery in 1992 and fully closed it in 1993. In 1995, the Shellfish Working Group made a decision rule to re-open the fishery when the size of the oyster population in the 1975–76 area had reached 40% (Cranfield et al. 1996). By 1995 the population level was 35% and the fishery reopened in 1996. The population has not changed significantly since 1995, but the point estimate was about 44% of the 1975–76 level by 1999. However, the size of the fishery area and the distribution of fishing effort have changed markedly since 1975. The Working Group considered it more appropriate to remove the decision rule based on the 1975–76 survey area and to consider the population of the area fished since 1992 when assessing the likely effect of current levels of fishing.

3.4.2 Estimates of recruitment between 1993 and 1999

The populations of pre-recruit oysters (50–57 mm) and small oysters (10–49 mm) were estimated in surveys between 1993 and 1999 (Table 7). Pre-recruits were probably caught with similar efficiency to recruited oysters by the dredge. Most small oysters are attached to larger oysters or shell. However, some oysters and shell clumps (groups of oysters cemented together) may be broken apart in the dredge, allowing small oysters to pass through the rings of the dredge. The small oysters may be caught with a lower dredge efficiency.

Table 7: Population estimates of oysters (millions) within the area of Foveaux Strait surveyed in 1995 (680 km^2), in 1992, 1993, 1995 (two surveys), 1997, and 1999. Recruited oysters (58 mm in length and greater), pre-recruit oysters (50–57 mm in length), and small oysters (10–49 mm in length); 95% confidence intervals in parentheses includes error in dredge efficiency 1993–99. –, no pre-recruit or small oyster data in 1995.

Year and month of survey	Recruited oysters	Percentage of 1992	Pre-recruits oysters	Small oysters
1992 (March)	238 (143–352)	100	–	–
1993 (October)	283 (178–402)	119	273 (171–390)	443 (282–630)
1995 (March)	543 (254–878)	228	377 (177–612)	370 (187–582)
1995 (October)	679 (448–949)	285	299 (196–418)	538 (252–855)
1997 (October)	630 (395–899)	264	689 (432–991)	859 (547–1223)
1999 (October)	1 183 (721–1874)	497	723 (467–1087)	1 110 (710–1687)

Since 1992 (after mortality from *Bonamia* sp. had ceased), the population of pre-recruit oysters and small oysters has been increasing. If this level of recruitment continues, the numbers of pre-recruit and small oysters suggest that the Foveaux Strait oyster fishery will continue to rebuild slowly.

3.4.3 Estimation of commercial population

In 1995 and 1997, the commercial population was estimated as the percentage of the population above a density of 400 oysters per tow (equivalent to about 6–8 sacks per hour during commercial dredging) over the entire survey area. The percentages of the commercial populations to the total populations and the number of stations surveyed in surveys between 1975 and 1997 are given in Table 8.

In 1999, the Ministry of Fisheries and the Bluff Oyster Management Company changed the methods of estimating the size of the commercial oyster population. Bluff oyster skippers designated fishery areas that were likely to have commercial densities of oysters in 2000 and the boundaries of the survey area. Commercial areas were designated before the survey (see Appendix A for method). The yield for 2000 was calculated from the entire oyster population in designated commercial areas only. The population of recruited oysters in commercial strata was estimated as 275.3 million (95% CI = 167.1– 437.1). The combined area of the commercial strata represents about 15% of the 1995 and 1997 survey areas.

Estimates of commercial population using the 1995 and 1997 method cannot be directly compared with the estimate from 1999. Using the 1995 method to estimate commercial population in commercial strata only in 1999 (only commercial strata will be used to estimate yield for 2000) the commercial population was 235 million, 60% of the total population.

Table 8: Percentage of the oyster population in areas above a density of 400 oysters per survey tow (equivalent to about 6–8 sacks per hour in commercial dredging) in the area surveyed in 1975–76.

Survey	Percentage	Number of stations
1975	91	929
1990	56	116
1992	11	370
1993	26	177
1995	55	154
1997	40	107
1999	60	199

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 118 million in 1999 compared to 109 million in 1997. Based on this 1997 methodology, the yield for the 2000 fishing year would remain the exactly same.

3.5. Yield estimates

TACC estimates in previous years used the portion of the population over 400 oysters per tow from the entire survey area. Current Annual Yeild (CAY) has been used to estimate yield since 1996. CAY is based on commercial population estimates from surveys every two years.

The TACC for the 2000 fishing year was based on an estimate of the entire population from the commercial strata alone. The population of recruited oysters in the six commercial strata was estimated as 275.3 million.

3.5.1 Estimation of Current Annual Yield (CAY)

CAY was estimated using Method 1 Annala et al. (1999) where most fishing mortality occurs over a short period at the beginning of the year. The oyster season is 1 March to 31 August each year, and fishing usually begins early in March and mostly finishes between June and July.

$$CAY = (1-e^{-F0.1}) B_{beg}$$

Estimates of B_{beg} and $F_{0.1}$ were used to estimate CAY. B_{beg} is the recruited commercial population at the beginning of the fishing year, 275 million oysters. At each level of assumed M, CAY was estimated from the population point estimate and the 95% confidence limits of the estimate (Table 9).

Table 9: Estimates of CAY in numbers. At each assumed value of natural mortality, the table shows $F_{0.1}$, the CAY from the point estimate of abundance and the 95% confidence limits around the point estimate.

M (y^{-1})	$F_{0.1}$	CAY (millions)	(95% confidence limits)
0.020	0.116	30	(18–47)
0.042	0.129	33	(20–52)
0.100	0.173	44	(27–69)

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

3.5.2 Estimation of Maximum Constant Yield (MCY)

The Foveaux Strait oyster fishery is managed by current annual yield (CAY) based on the estimate of the current population. It is therefore not appropriate to estimate MCY.

4. FACTORS MODIFYING YIELD ESTIMATES

4.1 Dredge efficiency

The major factor likely to modify the estimate of yield is the estimate of dredge efficiency and its impact on the estimate of population. Dredge efficiency was last estimated in 1990 to be 0.166, but is believed by some fishers to have increased. A small increase in dredge efficiency to 0.20 would positively bias population estimates by 20%. The current efficiency of dredges cannot be estimated without a dredge efficiency trial.

4.2 Concentration of fishing on only a few populations

Oyster fishers tend to concentrate fishing on populations giving the highest catch rates and cease fishing these when the catch rate drops below a level that is commercially viable. Yield estimates above are made under the assumption that all recruited oysters within the commercial strata (1–6) are vulnerable to the commercial fishery.

4.3 Continuing mortality from *Bonamia* sp.

Very few shells of recently dead oysters were found during the 1999 survey, suggesting low mortality and no heightened mortality from *Bonamia* sp. Natural mortality of oysters is assumed to have returned to pre-epizootic levels.

4.4 Recruitment overfishing

Stock size and recruitment are frequently unrelated in shellfish fisheries, but a number of life history traits of *T. chilensis* indicate that this may not be true. This species produces large eggs, has a low fecundity, and only a low percentage of the population in Foveaux Strait breed 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. 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 not typical of commercially fished bivalves. Most commercially fished species generally produce millions of larvae that have a moderately long planktonic life and 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 three years with no fishing. This population apparently has the capacity to rebuild in the absence of fishing, even at low biomass levels. Oyster density in central Foveaux Strait was reduced to very low levels by *Bonamia* in 1990. By 1995, the oyster population in this area had rebuilt to commercial densities. However, the population has not rebuilt uniformly throughout Foveaux Strait. The recruited oyster density is still very low in some localities, especially to the east (in statistical areas B5, C5, and A) and recovery may be slow in these areas.

4.5 Indirect fishing mortality

A small-scale experimental study suggested that dredging caused little indirect mortality to recruited oysters (Cranfield and Michael unpublished results). This was supported by few new clocks found in heavily fished areas in the 1999 survey. However, mortality of small oysters is likely to be higher with the heavy dredges used currently compared with the lighter dredges used in 1975.

5. STATUS OF THE STOCKS

The absolute population of recruited, pre-recruit, and small oysters in Foveaux Strait is continuing to increase slowly. The recruited oyster population in the 1995 survey area has increased from 238 million in 1992 to 1183 million in 1999. The proportion of the recruited oyster population in the 1975–76 survey area has increased from 9% of the 1975–76 population in 1992 to about 44% in 1999.

Changes in the commercial population of oysters in Foveaux Strait and the impact of fishing on it cannot be assessed, as estimates of commercial population are not directly comparable. In 1995 and 1997, the commercial population was estimated as the percentage of the population above a density of 400 oysters per tow over the entire survey area. A change in the method of estimating the commercial population in 1999 used the entire population of recruited oysters from the designated commercial strata alone. The combined area of the commercial strata in 1999 represents about 15% of the areas used to calculate commercial population in 1995 and 1997.

Point estimates of commercial population size in 1999 (275 million oysters), 1997 (254 million), and 1995 (331 million) cannot be directly compared. The population in patches greater than 400 oysters per tow in the 1999 commercial strata (1–6) was estimated to be 235 million oysters.

The estimated mean density of recruited oysters in Foveaux Strait increased between 1992 and 1999 (see Table A2, Cranfield et al. (1996), Cranfield et al. (1999b)), but dense aggregations of oysters may not be increasing. Estimates of oyster density were calculated with a dredge efficiency of 0.166, which may have increased. Any increase in dredge efficiency will produce a significant positive bias in these estimates, over estimating the population. There is no information available on how dredge efficiency has changed since 1990.

Survey data from 1990 to 1999 suggest that dense aggregations of oysters can rebuild over time in areas where there were few oysters previously. There are some signs of rebuilding in western and eastern Foveaux Strait, but more research needs to be done to establish the nature and strength of this rebuilding.

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Appendix A. Foveaux Strait oyster survey, October 1999

INTRODUCTION

A *Bonamia* sp. epizootic between 1986 and 1992 caused catastrophic mortality, reducing the Foveaux Strait oyster population to 9% of its pre-disease level and significantly changing the distribution of oysters (Cranfield et al. 1993, Doonan et al. 1994). This mortality, combined with increasing fishing intensity on remaining dense patches of oysters, reduced the number patches available to fishers (Cranfield et al. 1999a). In 1993, the Minister of Fisheries closed Foveaux Strait to commercial oyster fishing to allow the oyster population to rebuild.

A grid design dredge survey of the Foveaux Strait oyster population after the fishery was closed in October 1993 (Cranfield et al. 1993) found no change in the population size from the previous survey in 1992 (Doonan & Cranfield 1992). Mortality from *Bonamia* was waning and confined to the periphery of the oyster fishery (Cranfield et al. 1993). The Shellfish Working Group recommended that the population size be regularly surveyed to monitor its recovery. The objective of the surveys was to estimate the absolute population size over the entire fishery. A stratified random design was chosen as the most effective and economic survey method. The Foveaux Strait oyster population was surveyed every two years to increase the likelihood of detecting statistically significant changes in the population size between surveys.

Estimates of population size from surveys in 1992, 1993, and 1995 showed the population was rebuilding (Doonan & Cranfield 1992, Cranfield et al. 1993, 1996). 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 reopen the fishery when the population in the area surveyed in 1975–76 (Cranfield & Allen 1979, Doonan et al. 1994) had increased to at least 40% of the 1975–76 population size. The area surveyed in 1975–76 has been included in all surveys since 1990. In 1995, the oyster population had rebuilt to 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. The density of oysters that could support commercially viable fishing was estimated by Cranfield et al. (1996) to be greater than 400 recruited oysters per standard survey tow (0.2 n.mile). The 1995 estimate of commercial oyster population size was used to estimate current annual yield (CAY) and to set the quota for the 1996 and 1997 oyster seasons.

The Foveaux Strait oyster population was last surveyed in 1997. The absolute population size of recruited (58 mm in length and over) oysters (630 million) was not significantly different from 1995 (680 million), but the number of pre-recruit (50–57 mm) oysters had increased significantly from 285 million in 1995 to 689 million in 1997 (Cranfield et al. 1999b). The size of the population in the 1975–76 survey area (31%) was not significantly different to that in 1995, but below the 40% threshold used by the Ministry of Fisheries for reopening the Fishery. The failure of the large number of pre-recruit oysters in 1995 to recruit into the fishery in 1997 was attributed to poor recruitment between 1995 and 1997. A CAY of 20.3 million oysters was estimated from the 1997 survey and TACCs for the 1998 and 1999 oyster seasons were set at 14.95 million by the Minister of Fisheries, remaining unchanged from the 1996 and 1997 oyster seasons.

This document describes a population survey of the Foveaux Strait oyster population carried out in October 1999 and presents the results. The aims of the survey were (a) to determine the distribution and absolute abundance of pre-recruit and recruited oysters in non-commercial and commercial areas of Foveaux Strait; (b) to collect size and weight data for yield per recruit analysis and data to be used in developing a size based fishery model for Foveaux Strait oysters.

METHODS

In 1999, the Ministry of Fisheries and the Bluff Oyster Management Company changed the methods of selecting survey areas and estimating the size of the commercial oyster population. Bluff oyster skippers designated fishery areas that were likely to have commercial densities of oysters in 2000 and the boundaries of the survey area. Commercial areas were designated before the survey, based on examination of charts and analyses of their 1999 logbooks, their own information, and data from previous surveys. The skippers also designated exploratory areas that were not currently fished, but might have provided commercial catches in the future. The yield for 2000 was calculated from the entire oyster population in designated commercial areas, a change from the previous method of estimating yield which used the proportion of the population above 400 oysters per standard tow from the entire survey area.

The aim of the survey was to determine the distribution and absolute abundance of pre-recruit (50–57 mm in length) and recruited (at least 58 mm in length) oysters in both non-commercial and commercial areas of Foveaux Strait in 1999. The target coefficient of variation (c.v.) of the estimate of absolute recruited abundance was 0.20. Data were also collected on the abundance of small oysters (10–49 mm in length). A two-phased stratified random dredge survey (Francis 1984) focused survey effort in strata designated as commercial (Areas 1–6 in Figure A1). Exploratory, non-commercial, and recreational areas on the Stewart Island coast were surveyed in a single-phase.

Size (height and length) frequency samples were taken from every survey tow to provide data on the size-structure of the oyster population which will be integral to any size-based population modelling developed for the Foveaux Strait oyster fishery. Height, length, and weight data were collected for yield per recruit analyses.

Estimates of population size in the 1975–76, 1995, and 1999 survey areas were recalculated using data from previous surveys and compared. Estimates of the commercial population size from the 1999 survey data were calculated using both the 1997 and 1999 methods.

Stratification

The area limits of the Foveaux Strait oyster fishery were designated by the Bluff oyster boat skippers and used to define the survey area (Figure A1). The 1999 survey area includes all areas surveyed since 1975–76 with the exception of parts of the 1990 multi-vessel dredge survey area (Doonan & Cranfield 1992).

Within this fishery area, patches containing oysters at commercial densities have been determined from all the data available, including the distribution and density of oysters found in previous surveys, and from 1999 logbook information and fisher's personal information. These logbook data were summarised in two ways: using rectangular binned counts of number of tows, total catch (sacks), unstandardised catch per hour, and unstandardised catch per tow. Bin size was set to about 0.3 nautical mile, and reflected the underlying accuracy of the patch records from logbooks. The second set of summaries were statistically smoothed (kernel density smoothing, Wand & Jones 1995) estimates of relative oyster density based on catch per tow from logbooks and on point density estimates from surveys. Kernel density estimates were generated using estimates of bandwidth derived from a normal distribution approximation (Sheather & Jones 1991). These estimates were designed to produce smoothed maps that account for macro-scale variation. Density estimates were based on estimated density (catch per tow) at reported locations. All density estimates were scaled to lie between zero and one.

Based on summaries of these data, commercial and exploratory areas designated by the Bluff oyster boat skippers were used to define strata. The remaining area within the fishery boundary was designated as a single non-commercial stratum. A recreational area gazetted on the Stewart Island coast was also surveyed (Figure A1). Stratum numbering, their designation and the stratum areas are shown in Table A1.

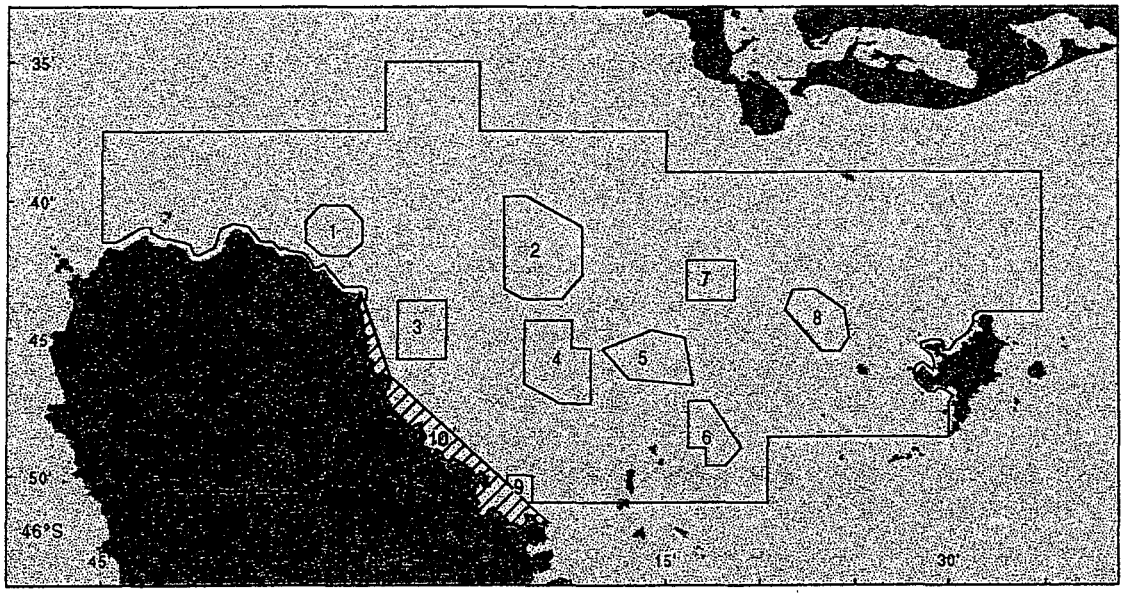

Figure A1: The survey area and strata for the 1999 Foveaux Strait oyster population survey. Fishers defined the survey boundary and designated strata 1–6 as commercial strata, strata 7–9 as exploratory, and the remaining area a non-commercial background stratum (0). Yield was calculated from the estimate of absolute population from commercial strata (1–6) only. Data from the recreational area (stratum 10) have not been included in the estimates of population size.

Table A1: The Foveaux Strait oyster survey stratum numbers, designation, stratum area, and the numbers of first and second phase stations sampled in October 1999.

Stratum number	Designation	Area (km^2)	No. of stations phase 1	No. of stations phase 2
0	non-commercial	928.5	50	-
1	commercial	11.1	12	0
2	commercial	31.7	33	22
3	commercial	13.2	14	0
4	commercial	21.5	23	0
5	commercial	15.6	17	3
6	commercial	10.2	11	-
7	exploratory	8.9	8	-
8	exploratory	11.8	9	-
9	exploratory	2.4	3	-
10	recreational	26.8	5	-
Total		1081.7	185	25

Station selection

Sampling was focused on areas in the fishery most likely to be fished in 2000. Most (135) of the 210 stations sampled were allocated to commercial strata (110 first-phase and 25 second-phase). The variance in oyster density in commercial strata was likely to be low, and therefore the allocation of the number of stations to each stratum was proportional to their area. Dynamic allocations of second-phase stations in the commercial strata were based on the estimated variance in each stratum from the first-phase sampling (Francis 1984). Non-commercial strata received 50 stations, exploratory strata 20, and the recreational area 5. The allocation of first and second-phase stations by stratum is shown in Table A1.

Stations were randomly selected with exclusion zones (at least 0.3 nautical mile) to avoid spatial correlation of catches and to spread stations throughout the strata. Sufficient random stations were generated in each of the commercial strata for both first-phase and secondphase stations where applicable.

Operational procedures

Sampling procedures were the same as in previous surveys in 1990, 1992, 1993, 1995, and 1997 (Cranfield et al. 1991, Doonan & Cranfield 1992, Cranfield et al. 1993, 1996, and 1999). A commercial oyster vessel, *Toiler*, skippered by Rex Ryan was used for the survey. The skipper has been involved in previous surveys and is experienced in the procedures and standards required. The survey vessel used satellite-derived differential GPS position fixing to ensure precise navigation. Differential corrections from a Fugo Omnistar receiver were interfaced to a Furuno GP-31 by cable using NMEA 0183 data format. NIWA staff navigated to survey stations and ensured standard sampling procedures were maintained.

At each station, a standard commercial dredge (550 kg, 3.35 m wide) was towed in a straight line for 0.2 nautical mile (370 m). The start of tow position was recorded when the towing warp became tight after the winch brake had been applied. Tow length was controlled using the distance elapsed and GPS alarm features. The end of tow position was recorded from the point at which the winch began retrieving the dredge. Both forward and after dredges were used to sample stations to increase the number of stations sampled in a day. Dredges were landed onto their respective forward and after culching benches unwashed to avoid the loss of small oysters and so that the percentage fullness of the dredge could be better estimated.

Before any of the catch was sorted, a random size frequency sample was taken from each tow. The sorting bench was divided into six cells and one cell selected randomly. A sample containing a minimum of 40 recruited oysters and at least 200 oysters in total including spat, were randomly sampled and bagged. The sampling procedure ensured that oysters remained in their clump structures to provide information on population structure and recruitment. Where a single cell did not contain sufficient oysters for a size frequency sample, more cells were randomly sampled until the minimum sample size was obtained or the whole catch was sampled. The proportion of the whole catch sampled was recorded.

The catch was sorted into live oysters and new and old clocks. Clocks are the articulated shells of dead oysters with the ligament intact. The shells of new clocks were clean and without fouling on the inner surface. These clocks are shells of oysters that have died since the seasonal settlement of fouling organisms in the 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).

Each of these three samples were accurately grouped by size. Reference rings (58 and 50 mm internal diameter) were used to ensure accurate allocation to each size group. Size was determined by the failure of an oyster to pass through a 58 or a 50 mm diameter ring. The catch from each survey tow was sorted into live oysters and new and old clocks in two size groups; recruited (58 mm in length and greater, length measured along the anterior-posterior axis parallel to the hinge line) and pre-recruit oysters (50–57 mm in length). Small live oysters (10–49 mm in length) were sorted into a third size group. The smallest size at which small oysters could be counted reliably was 10 mm. Two NIWA staff supervised the operation and recorded all information (Appendix B).

A sample of 1000 live oysters representative of the entire size range in Foveaux Strait was sampled for length, height, and green weight measurements for yield per recruit. Fifty oysters were randomly selected from 20 random dredge tows over the whole survey area.

Size frequency samples were measured onshore (Appendix C). The data from each cluster of oysters (a number of oysters joined together from successive settlements of oysters) in each sample were recorded separately. Each oyster was categorised into a size group using the 58 and 50 mm reference rings. Recruited oysters (those unable to pass through a 58 mm internal diameter ring) were assigned to size group 2. Pre-recruit oysters (those able to pass through a 58 mm ring, but not a 50 mm ring) were assigned to size group 1. Small oysters (those able to pass through a 50 mm ring) assigned to size group 0. Size frequency samples were measured for height and length to the nearest millimetre down using finely graduated rulers. The height, length, and weight samples were processed in the same manner and weighed to 0.1g (Appendix D).

Population estimates

The estimates of population size excluded data from stratum 10, the recreational fishing area outside the commercial fishery area. Six stations with tow lengths less than 100 m were removed from the data set and the density of oysters standardised to a 370 m (0.2 nautical mile) tow. All tows shorter than 100 m came fast on foul ground.

We estimated the absolute population size of recruited oysters using a revised estimate of mean efficiency of dredges estimated in 1990, 0.166 (95% confidence intervals 0.13–0.22, the original estimate of Doonan et al. 1994 was 0.164), where

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

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

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

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, the ratio of normally distributed variables 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.

Distribution of oysters

Data from the 1999 Foveaux Strait oyster dredge survey have been summarised using the same method as for previous survey data (see stratification above). These data were summarised using rectangular binned counts (unstandardised catch per tow) with bin size set to about 0.3 nautical mile and smoothed estimates of relative oyster density based point density estimates from the 1999 surveys.

RESULTS

The survey area and stratum boundaries are shown in Figure A1. The absolute population size and 95% confidence intervals for recruited, pre-recruit, and small oysters by stratum in Table A2.

Factors that may affect the estimates of density at each station

Differential GPS ensured dredge tow lengths were closely clustered around the 0.2 nautical mile (370 m) standard tow length (Figure A2), thus avoiding any bias in the estimates of oyster density due to variable tow lengths.

Oyster dredges are considered saturated and to have ceased fishing before the end of tow when they are more than 80% full on landing. Dredge saturation may lead to an underestimate of oyster density. Tow lengths with both dredges were consistent and there was no evidence of dredge saturation (Figure A3). The after dredge was used for 191 of the 210 tows. The dredges had identical construction specifications and were assumed to catch oysters with the same efficiency. Because of the vastly different numbers of tows made with each dredge, we could not compare their performance in a robust manner. A Mann-Whitney test for non-normally distributed data showed no difference in catch efficiency ($P = 0.4483$) between the two dredges.

Most of the survey stations were sampled in light wind conditions; the median wind force was 2 on the Beaufort scale (4–6 knots), with 5 and 95 percentiles of Beaufort scale 1 (1–3 knots) and 5 (17–21 knots) respectively (Figure A4). These wind strengths and resulting sea conditions were well below the levels likely to affect dredge efficiency and we assume no significant effects on the sampling effectiveness of the survey.

Table A2: The number of stations sampled (No. stations), the mean oyster density per m^2 (mean density), standard deviation (*s.d.*) of the density estimate, coefficient of variation (*c.v.*) of the population estimate, mean population size (Mean population), upper and lower 95 % confidence intervals (CI), and the area of each stratum, by stratum number for the October 1999 Foveaux Strait oyster survey.

Recruited oysters (≥ 58 mm)				Population estimates in millions of oysters				
Strata	No. stations	Mean density	Density s.d.	c.v.	Mean population	Lower 95% CI	Upper 95% CI	Area km^2
0	44	1.26	0.25	0.20	1171.92	624.45	1930.91	928.52
1	12	1.85	0.32	0.17	20.55	11.89	33.53	11.10
2	55	3.57	0.26	0.07	113.06	75.31	170.75	31.68
3	14	1.31	0.31	0.24	17.27	8.48	29.98	13.15
4	23	2.30	0.50	0.22	49.47	25.41	84.66	21.52
5	20	3.61	0.47	0.13	56.19	34.65	88.31	15.56
6	11	1.84	0.27	0.15	18.74	11.37	29.90	10.18
7	8	0.65	0.15	0.24	5.78	2.83	10.02	8.86
8	9	0.66	0.09	0.14	7.73	4.76	12.21	11.78
9	3	0.00	0.00	1.00	0.01	0.00	0.02	2.35
All	199	1.38	0.22	0.16	1460.72	871.88	2334.31	1054.71

Pre-recruit oysters (50–57 mm)				Population estimates in millions of oysters				
Strata	No. stations	Mean density	Density s.d.	c.v.	Mean population	Lower 95% CI	Upper 95% CI	Area km^2
0	44	0.75	0.11	0.15	692.98	413.73	1094.67	928.52
1	12	1.03	0.15	0.15	11.47	6.96	18.35	11.10
2	55	2.65	0.20	0.08	83.79	55.60	127.02	31.68
3	14	0.48	0.12	0.24	6.32	3.07	11.00	13.15
4	23	1.09	0.23	0.21	23.45	12.20	39.96	21.52
5	20	3.01	0.46	0.15	46.84	27.73	74.91	15.56
6	11	1.28	0.22	0.17	13.02	7.56	21.20	10.18
7	8	0.58	0.17	0.29	5.14	2.05	9.45	8.86
8	9	1.33	0.22	0.16	15.69	9.27	25.28	11.78
9	3	0.01	0.01	1.00	0.03	0.00	0.09	2.35
All	199	0.85	0.10	0.12	898.72	570.48	1386.79	1054.71

Small oysters (<50 mm)				Population estimates in millions of oysters				
Strata	No. stations	Mean density	Density s.d.	c.v.	Mean population	Lower 95% CI	Upper 95% CI	Area km^2
0	44	1.21	0.17	0.14	1123.24	681.85	1759.49	928.52
1	12	3.02	0.48	0.16	33.49	19.96	53.96	11.10
2	55	2.45	0.21	0.09	77.68	51.21	118.35	31.68
3	14	0.80	0.21	0.27	10.47	4.69	18.71	13.15
4	23	1.30	0.33	0.25	28.03	12.98	49.50	21.52
5	20	3.31	0.48	0.15	51.52	30.86	82.01	15.56
6	11	1.25	0.25	0.20	12.70	6.87	21.38	10.18
7	8	1.02	0.32	0.31	9.08	3.41	16.93	8.86
8	9	2.27	0.30	0.13	26.76	16.74	42.00	11.78
9	3	0.01	0.01	1.00	0.03	0.00	0.11	2.35
All	199	1.30	0.15	0.11	1373.00	873.98	2115.14	1054.71

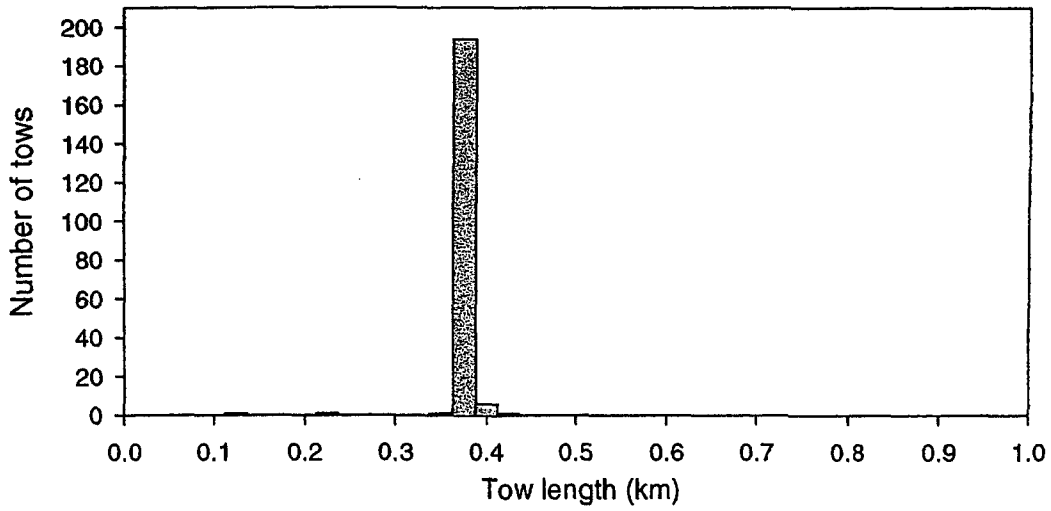

Figure A2: Dredge tow length frequencies from the October 1999 Foveaux Strait oyster survey, N=204.

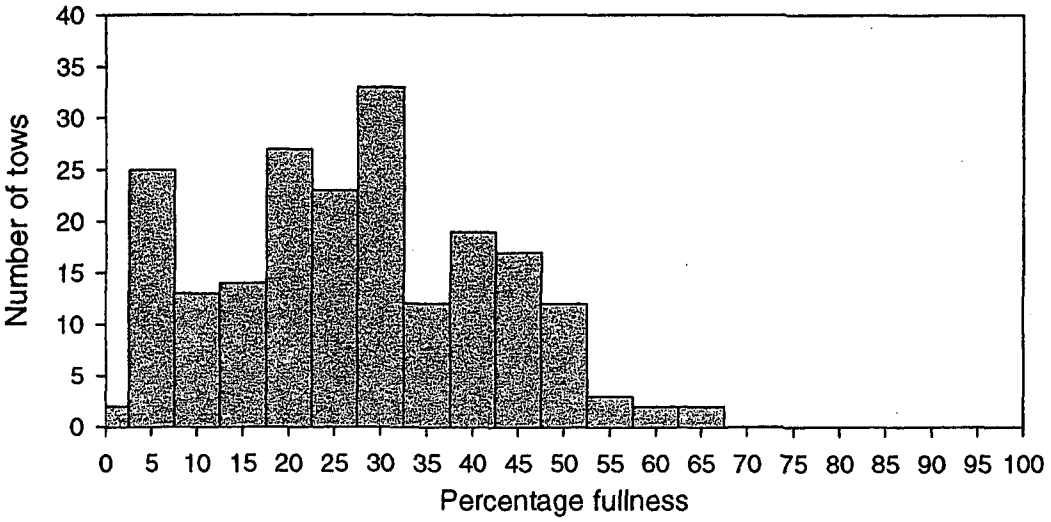

Figure A3: Dredge fullness (%) from the October 1999 Foveaux Strait oyster survey, N=204.

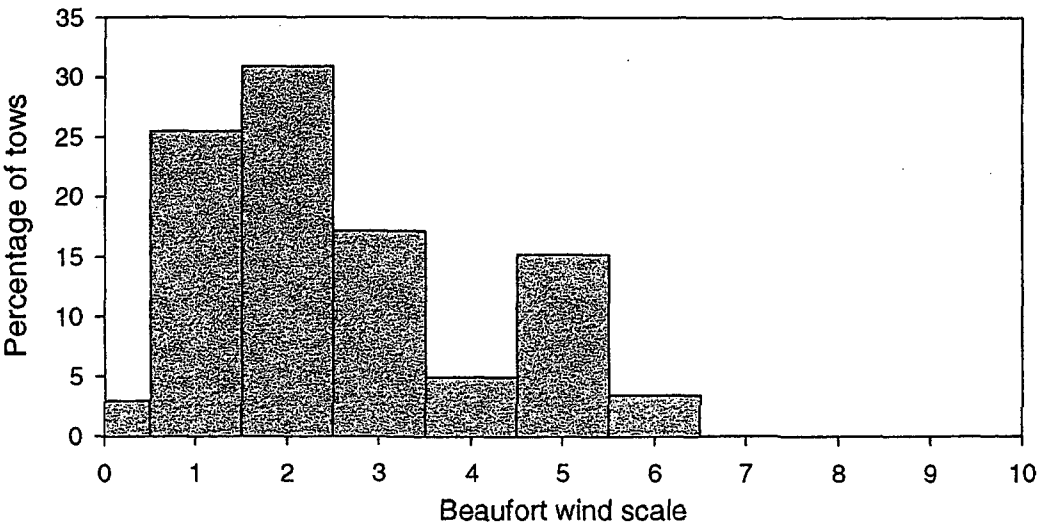

Figure A4: Percentage frequency of wind force (Beaufort scale) from the October 1999 Foveaux Strait oyster survey, N=204.

Distribution

The distributions of recruited, pre-recruit, and small oysters in the 1999 survey area are shown in Figures A5–A7. As the density estimates for each size group were scaled to lie between zero and one (see plot scales), it is not possible to compare the abundance of oysters between size groups or years. The distribution of recruited oysters from the 1999 logbook data are shown in Figure A8. The distribution of recruited oysters from surveys in 1993, 1995, and 1997 are shown in Figures A9–A11, pre-recruit oysters in Figures A12–A14, and small oysters in Figures A15–A17.

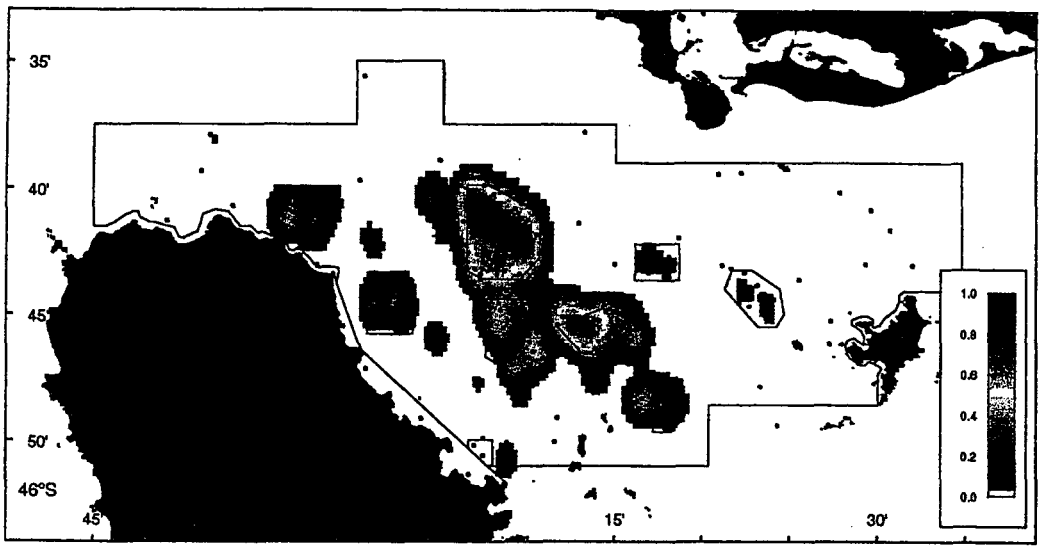

Figure A5: The smoothed density of recruited oysters from the 1999 Foveaux Strait oyster population survey. Location of tows marked by black dots.

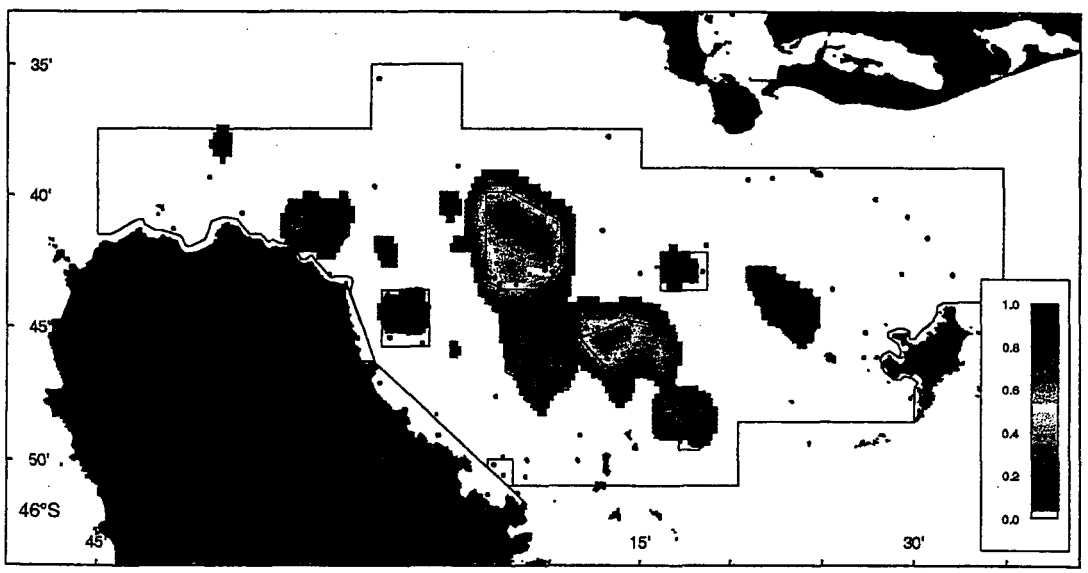

Figure A6: The smoothed density of pre-recruit oysters from the 1999 Foveaux Strait oyster population survey. Location of tows marked by black dots.

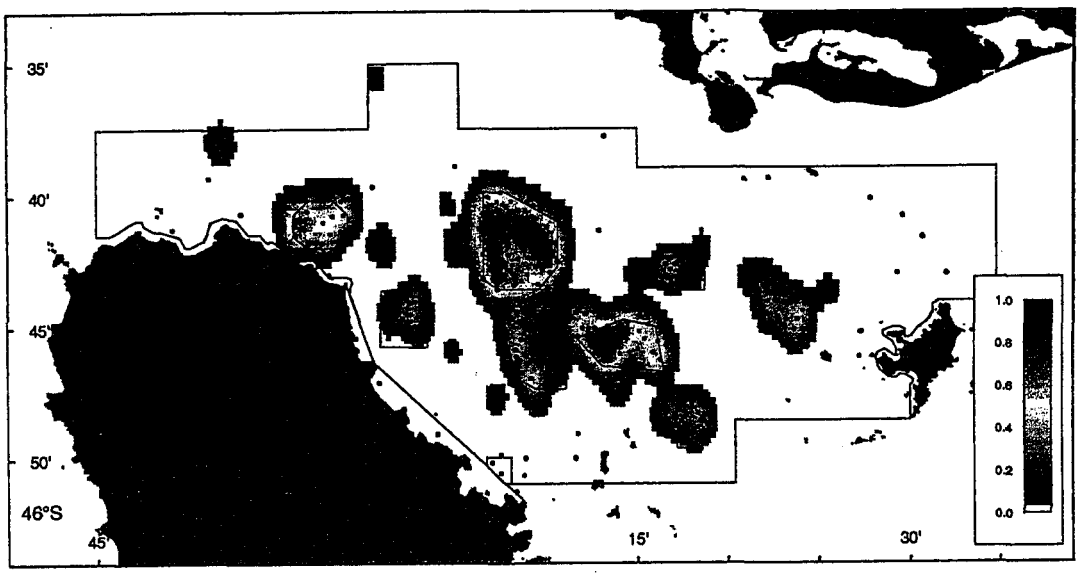

Figure A7: The smoothed density of small oysters from the 1999 Foveaux Strait oyster population survey. Location of tows marked by black dots.

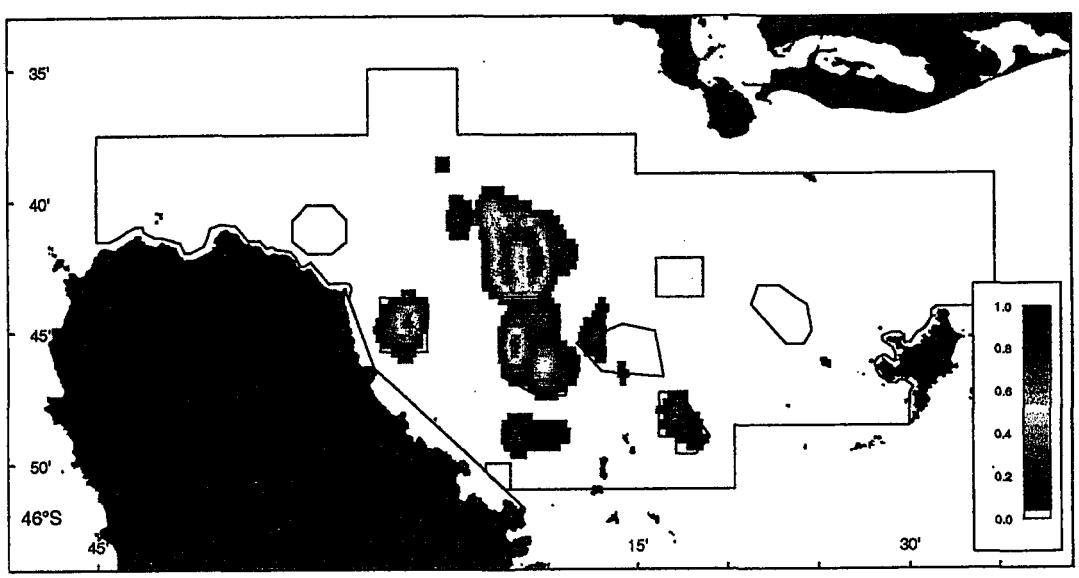

Figure A8: The smoothed density of recruited oysters from the 1999 Foveaux Strait logbook data.

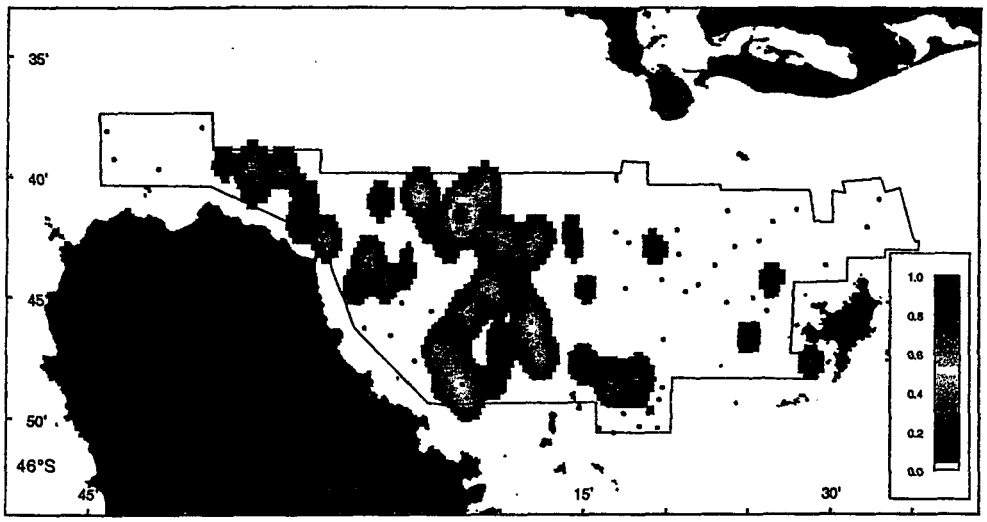

Figure A9: The smoothed density of recruited oysters from the 1997 Foveaux Strait oyster population survey. Location of tows marked by black dots.

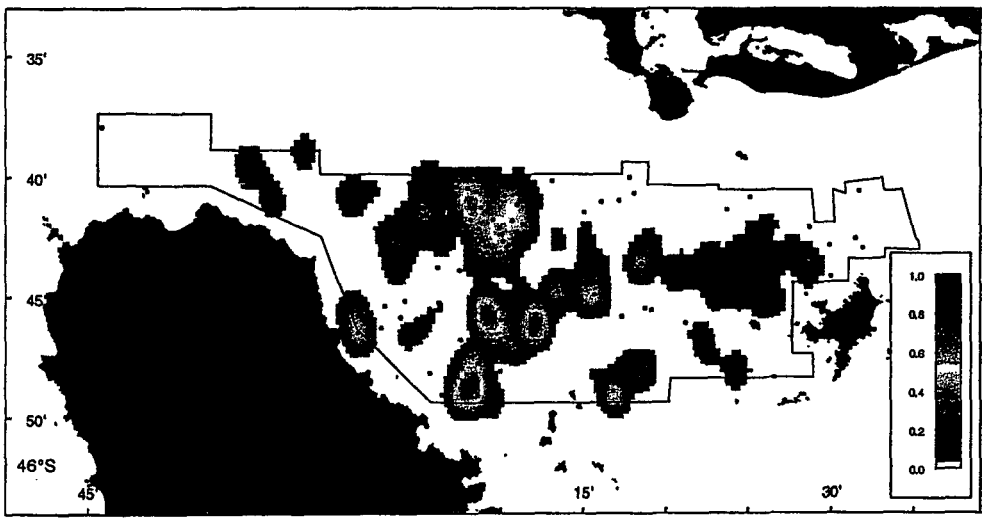

Figure A10: The smoothed density of recruited oysters from the 1995 Foveaux Strait oyster population survey. Location of tows marked by black dots.

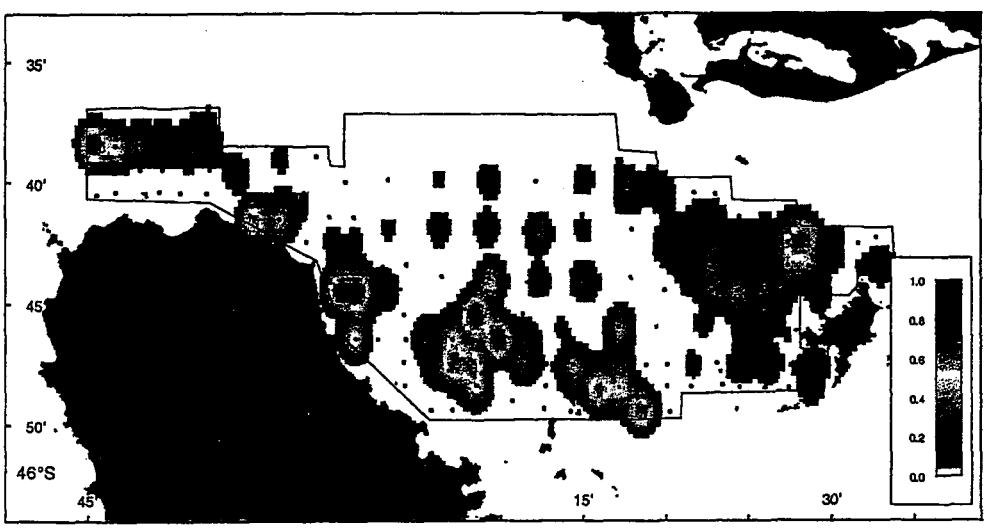

Figure A11: The smoothed density of recruited oysters from the 1993 Foveaux Strait oyster population survey. Location of tows marked by black dots.

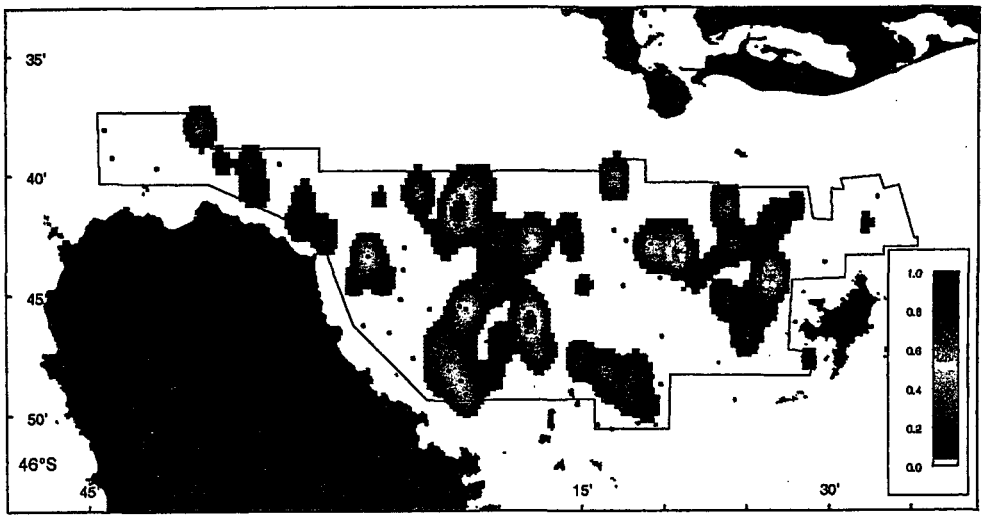

Figure A12: The smoothed density of pre-recruited oysters from the 1997 Foveaux Strait oyster population survey. Location of tows marked by black dots.

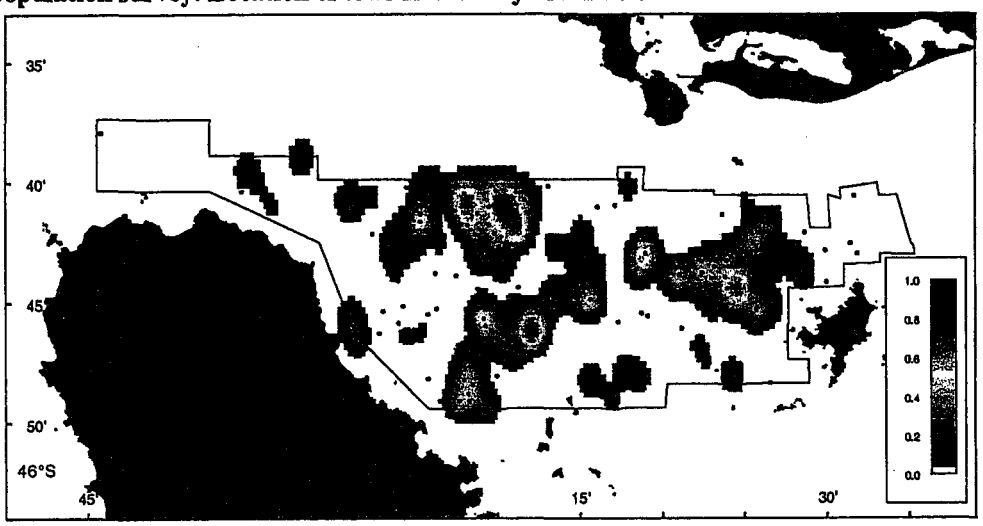

Figure A13: The smoothed density of pre-recruited oysters from the 1995 Foveaux Strait oyster population survey. Location of tows marked by black dots.

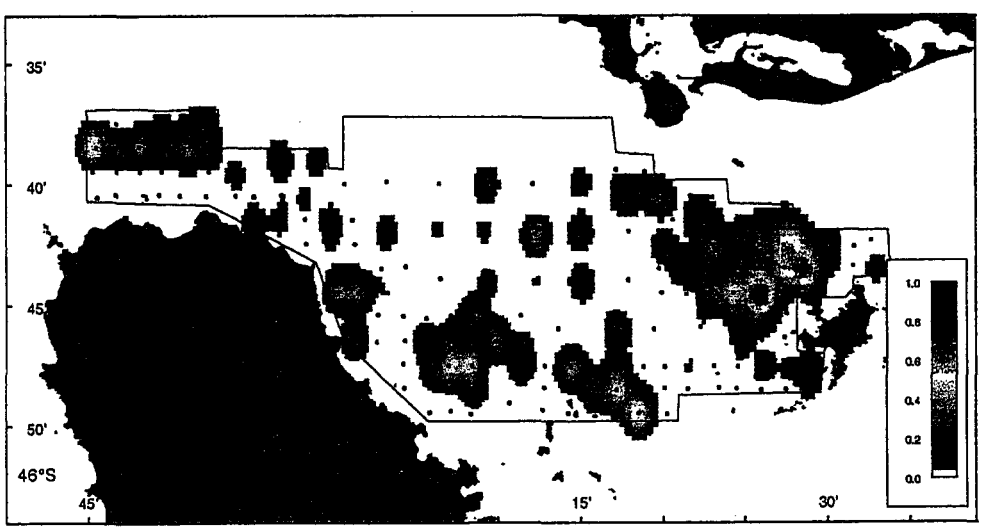

Figure A14: The smoothed density of pre-recruited oysters from the 1993 Foveaux Strait oyster population survey. Location of tows marked by black dots.

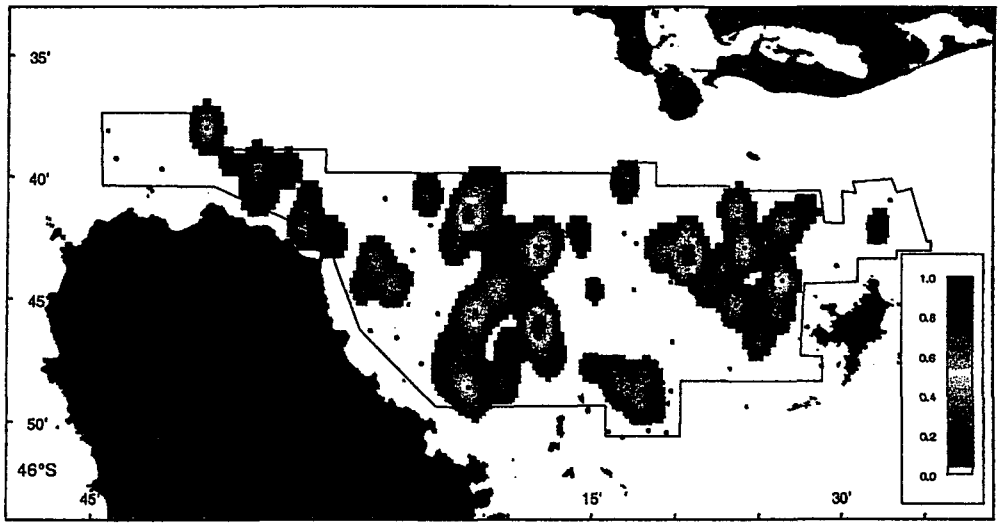

Figure A15: The smoothed density of small oysters from the 1997 Foveaux Strait oyster population survey. Location of tows marked by black dots.

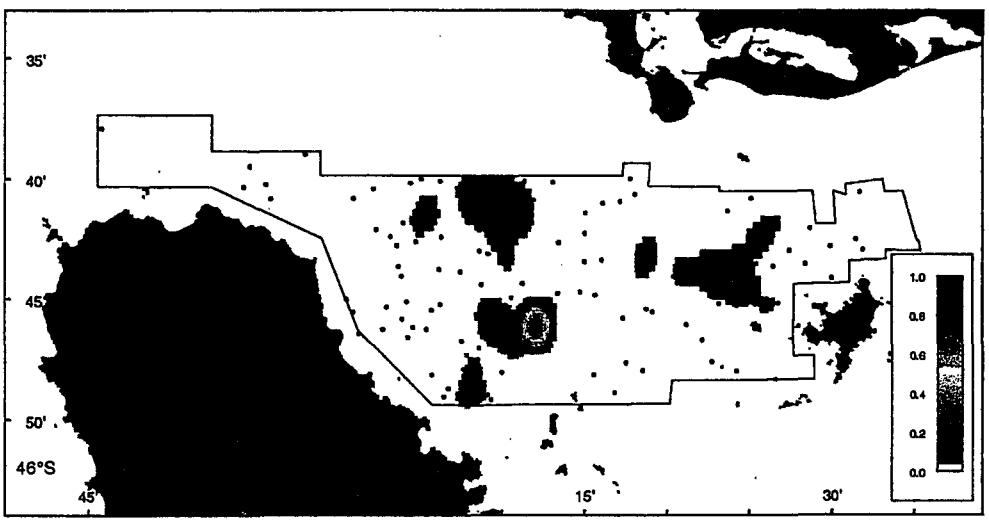

Figure A16: The smoothed density of small oysters from the 1995 Foveaux Strait oyster population survey. Location of tows marked by black dots.

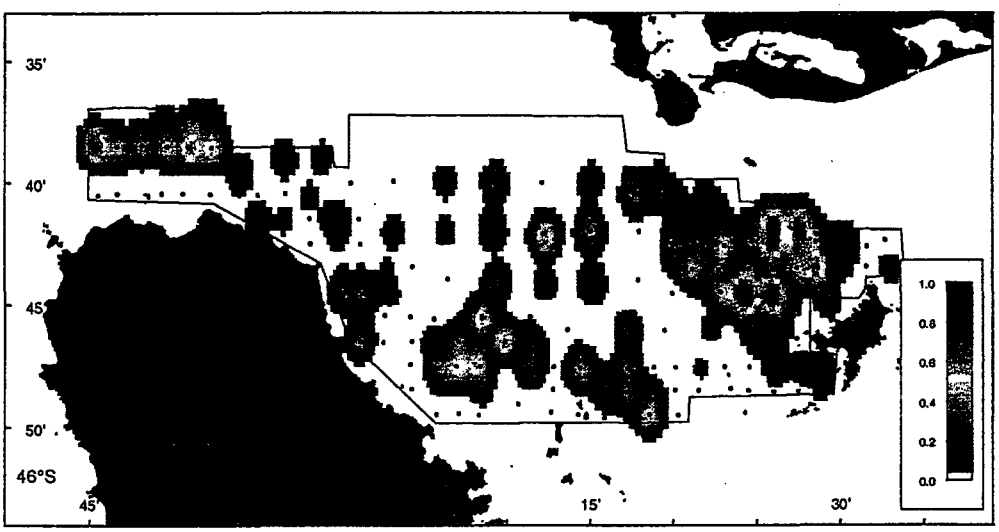

Figure A17: The smoothed density of small oysters from the 1993 Foveaux Strait oyster population survey. Location of tows marked by black dots.

Population size structure

Weighted length frequencies for all oysters sampled are shown in Figure A18.

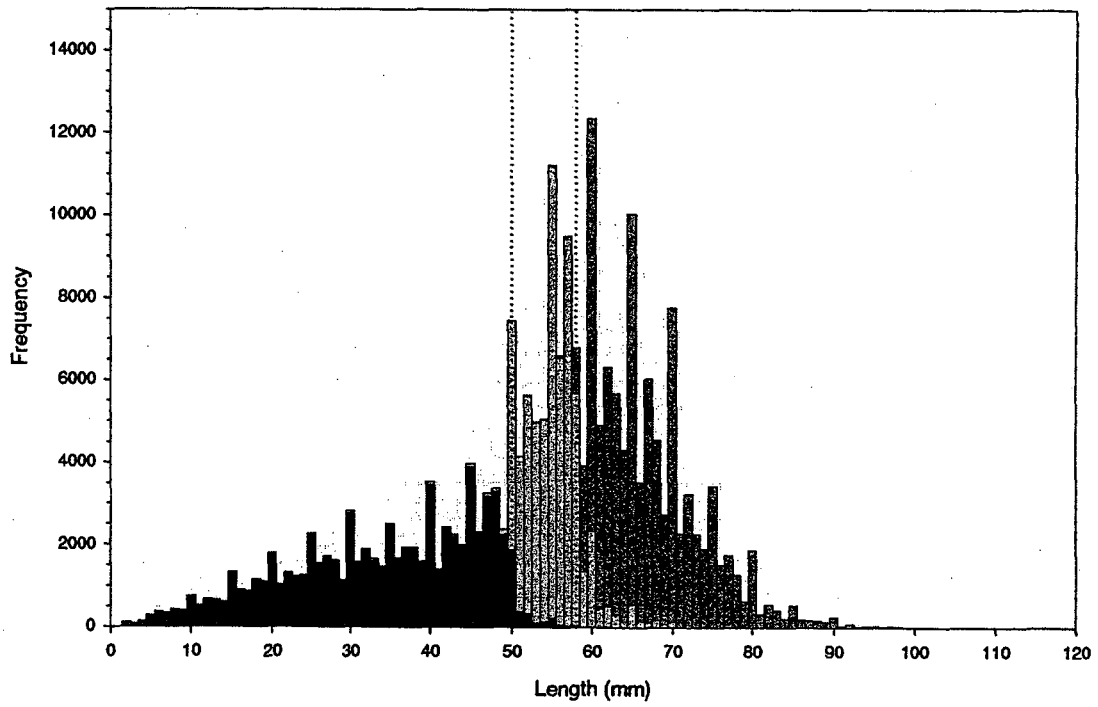

Figure A18: The weighted length frequency distribution of all oysters sampled during the October 1999 Foveaux Strait oyster survey, N = 40 594. Bar shading; black for group 0 (small oysters 10–49 mm in length), light grey for group 1 (pre recruit oysters 50–57 mm), and dark grey for group 2 (recruited oysters (≥58 mm). Vertical reference lines indicate shell lengths of 50 mm and 58 mm.

The peaks in distribution at about 5 mm intervals in Figures A18 show a strong measuring artefact, probably measurement rounding errors. There is some variation in oyster lengths assigned to the three size groups. This variation is relatively small and probably attributed to the oddly shaped oyster shells found in the oyster population.

The weighted percentage length frequency distributions of oysters sampled from commercial, exploratory, and non-commercial strata are shown in Figure A19. The proportions of recruited, pre-recruit, and small oysters for each of these strata categories are shown in Table A3.

Table A3. Percentages of recruited, pre-recruit, and small oysters sampled from commercial, exploratory and non-commercial strata, in Foveaux Strait 1999.

	Percentage of weighted length frequency by strata		
Size group	Commercial	Exploratory	Non-commercial
Recruited	47.8	27.3	49.2
Pre-recruit	19.6	24.6	17.4
Small	32.6	48.1	33.4

Commercial and non-commercial strata showed similar proportions of recruited, pre-recruit, and small oysters, but exploratory strata presumably areas that contained commercial densities in the past showed higher proportions of pre-recruit and small oysters. These strata are in the east and south of Foveaux Strait amongst the last areas where *Bonamia* caused heavy mortalities and may be rebuilding.

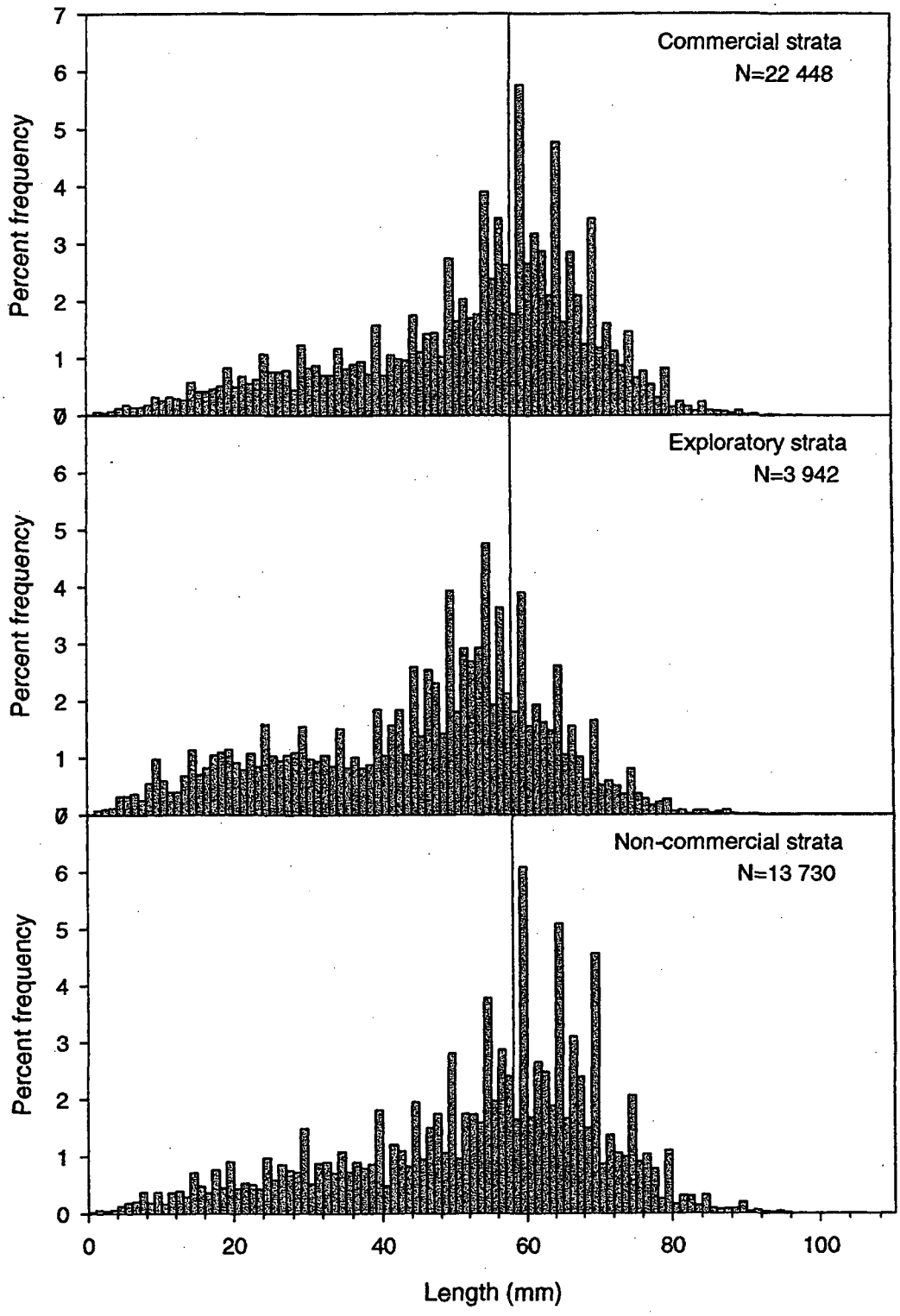

Figure A19: The percent length frequency distributions from commercial, exploratory, and non-commercial strata sampled by the 1999 Foveaux Strait oyster survey. Vertical reference lines indicate shell lengths of 58 mm.

The length weight data are shown in Figure A20. The variance in green (shell) weight for Foveaux Strait oysters is proportional to length.

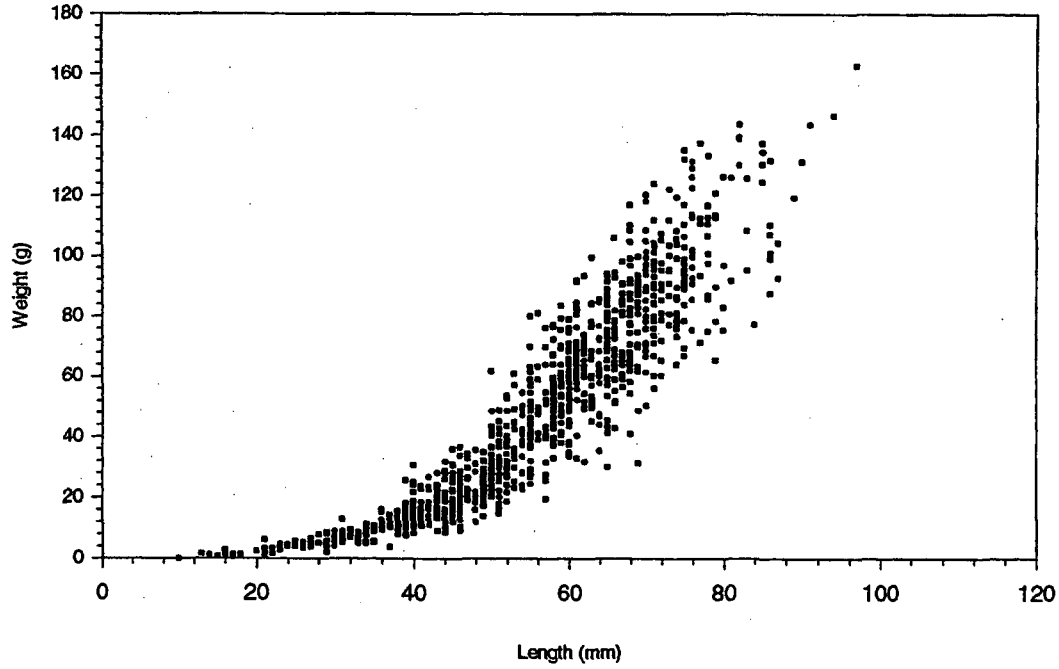

Figure A20: Length and weight for a sample of oysters collected from random tows covering the whole of the Foveaux Strait survey area, October 1999, N = 1032.

Mortality inferred from clock ratios

There were very few new clocks caught on the survey indicating low recent mortality. Cranfield et al. (1993) used the ratio of new clocks to new clocks and live oysters to indicate mortality caused by *Bonamia*. In 1999 this ratio was 0 for recruits and pre-recruits at virtually all stations sampled except Station 40, Stratum 4) which had 6% mortality.

Population size

The absolute population size of recruited oysters in Foveaux Strait in 1999 was estimated to be 1461 million (95% confidence interval 872–2334) with a c.v. of 0.16. The absolute population size of recruited oysters in the 1975–76 survey area in 1999 was 502 million (95% confidence interval 301–798) with a c.v. of 0.16. This is about 44% of the 1975–76 population estimate.

Absolute population size of recruited oysters in the commercial strata

The recruited population within commercial strata in the 1999 survey was estimated to be 275 million oysters (95% confidence interval 167–437 million).

DISCUSSION

Survey performance

The factor most likely to modify the estimate of oyster population size is the estimate of dredge efficiency, which was last calculated in 1990. The distribution of oysters, the structure of oyster beds, the substrate and epifauna, and the number of clocks are likely to have changed since then. Dredge efficiency is believed to have increased from 0.166.

Other operational factors such as tow length, weather, fullness of the dredge, and the accuracy of sizing oysters are not likely to have had an impact on the estimate of population size. The satellite differential GPS system ensured dredge tow lengths were close to the 0.2 nautical mile (370 m) standard tow length. The dredge coming fast on foul ground caused short tows.

Estimates of the absolute population size of oysters in Foveaux Strait

The survey estimated the absolute population size of recruit and pre-recruit oysters in Foveaux Strait with a c.v. of 0.16, well within the target c.v. of 0.20. The absolute population size of recruited, pre-recruit, and small oysters is continuing to increase slowly, assuming dredge efficiency has remained at 0.166 and not increased.

The recruited oyster population in the 1995 survey area has increased from 238 million in 1992 to 1186 million in 1999. The area surveyed in 1995 is 64% of the area surveyed in 1999, and contains 81% of the oyster population.

The current population in the area surveyed in 1975–76 is 502 million oysters (95% confidence interval 301–798), about 44% of the population estimated in 1975–76 and up from 9% in 1992.

The population size in the designated commercial areas (strata 1 through 6) was 275 million oysters (184–408 million). Point estimates of commercial population size for the 1995 and 1997 surveys, from the entire survey areas were 254 and 331 million oysters respectively. The portion of the population in patches greater than 400 oysters per tow, in the 1999 commercial strata (1–6) was estimated to be 235 million oysters.

Distribution of oysters in 1999

The highest densities of recruited oysters were in fishery areas 2 and the northwestern corner of 5 (see Figures 1 and 5). The commercial fishery in 2000 is likely to be based in an area of central Foveaux Strait around fishery areas 2, 4, and 5. The highest densities of pre-recruited and small oysters were found in the same areas as high densities of recruits. However, the distribution of small oysters suggests rebuilding in non-commercial areas 1 in the west and 8 in the east, but the nature and strength of this rebuilding remains poorly described.

Survey data from 1990 to 1999 suggest that dense aggregations of oysters can rebuild over time in areas where there were few oysters previously. There are some signs of rebuilding in western and eastern Foveaux Strait.

ACKNOWLEDGMENTS

This survey was carried out for the Ministry of Fisheries under project code OYS1999/01.

We thank David Fisher and Brian Sanders for supervising the survey and recording all the data. We thank Rex Ryan and the crew of FV *Toiler* for the enthusiastic and efficient way they carried out the survey. We thank Bluff Oyster Management Company staff for their assistance and support, and Dean Stotter and NIWA staff who completed measuring the size samples.

Appendix B. Survey station data form

FOVEAUX STRAIT OYSTER SURVEY, STATION DATA RECORD

Vessel name _____ Recorder .....

Date: Day | Month | Year | Time NZST | Station number

Start position: Latitude ° ' S Longitude ° ' E | Depth (m) | Speed (knots)

Finish position: Latitude ° ' S Longitude ° ' E | Dredge forward=1, aft=2

Number of Oysters ≥58 mm: Live | New clocks** | Old clocks*** | % of catch taken for size sample

Number of Oysters 50-57 mm: Live | New clocks** | Old clocks*** | Number of Oysters <50 mm: Live

% fullness of dredge including sediment | Wind force, beaufort | Did the dredge fish well Y or N

If N please repeat tow and record both tows. Use * to donate replicate after station No.

Sediment type

circle the main type (one only)

Weed	Shell	Shell/sand	Shell/gravel	Pea gravel	Sand	Silt	Sponges	Bryozoa
0	1	2	3	4	5	6	7	8

Comments: _____

1 Nautical mile = 1.853 km

** New clocks are hinged shells of recently dead oysters with no fouling inside

*** Old clocks are hinged shells of dead oysters with fouling inside

Appendix C. Length height data form

FOVEAUX STRAIT OYSTER LENGTH HEIGHT DATA RECORD

Page ___ of ___

Date

Station number | Day | Month | Year | Time NZST

Recorder .....

% of catch sampled ☐ number oys <30mm (if not all measured) ☐

Length (mm)	height (mm)	takeable 1=yes 0=no	Length (mm)	height (mm)	takeable 1=yes 0=no	Length (mm)	height (mm)	takeable 1=yes 0=no

1) Start a new form for each new station
2) Measure oysters to the nearest mm down
3) Separate oyster units by entering NAs in fields before a new oyster unit is measured. Oyster units can comprise of a single oyster large or small, to a cluster of oysters of all sizes joined together.

Appendix D. Length height and weight data form

FOVEAUX STRAIT OYSTER LENGTH HEIGHT WEIGHT DATA RECORD

Page ___ of ___

Station number | Date: Day | Month | Year | Time NZST

Recorder .....

% of catch sampled ☐ number oys <30mm (if not all measured) ☐

Length (mm)	height (mm)	takeable 1=yes 0=no	weight (g)	Length (mm)	height (mm)	takeable 1=yes 0=no	weight (g)

1) Start a new form for each new station
2) Measure oysters to the nearest mm down
3) Separate oyster units by entering NAs in fields before a new oyster unit is measured. Oyster units can comprise of a single oyster large or small, to a cluster of oysters of all sizes joined together.