MINISTRY OF FISHERIES
Te Tautiaki i nga tini a Tangaroa

ISSN 1175-1584

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New Zealand Fisheries Assessment Report 2004/14
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Published by Ministry of Fisheries
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ISSN 1175-1584

Citation:
Michael, K.P.; Dunn, A.; Diggles, B.K.; Forman, J. (2004).
Foveaux Strait dredge oyster (*Ostrea chilensis*) population and bonamia surveys, October 2002.
New Zealand Fisheries Assessment Report 2004/14. 22 p.

This series continues the informal
New Zealand Fisheries Assessment Research Document series
which ceased at the end of 1999.

EXECUTIVE SUMMARY

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The October 2002 Foveaux Strait oyster survey was a joint programme between the Bluff Oyster Management Company and NIWA. The survey was successfully completed between 16 and 29 October, sampling on 11 days at an average of 16 stations per day. Sea conditions were good for dredge sampling and all dredge tows were less than 80% full, indicating effective sampling. The operational procedure was comparable to that of previous surveys. The sampling design was similar to the 2001 oyster survey with sampling focused on the commercial areas designated by oyster skippers. Designated commercial, exploratory, and background areas were stratified with a number of small strata to spread the sampling effort more widely. Proportionately more stations than for previous surveys were allocated to exploratory and background strata to provide better information on the distribution of oysters and infection by *Bonamia exitiosus*. Of the 160 stations allocated, 155 first and second phase stations were sampled for relative oyster density to estimate population size. Five of these stations either could not be sampled in the strata or were in background areas where the time required to sample replacement stations exceeded the gain in value to the survey. Oyster samples were collected from 80 stations to determine the distribution of prevalence and intensity of infection by *B. exitiosus*.

Mortality from bonamia in 1999–2002 has reduced the size of the oyster population, oyster density, and the number of commercial fishery areas available to fishers. The population size of recruited oysters (58 mm in length and greater) of 502 million oysters (95% confidence interval 310–785 million) has been reduced to a third of the 1999 level (1461 million), pre-recruit oysters (50–57 mm in length) 520 million (333–795 million) have been reduced to a half (899 million), and the numbers of small oysters below breeding size (10–50 mm in length) have remained the same 1243 million (806–1884 million). The c.v.s of these estimates were 14%, 11%, and 10% respectively for recruit, pre-recruit, and small oysters, all below the target 20%.

The commercial population size of recruited oysters in designated commercial areas has been reduced to half that in 2001, from 295.3 million (195.3–441.5 million) to 143.7 million (93.3–216.4 million, c.v. 9%) in 2002. Over the same period, the designated commercial fishery area increased from 119.0 km^2 to 173.3 km^2, and the density in these areas decreased from 2.5 oysters/m^2 in 2001 to 0.8/m^2 in 2002.

The distribution of oyster density in designated commercial areas has decreased in the west and begun rebuilding in the east. However, the large numbers of pre-recruit oysters in some eastern areas are unlikely to recruit at the same rate as in western areas as many of these oysters have deeply cupped heavy shells typical of slow growing or stunted stocks.

The prevalence and intensity of infection by *B. exitiosus* has waned to almost background levels typical of winter, with a reduction in median prevalence from 25% in 2001 to 6% in 2002 and in the median intensity of infection from 1.8 in 2001 to 1.0 in 2002. However, *B. exitiosus* may cause further mortality in the areas of relatively high oyster density over the summer of 2002–03.

1. INTRODUCTION

The size of the oyster population and the distribution of oysters in Foveaux Strait have been estimated from stratified random dredge surveys using commercial oyster vessels at two-year intervals since 1995 (changes in the estimates of population size were more likely to be detected over two years (Annala & Sullivan 1997). These surveys estimated the size and distribution of recruit and pre-recruit oyster populations in the whole fishery area and estimate the size of the commercial population from designated commercial fishery areas, used to estimate current annual yield (CAY) for the following two years (Cranfield et al. 1996, 1998, Michael et al. 2001).

Since 1996, yield estimates have been based on estimates of commercial population size, i.e., the proportion of the recruited population that will be fished. Yield estimates 1996–99 used the portion of the population over 400 oysters per survey tow (equivalent to a commercial catch rate of 6–8 sacks per hour) from the entire Foveaux Strait oyster survey area. Yield estimates from the 2000 fishing year were based on an estimate of the entire recruited oyster population size in fishery areas designated as 'commercial' by fishers, after examination of charts and consideration of an analysis of their previous season's logbook data.

A survey in March 2000 of oyster beds near of a reported *Bonamia exitiosus* outbreak that year (Dunn et al. 2000) confirmed the presence of *B. exitiosus* infection and described the areal extent of the outbreak. Bonamia has reportedly caused significant mortality over the summers of 1999–2000 and 2000–01. The October 2001 survey also described the distribution of prevalence and intensity of infection by *B. exitiosus* to assess the effect any heightened mortality may have on the sustainability of the yield.

The October 2001 survey of the oyster population found that all areas with high densities of recruited oysters, including the designated commercial areas, had a high prevalence of infection by *B. exitiosus*. All areas also had some high intensity patches of infected oysters within or near them. The pattern of infection in March 2000 and changes in the distribution of high oyster density between 1999 and 2001 suggested some risk of heightened mortality by *B. exitiosus* over the summer of 2001–02. Two surveys of a subsample of 35 sites in designated commercial areas that were surveyed in October 2001 were completed in January and March 2002 (Dunn et al. 2002a, 2002b). These sites were sampled for changes in density of live recruit and pre-recruit sized oysters, new clocks, and the prevalence and intensity of *B. exitiosus* infection. Recent mortality caused by *B. exitiosus* infection was estimated and yield estimates updated.

The January and March 2002 surveys showed bonamia at all sites, most of which had a higher prevalence and intensity than in October 2001. By the beginning of the 2002 oyster season, mortality from *B. exitiosus* was estimated to have reduced the size of the recruited oyster population in designated commercial areas to about 40–65% of the estimated population size in October 2001. Estimated yields based on the estimate of commercial population size from the October 2001 survey ranged from 21 to 70 million oysters, the range of 95% confidence intervals for yields estimated with M of 0.020, 0.042, and 0.100. Yields based on the revised estimates of the commercial population size in March 2002 were between 8 and 45 million oysters (Dunn et al. 2002a). *B. exitiosus* was expected to cause further mortality in the future.

The 2002 oyster season was the first since the fishery was reopened in 1996 in which the catch limit of 14.95 million oysters was not caught: total landings were 13.77 million. Mean catch rate for the fishery, 3.2 sacks per hour (s.e. 0.05) was similar to 3.4 sacks per hour in 1992 (Annala & Sullivan 1997) when the fishery was closed. A survey of the Foveaux Strait oyster population was planned for October 2002 to estimate the yield in designated commercial areas for 2003.

The Foveaux Strait dredge oyster strategic research plan 2000–2004 proposed to develop a length-based population model for Foveaux Strait oysters, incorporating mortality from *B. exitiosus* and the effects of fishing-induced habitat changes (Andrew et al. 2000). Since the 2000 *B. exitiosus* epizootic began, research programmes have provided some understanding of the biology and epidemiology of *B. exitiosus* (Dunn et al. 2000, 2002a, 2002b, Diggles & Hine 2002). An understanding of the mechanics of disease transmission through oyster populations and an estimate of the annual mortality of oysters from *B. exitiosus* infection and its relationship with the fishery are of particular importance in developing a disease model. A research proposal for the Foveaux Strait oyster fishery (Michael et al. 2002) recommended research options for the 2002–03 year. Based on this advice, the Bluff Oyster Management Company agreed to carry out a survey of the Foveaux Strait oyster population and the prevalence and intensity by *B. exitiosus* in October 2002.

We present the results of a survey carried out in October 2002. This survey used a similar design and the same operational procedures as the survey of Foveaux Strait oysters in October 2001. The survey estimated numbers of recruited oysters and pre-recruit oysters to monitor the response of the population to increased mortality from *B. exitiosus* and to estimate the annual mortality caused by the epizootic. We investigated the distribution of the prevalence and intensity of infection to describe the annual cycle of mortality from *B. exitiosus* and to determine whether significant mortality was likely to occur between the end of the survey and the beginning of the 2003 oyster season.

2. OBJECTIVES

The survey had two objectives.

1. To survey the distribution and absolute abundance of pre-recruit and recruited oysters in designated commercial and non-commercial areas of Foveaux Strait in October 2002.

2. To map the distribution of the prevalence and intensity of infection by *Bonamia exitiosus* in oysters.

3. METHODS

3.1 Survey design

The October 2002 oyster survey used a similar design to the October 2001 survey. Skippers of oyster boats designated commercial and non-commercial fishery areas and the extent of the survey area, based on information collected in the 2002 fisher's logbooks (see Figure 3, Section 3.3.1). The survey effort was split between the designated commercial fishery areas, the non-commercial fishery areas, and the background area. The background area was stratified to spread sampling more evenly over the entire area surveyed.

A two-phase stratified random dredge survey was used to sample commercial strata only. Commercial strata were allocated 77 first-phase and 16 second-phase stations of the 160 survey stations available. The variance in oyster density in commercial strata was likely to be low and, therefore, the allocation of the number of stations per strata was proportional to the area of each stratum. Allocation of second-phase stations in the commercial strata was based on the estimates of mean density in each stratum after the first-phase sampling was completed (Francis 1984). Exploratory and non-commercial strata were surveyed in a single phase. Non-commercial strata were allocated 42 stations and exploratory strata 21 stations.

The randomly selected stations were generated with exclusion zones to avoid spatial correlation of catches and to spread stations throughout the strata. Sufficient random stations were generated in each stratum for both first-phase and second-phase stations.

3.2 Operational procedure

Sampling followed the same procedures as previous surveys 1990–2001 (Cranfield et al. 1999, Michael et al. 2001). The FV Golden Lea, a commercial oyster vessel sampled survey stations towing a standard commercial dredge (3.35 m wide). The vessel used a differential GPS receiver to ensure a precision of navigation of less than 1 m. NIWA staff ensured consistency of procedures.

3.2.1 Navigation

This survey used satellite-derived differential GPS position fixing. Differential corrections from a Dodici Omnistar DGPS receiver were interfaced to a Furuno GP-31 receiver by cable using NMEA 0183 data format. The vessel's Furuno GP30 connected to a Furuno 1250 plotter could be interfaced to the Omnistar to provide a back-up system if required. NIWA staff installed the differential GPS system and directed the navigation during sampling.

3.2.2 Station selection

All first-phase stations in the designated commercial strata were sampled first. Checks were made of all station positions for proximity to stratum boundaries to ensure they were sampled in the correct stratum. At the completion of the first-phase sampling, the dynamic allocation of second-phase stations was made from the numbers of recruit size oysters at each station using the methods of Francis (1984) on an Excel spreadsheet. Second-phase stations were allocated in their order on the station lists. As many as possible of the second-phase stations were sampled (or where stations could not be sampled, were reallocated in the same stratum).

3.2.3 Survey tows

Survey tows were started on the station position given where possible. Where the start of tow could not be made on position (because of weather, tide, or boundary constraints), the tow direction was reversed and the tow finished on that position.

Straight-line tows (compared with elliptical commercial tows) were made down tide for a distance of 0.2 nautical mile (370 m) at each station. The start of tow was taken from when the winch brake was applied and tension came on to the warp. The man overboard function on the DGPS receiver was used to enter the start of tow position and to measure distance towed. Once the dredge had travelled 0.2 nautical mile, the end of tow position was taken, the winch brake release and the dredged hauled aboard without washing. Start and finish positions were recorded on a station data record form and the waypoints recorded in the Furuno GP-31 GPS receiver memory saved to file to provide a backup.

Tows that could not be dredged because of foul ground were reallocated to the next available station on the station list and given a new station number. Tows were repeated with the same station number when the dredge became tangled or the dredge did not fish properly. Any time the dredge was landed more than 75% full the tow was repeated with a 0.1 nautical mile tow in the same position with the same station number. Tows were not repeated when the dredge was landed less than 75% full, but mainly filled with kaeos (*Pyura pachydermatina*) or weed or when the tow was completed before the dredge came fast.

3.2.4 Sorting the catch

The dredges were landed unwashed to avoid the loss of small oysters and benthic fauna and catches were photographed with a digital camera. The catch from each survey tow was sorted into live oysters, gapers (moribund oysters containing the whole oyster and valves remaining apart after the adductor muscle has lost its ability to contract), new clocks (articulated shells of oysters which have died since the last summer and have glossy inner valves with no fouling organisms), and old clocks (articulated shells of oysters which have died 1–3 years ago and have fouling organisms on their inner valves). The catch was further sorted into two size groups: recruit (unable to pass through a 58 mm internal diameter ring) and immediate pre-recruits (able to pass through a 58 mm internal diameter ring, but unable to pass through a 50 mm ring). Live oysters were sorted into a third size group, small oysters (able to pass through a 50 mm internal diameter ring down to 10 mm in length). Reference rings (58 mm and 50 mm internal diameter) were used to ensure accurate allocation to each size group. NIWA staff supervised the sampling and recorded all survey data.

Randomly selected samples of 30 recruit sized oysters for bonamia investigations were taken from the catch at 80 stations. When there were insufficient oysters in the catch, the whole catch was sampled. Samples were bagged and labelled with station number, date, and time on waterproof labels and the sacks tied securely. The oysters for bonamia samples were kept cool and wet in oyster sacks, transferred to poly bins, and flown to Greta Point, Wellington for processing.

3.2.5 Processing of bonamia samples, heart imprints, and histology protocols

Oyster samples generally arrived in Wellington within 36 hours of capture and were processed on the day they arrived. The samples were held in poly bins under cool conditions (about 12 °C in the aquarium). If they could not be processed the day they arrived, they were held in tanks of flowing seawater and processed at the first opportunity.

Station and sample data were recorded on bonamia sampling forms and the total numbers of live and dead oysters in the samples noted. Twenty-five recruit sized oysters were selected from the sample for heart imprints. Each oyster was assigned a number from 1 to 25, a size category, and measured for length and height (Figure 1) to the nearest millimetre down using callipers. If there were insufficient recruit sized oysters, pre-recruits and small oysters were included in the samples. Each oyster was assigned to a size category using oyster size rings (see Section 3.2.4). Recruit size oysters were denoted with an R, pre-recruit oysters with P, and small recruit oysters with an O. Gaping oysters with valves of the shell apart but closed when tapped were marked by with an asterisk alongside the corresponding oyster number. The first five oysters from each sample were selected for histology (as well as heart imprints).

Heart imprints were made by removing the heart (dark organ adjacent to adductor muscle, see Figure 2) with fine forceps, draining excess water and fluid on filter paper for a moment, and lightly dabbing the heart on a slide to deposit a small amount of haemolyph. Three rows of 8 to 10 imprints were made on labelled slides. Slides were placed in slide racks to air dry for at least 5 minutes. The slides were stained with Hemacolor © and oven dried at 60 °C.

The five oysters for histology were selected from those that had their hearts removed, and a 5 mm thick standard section was cut through the major organs (Figure 2) and placed in the histology cassettes. The corresponding oyster number was recorded on the cassette. The section was fixed in at least 5 volumes of 10% formalin in filtered seawater for histology and archived.

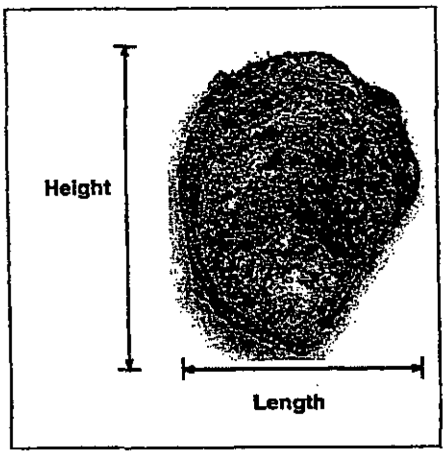

Figure 1: An oyster showing length (anterior-posterior axis) and height (dorsal-ventral axis) dimensions.

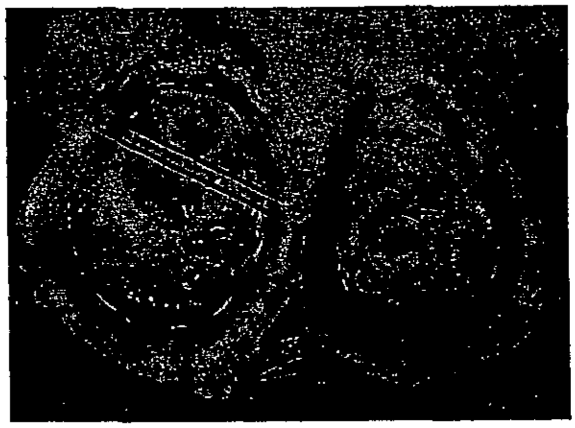

Figure 2: Lines on left oyster show location of 5 mm thick standard section taken for histology. The arrow on the oyster on the right shows the heart, a black organ adjacent to the adductor muscle.

3.3 Analysis

3.3.1 Estimating population size

We can estimate absolute abundance and variance from stratified random sampling theory (Jolly & Hampton 1990, Barnett 1991) assuming a mean dredge efficiency, estimated in 1990, of 0.17 (95% confidence intervals 0.13–0.22). The original estimate of Doonan et al. (1994) was 0.16. We assume that the areas of patches of commercial densities are known without error, and present estimates of population size for the designated commercial and non-commercial areas separately (Figure 3).

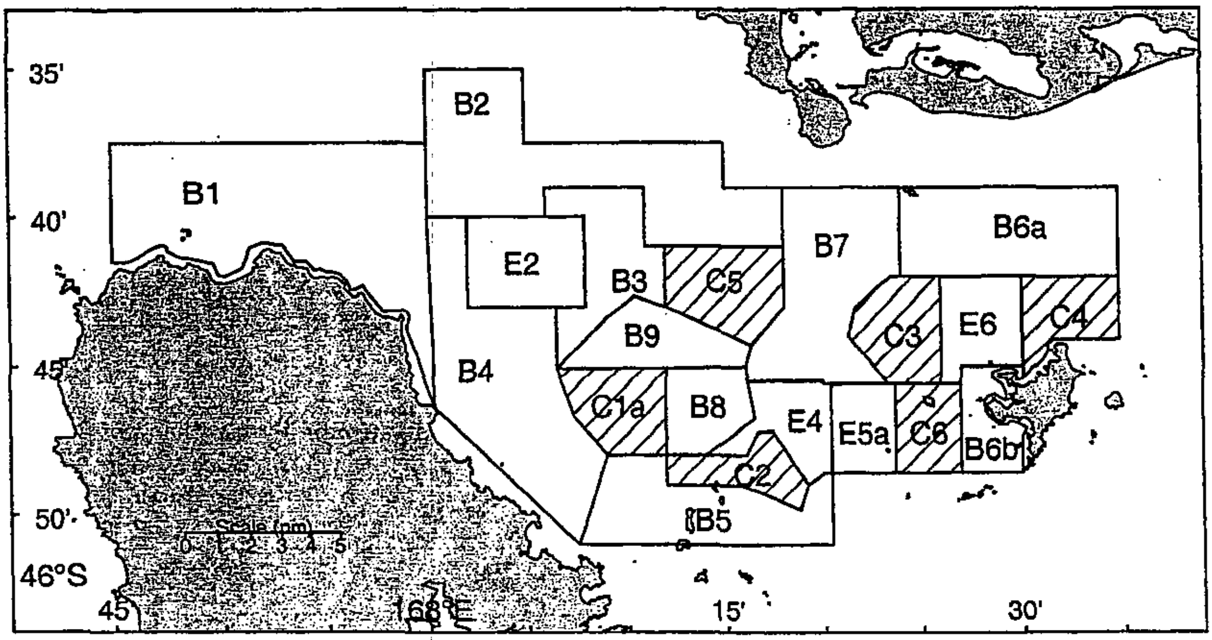

Figure 3: The area and stratifications used for the October 2002 survey. Strata designated commercial are defined by the hashed region and "C" prefix. Exploratory strata are prefixed "E" prefix, and background strata prefixed "B".

Similarly, an estimate of the number of pre-recruits and recruits are presented separately.

The variance of the population size was estimated by bootstrapped error of the estimated dredge efficiency (Cranfield et al. 1998) and the estimated relative population size, 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.

3.3.2 Analysis of oyster heart imprint data

Examination of heart imprints is at least as sensitive as histology, but whereas histology is time consuming and expensive, heart imprints can be screened rapidly and are comparatively inexpensive. The correlation studies with in situ hybridisation have shown that the prevalence estimated from heart imprints can underestimate the true infection rate by about 10–20% (Diggles & Hine 2002). All histology samples will be archived at NIWA, and will be available for future work.

Samples to determine the prevalence and intensity of *Bonamia exitiosus* from heart imprints were taken from 80 stations over the entire survey area (Figure 4). The samples of 25 oysters give an 80% chance of detecting the prevalence of infection by *B. exitiosus* down to 10%.

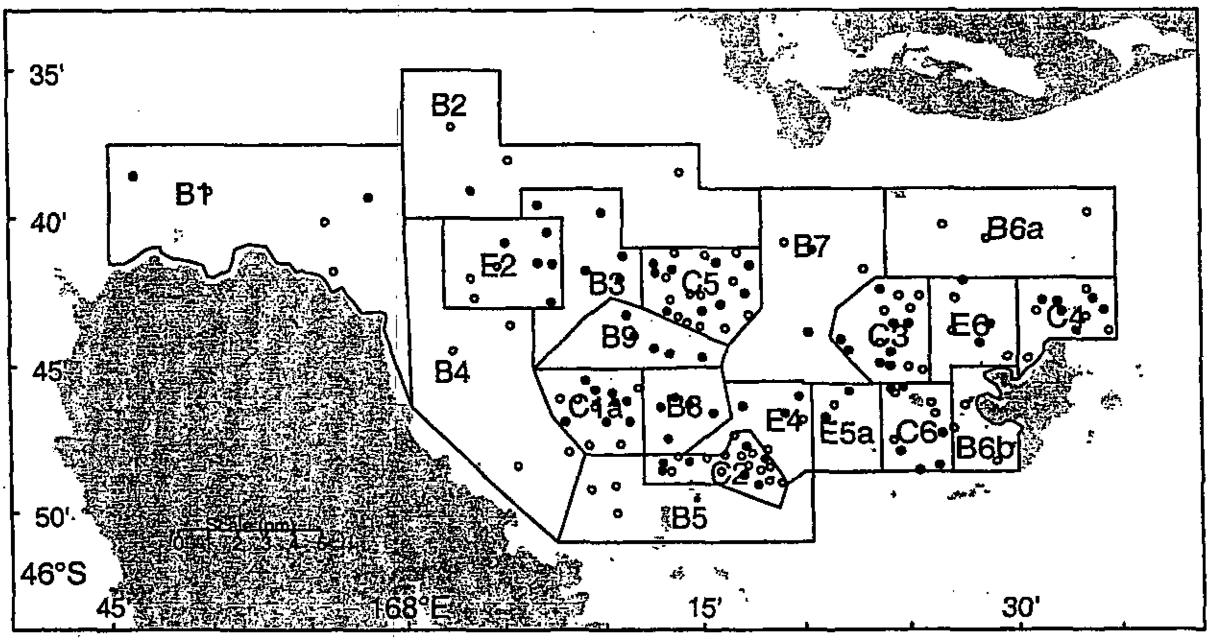

Figure 4: The survey stations sampled in October 2002: open circles are stations sampled to estimate the size of the oyster population; filled circles were also sampled for bonamia.

Oyster heart imprints were examined under a microscope using a x50 objective under oil and scored for intensity of infection using the criteria in Table 1. Three good heart imprints containing oyster haemocytes were located and examined on each slide, and the number of *B. exitiosus* cells counted for each.

Table 1: Criteria used to stage intensity of infection from *Bonamia exitiosus* in oysters.

Stage	Category of infection
0	Not infected.
1	One *B. exitiosus* observed after examining an imprint.
2	More than 1, but less than 10, *B. exitiosus* observed after examining an imprint.
3	More than 10 *B. exitiosus* present in the imprint, but few parasites in each haemocyte.
4	*B. exitiosus* present in many haemocytes of each imprint, and many parasites in each haemocyte.
5	*B. exitiosus* present in nearly all haemocytes of each imprint, many parasites in each haemocyte and extracellularly.

Previous correlation studies with histopathology (NIWA, unpublished data) suggest that stages 1 and 2 are relatively light infections and do not appear to affect the health of the host. Stage 3 infections are elevated and systemic, with minor tissue damage throughout the host. It appears likely they will progress to stage 4. Stage 4 infections are systemic and all tissues are congested with infected haemocytes; death appears inevitable. Stage 5 infections differ from those of stage 4 in that tissue damage is extreme throughout the animal, tissues have lost their integrity, and the oyster is near death. We assume that category 0 oysters are not infected. However, heart smears can underestimate *B. exitiosus* prevalence by up to 30%, particularly in light infections (Diggles & Hine 2002).

For each station, prevalence is defined as the proportion of oysters in a sample with at least one *B. exitiosus* cell observed (i.e., the number of stage 1–5 oysters divided by the number of all oysters examined in the sample). Mean intensity is defined as the mean frequency of stage 1–5 oysters (i.e., the mean stage of all oysters examined that had at least one *B. exitiosus* cell observed). The inclusion of the additional smaller oysters at sites where few recruited oysters were caught is likely to introduce a bias to estimates of prevalence and intensity of infection. Sites where additional small-sized samples were included were distant from the focal point of the infection and had low densities of recruits — so any such bias is likely to be small. Exact 95% confidence intervals are given for prevalence and for the proportion of new clocks, determined from the *F*-distribution, i.e., for a proportion π, where $\pi = r/n$, (where r is the number of oysters infected with *B. exitiosus* and n the number of oysters in the sample, the 95% confidence interval is determined by

$$\pi_{0.025} = \frac{r}{r+(n-r+1)F_{0.025,2n-2r+2,2r}}$$

$$\pi_{0.975} = \frac{r+1}{r+1+(n-r)F^{-1}_{1-0.975,2r+2,2n-2r}}$$

3.3.3 The distribution of oysters and spread of *Bonamia exitiosus*

Kriging (Ripley 1977, Cressie 1991) was used to estimate oyster population density and *B. exitiosus* infection density surfaces, and thus to determine the spread of *B. exitiosus* over the oyster population.

4. RESULTS

4.1 Survey operational detail

Sampling began on 16 October and was completed by 29 October; sampling took place on 11 days. On average, 16 stations were sampled each day. The low catches of oysters, the efficiency gained in culching the catch using a fourth crew member, and the reduced sampling compared to previous surveys increased the sampling efficiency. Of the 160 stations allocated, 155 first and second phase stations were sampled for relative oyster density to estimate population size (Table 2). Oyster samples were collected from 80 stations for bonamia investigations. Where possible, tows that could not be sampled because of foul ground were reallocated in the same strata. Five stations could not be either sampled in the strata or were in background areas where the time required to sample a replacement station exceeded the gain in value to the survey. Survey strata are shown in Figure 1 and dredge tow start positions in Figure 2. The survey data are held on the Foveaux Strait dredge oyster database at NIWA Greta Point, Wellington.

Table 2: The number of first and second phase stations sampled in each stratum from the October 2002 Foveaux Strait oyster survey. Commercial strata prefixed "C"; exploratory strata prefixed "E"; background prefixed "B".

Stratum	No. 1st phase	No. 2nd phase	Stratum	No. 1st phase	Stratum	No. 1st phase
C1a	14	0	E2	8	B1	5
C2	10	10	E4	5	B2	4
C3	15	0	E5a	3	B3	5
C4	11	0	E6	6	B4	4
C5	16	6			B5	3
C6	10	0			B6a	3
					B6b	3
					B7	4
					B8	5
					B9	5
Total	76	16		22		41

The satellite differential GPS system provided navigation accuracy to less than 1 m most of the time. Dredge tow lengths were closely clustered around the 0.2 nautical mile (370 m) standard tow length (Figure 5). Most of the survey stations were sampled in light wind conditions; the median wind force was 4 on the Beaufort scale (11–16 knots), with 5 and 95 percentiles of Beaufort scale 1 (1–3 knots) and 6 (22–27 knots) respectively (Figure 6). These wind and resulting sea conditions were mostly below the level likely to affect dredge efficiency. Oyster dredges are considered saturated and cease 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 at that station. All dredge tows were landed less than 65% full (Figure 7), suggesting sea conditions and dredge saturation had minimal effect on sampling effectiveness and the survey.

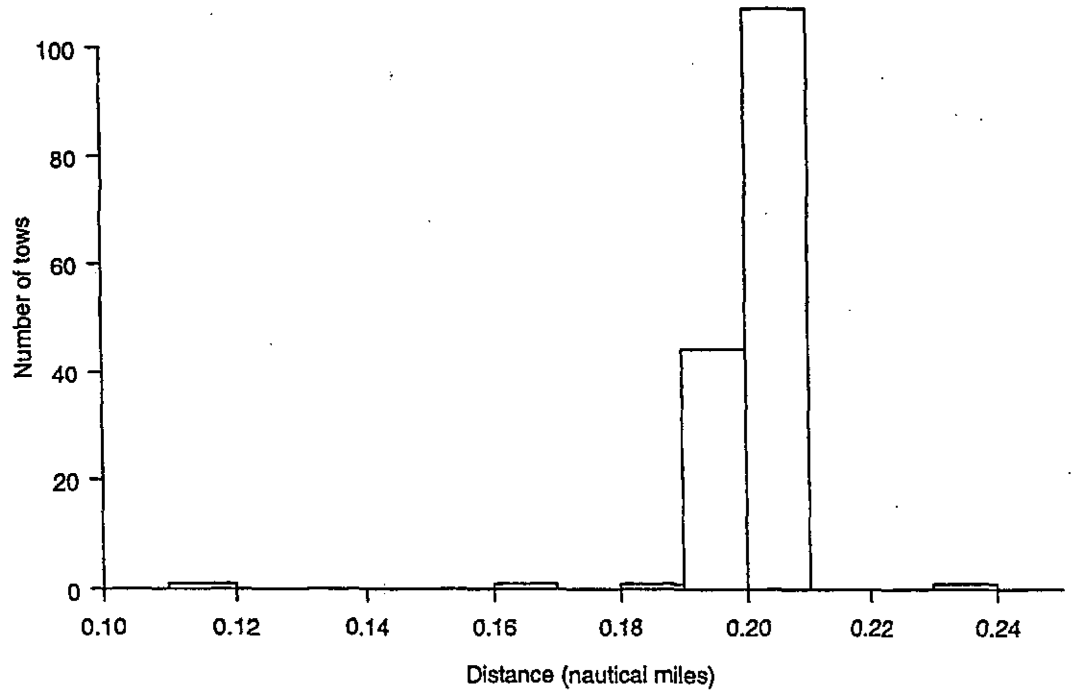

Figure 5: A histogram of tow lengths sampled on the October 2002 survey. The standard tow length was 0.2 nautical mile (370 m).

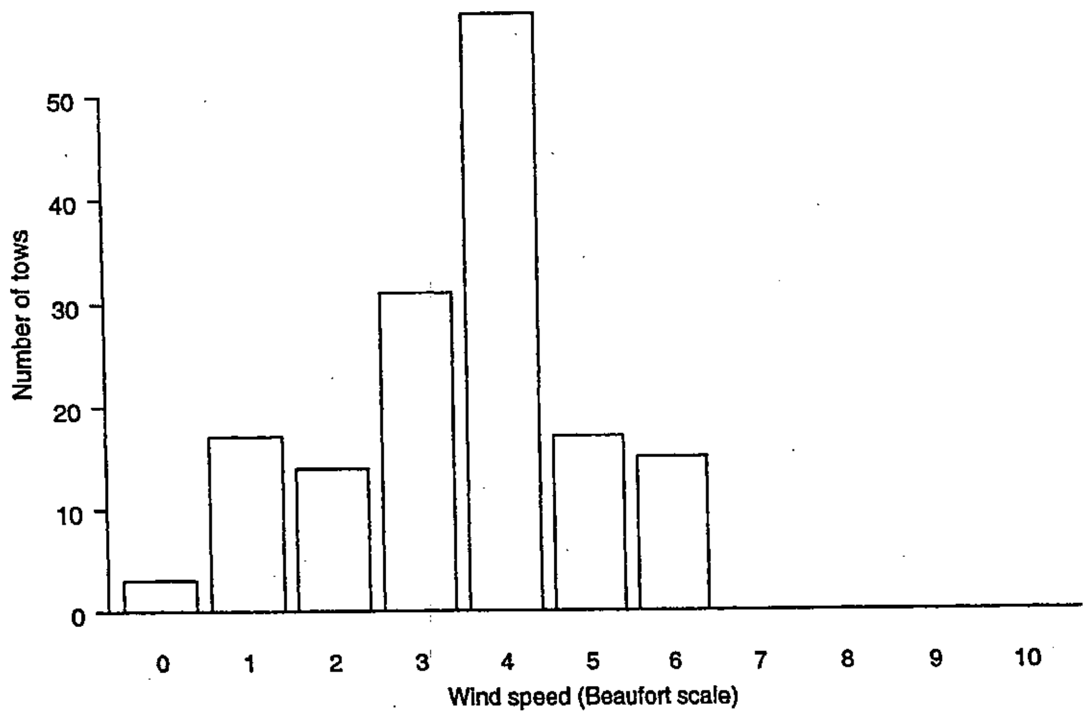

Figure 6: A histogram of wind speed (Beaufort scale) recorded during survey tows on the October 2002 survey.

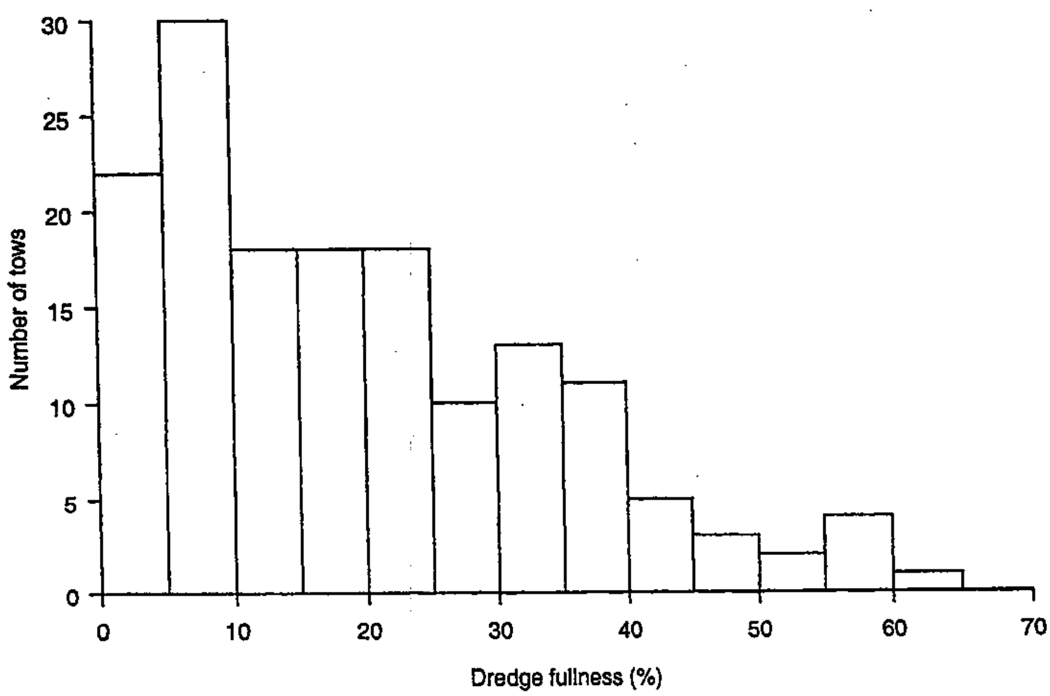

Figure 7: A histogram of dredge fullness recorded for survey tows on the October 2002 survey. Dredge tows landed greater than 80% full are considered to have saturated during the tow underestimating oyster density.

4.2 Estimates of absolute population size

Absolute population estimates for recruit, pre-recruit, and small oysters were estimated with c.v.s of 14%, 11%, and 10% respectively, well below the 20% target. The estimates by stratum are given in Tables 3–5 and comparisons between the 1999, 2001, and 2002 estimates for Foveaux Strait are given in Table 6. The population size of recruited oysters has been reduced to a third of the 1999 level (502 million in 2002 compared with 1461 million in 1999); pre-recruit oysters have been reduced to a half (520 million) and the numbers of small oyster below breeding size (under 50 mm long) have remained the same (1250 million). These small oysters do not appear to be as vulnerable to mortality from infection by *B. exitiosus* as breeding size oysters.

Table 3: Absolute population estimate for recruited oysters (≥ 58 mm long): 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 for the October 2002 Foveaux Strait oyster survey.

					Population estimates (millions) and stratum areas			
Stratum	No. stations	Mean density	Density s.d.	c.v.	Mean population	Lower 95% CI	Upper 95% CI	Area km^2
B1	5	0.13	0.07	0.51	21.08	0.00	46.79	160.61
B2	4	0.12	0.09	0.77	15.81	0.00	43.73	131.00
B3	5	0.53	0.33	0.63	23.51	0.00	58.51	44.67
B4	4	0.09	0.02	0.21	10.66	5.60	18.07	112.40
B5	3	0.77	0.65	0.84	49.00	0.00	143.50	63.67
B6a	3	0.03	0.02	0.74	1.99	0.00	5.38	77.12
B6b	3	0.67	0.22	0.32	13.31	4.79	25.25	19.83
B7	4	0.73	0.38	0.53	62.74	0.00	141.81	86.13
B8	5	1.44	0.32	0.22	38.72	19.83	65.77	26.84
B9	5	0.27	0.06	0.21	9.19	4.90	15.49	34.45
C1a	14	0.89	0.24	0.27	27.71	12.16	49.44	31.27
C2	20	1.16	0.21	0.18	25.37	14.23	41.45	21.91
C3	15	0.68	0.12	0.17	22.11	12.67	36.11	32.73
C4	11	0.63	0.16	0.25	16.51	7.51	28.90	26.29
C5	22	1.08	0.18	0.17	40.53	23.84	65.56	37.62
C6	10	0.49	0.23	0.47	11.44	0.94	24.80	23.52
E2	8	0.48	0.12	0.25	20.43	9.68	35.41	42.83
E4	5	0.51	0.39	0.76	14.27	0.00	39.88	28.03
E5a	3	1.15	1.00	0.87	27.16	0.00	80.56	23.52
E6	6	1.69	0.63	0.37	50.57	13.17	100.16	29.97
All	155	0.48	0.06	0.14	502.11	309.59	785.06	1054.42

Table 4: **Absolute population estimate for pre-recruited oysters (50–57 mm long): 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 for the October 2002 Foveaux Strait oyster survey.**

						Population estimates (millions) and stratum areas		
Stratum	No. stations	Mean density	Density s.d.	c.v.	Mean population	Lower 95% CI	Upper 95% CI	Area km^2
B1	5	0.08	0.02	0.29	12.98	5.16	23.45	160.61
B2	4	0.08	0.04	0.44	10.73	1.73	22.48	131.00
B3	5	0.55	0.36	0.66	24.72	0.00	63.35	44.67
B4	4	0.08	0.02	0.24	8.86	4.38	15.35	112.40
B5	3	0.24	0.15	0.63	14.98	0.00	37.50	63.67
B6a	3	0.07	0.06	0.86	5.10	0.00	15.02	77.12
B6b	3	1.03	0.35	0.34	20.42	6.86	39.24	19.83
B7	4	1.29	0.41	0.32	110.71	39.80	208.11	86.13
B8	5	0.97	0.32	0.33	26.15	8.97	49.06	26.84
B9	5	0.16	0.04	0.23	5.36	2.68	9.24	34.45
C1a	14	0.42	0.11	0.27	13.04	5.68	23.32	31.27
C2	20	0.82	0.13	0.15	17.99	10.60	28.83	21.91
C3	15	2.21	0.39	0.18	72.45	41.49	118.40	32.73
C4	11	0.53	0.22	0.41	14.06	2.58	28.75	26.29
C5	22	1.19	0.19	0.16	44.62	26.42	71.77	37.62
C6	10	0.71	0.31	0.44	16.68	2.48	35.02	23.52
E2	8	0.28	0.10	0.35	11.84	3.48	22.78	42.83
E4	5	0.23	0.15	0.66	6.40	0.00	16.52	28.03
E5a	3	0.87	0.76	0.87	20.55	0.00	60.88	23.52
E6	6	2.06	0.87	0.42	61.87	10.94	128.29	29.97
All	155	0.49	0.05	0.11	519.51	332.88	795.10	1054.42

Table 5: Absolute population estimate for small oysters (10–49 mm long): 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 for the October 2002 Foveaux Strait oyster survey.

					Population estimates (millions) and stratum areas			
Stratum	No. stations	Mean density	Density s.d.	c.v.	Mean population	Lower 95% CI	Upper 95% CI	Area km^2
B1	5	0.50	0.30	0.59	80.83	0.00	192.25	160.61
B2	4	0.42	0.12	0.30	54.68	21.84	100.28	131.00
B3	5	1.22	0.43	0.36	54.36	15.28	106.31	44.67
B4	4	0.15	0.02	0.15	17.33	10.51	27.55	112.40
B5	3	0.34	0.21	0.63	21.43	0.00	53.80	63.67
B6a	3	0.42	0.32	0.76	32.69	0.00	90.06	77.12
B6b	3	2.07	0.75	0.36	41.02	11.69	80.98	19.83
B7	4	2.69	0.70	0.26	231.94	106.53	411.16	86.13
B8	5	1.17	0.38	0.32	31.41	11.04	58.69	26.84
B9	5	0.33	0.08	0.25	11.53	5.48	20.27	34.45
C1a	14	0.27	0.06	0.22	8.38	4.27	14.27	31.27
C2	20	0.80	0.12	0.15	17.51	10.41	28.00	21.91
C3	15	8.80	1.31	0.15	287.99	173.43	459.59	32.73
C4	11	0.59	0.21	0.35	15.59	4.53	30.00	26.29
C5	22	2.01	0.28	0.14	75.52	46.68	118.71	37.62
C6	10	2.08	0.62	0.30	49.01	19.44	89.92	23.52
E2	8	0.65	0.14	0.21	27.97	14.78	46.74	42.83
E4	5	0.64	0.35	0.55	17.84	0.00	41.74	28.03
E5a	3	0.57	0.41	0.73	13.38	0.00	35.72	23.52
E6	6	5.08	2.08	0.41	152.27	30.19	312.35	29.97
All	155	1.18	0.11	0.10	1242.69	806.47	1883.87	1054.42

Table 6: Population estimates of oysters (millions) within the area of Foveaux Strait surveyed in 1999 (1054 km^2). 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.

Survey	Recruits	Pre-recruits	Small
1999 (October)	1 461 (872–2 334)	899 (570–1 387)	1 373 (874–2 115)
2001 (October)	995 (632–1 511)	871 (548–1 330)	1 410 (884–2 156)
2002 (October)	502 (310–785)	520 (333–795)	1 243 (806–1 884)

4.3 Estimates of commercial population size

The population of recruited oysters in the designated commercial fishery areas (see Figure 3) was estimated with a c.v. of 9% in 2002. The mean commercial population size in 1999–2001 is shown in Table 7. The population size of recruited oysters in designated commercial fishery areas has halved since 2001, the size of designated commercial fishery areas has increased by half, and the density of oysters within them reduced to a third. Commercial population estimates by stratum (prefixed "C") are given in Table 3.

Table 7: The population estimates for recruited oysters (≥ 58 mm long) in designated commercial areas 1999–2001: Year in which the October survey was completed; the number of stations sampled (No. stations), the mean oyster density per m² (mean density), standard deviation (s.d.) of the density estimate, coefficient of variation (c.v.) of the population estimate, mean population size (Mean population with upper and lower 95% confidence intervals in parenthesis), and the area of each survey.

Year	No. stations	Mean density	s.d.	c.v.	Mean population	Area km²
1999	135	2.41	0.36	0.16	275 (184–408)	103
2001	103	2.48	0.18	0.07	295 (196–441)	119
2002	92	0.83	0.08	0.09	144 (93–216)	173

4.4 Distribution of oysters

Data on the distribution of oyster density from the October 2002 Foveaux Strait oyster survey were summarised using the same method as for previous surveys. The estimated kriged densities of recruited, pre-recruit, and small oysters from the October 2002 survey are shown in Figures 8–10. The estimated kernel densities (Ripley 1977) of oysters from the 2002 fishers' logbooks are shown in Figure 11. The size of the designated commercial fishery area has increased by two-thirds since 1999, but the size and number of patches of oysters of relatively high densities have decreased markedly and their distribution has changed. Designated commercial areas have decreased in central western Foveaux Strait and begun rebuilding in the east. However, the higher density pre-recruit oysters in eastern areas C3 and E6 are unlikely to recruit at the same rate as in western areas as many of these oysters have deeply cupped, heavy shells typical of slow growing or stunted stocks.

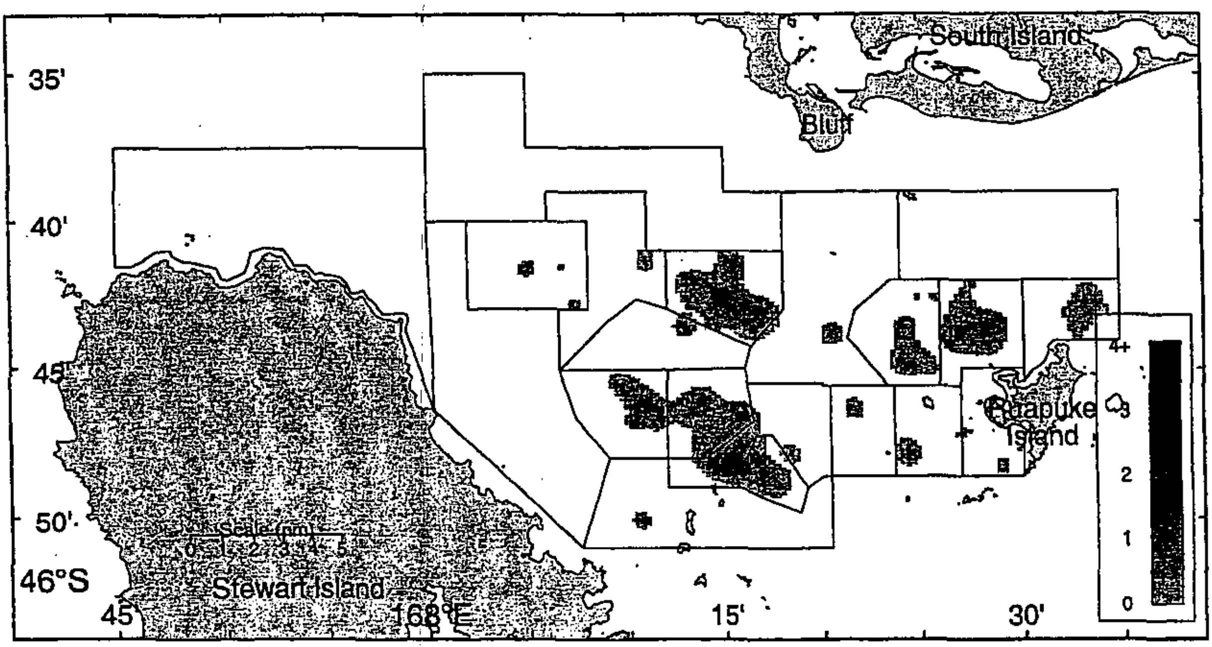

Figure 8: Estimated (kriged) density of live recruited oysters (oysters per m²) from the October 2002 survey.

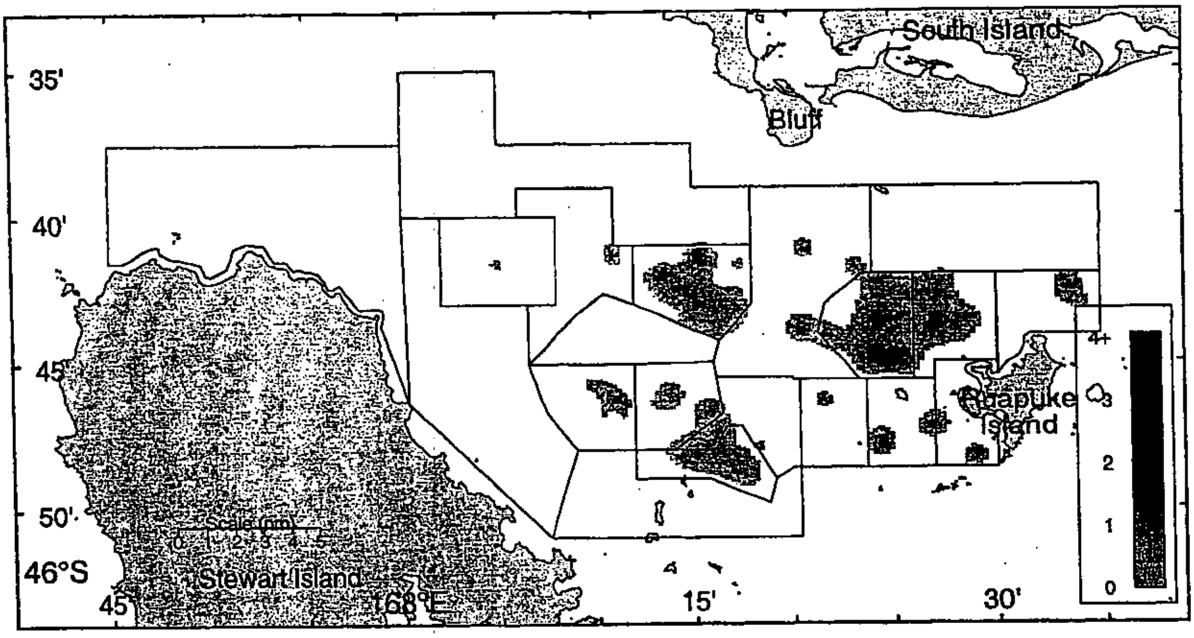

Figure 9: Estimated (kriged) density of live pre-recruited oysters (oysters per m^2) from the October 2002 survey.

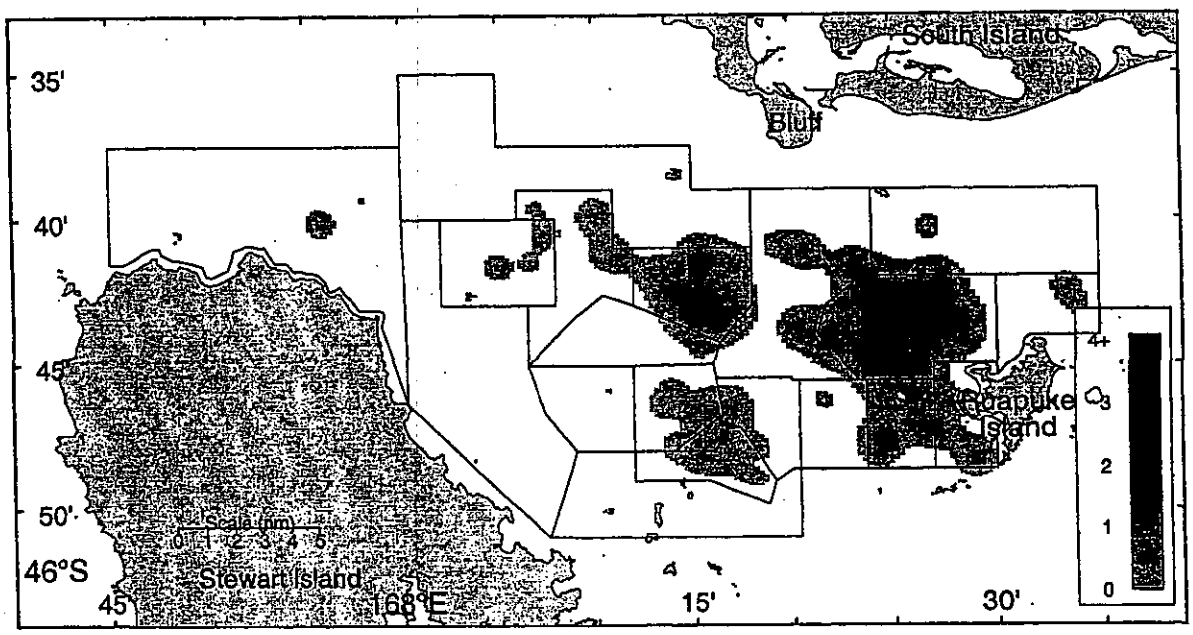

Figure 10: Estimated (kriged) density of live small oysters (oysters per m^2) from the October 2002 survey.

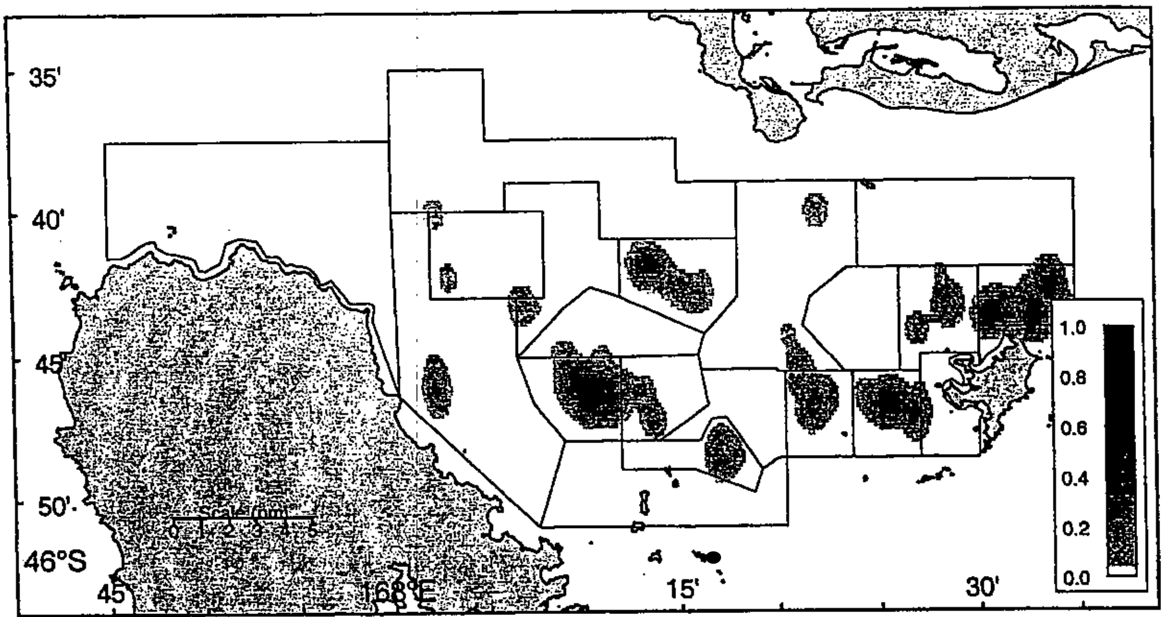

Figure 11: Estimated (kernel) density of live recruited oysters (oysters per m²) reported by fishers in the 2002 Foveaux Strait logbook data.

4.5 Prevalence and intensity of oysters infected with *Bonamia exitiosus*

The survey of the prevalence and intensity of infection in oysters by *B. exitiosus* in October 2002 was carried out at a time of year when mortality from *B. exitiosus* is thought to be at its lowest and the prevalence and intensity of infection also low in oysters. The estimated density of infected recruits is shown in Figure 12. Pre-recruit and small oysters appeared in bonamia samples less frequently than recruits and so the density of infected oysters in these two size groups is underestimated. It is, however, consistent with the distribution of oyster density. Heart imprint analysis from a sample of 25 recruit-sized oysters has a 70% chance of detecting low levels of infection. The October 2002 survey found a significant reduction in both prevalence and intensity of infection since October 2001 (Figures 13 and 14), with a reduction in median prevalence from 25% in 2001 to 6% in 2002 and in the median intensity of infection from 1.8 in 2001 to 1.0 in 2002.

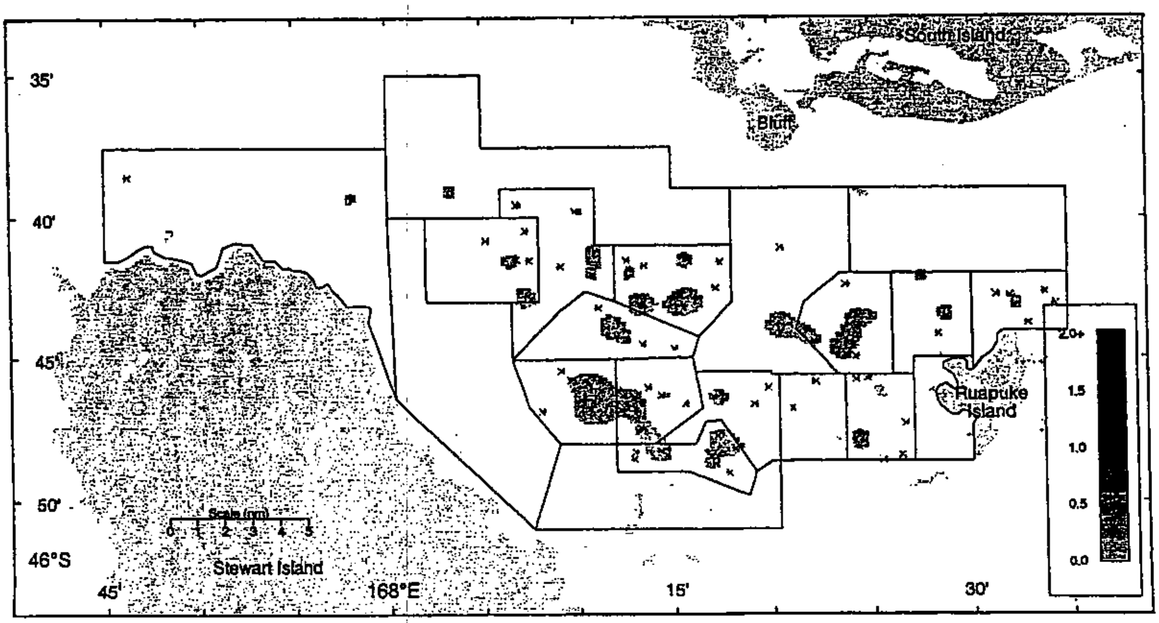

Figure 12: Estimated density of *Bonamia exitiosus* infected live recruits from the October 2002 survey. Stations sampled for *Bonamia* are marked with a full circle.

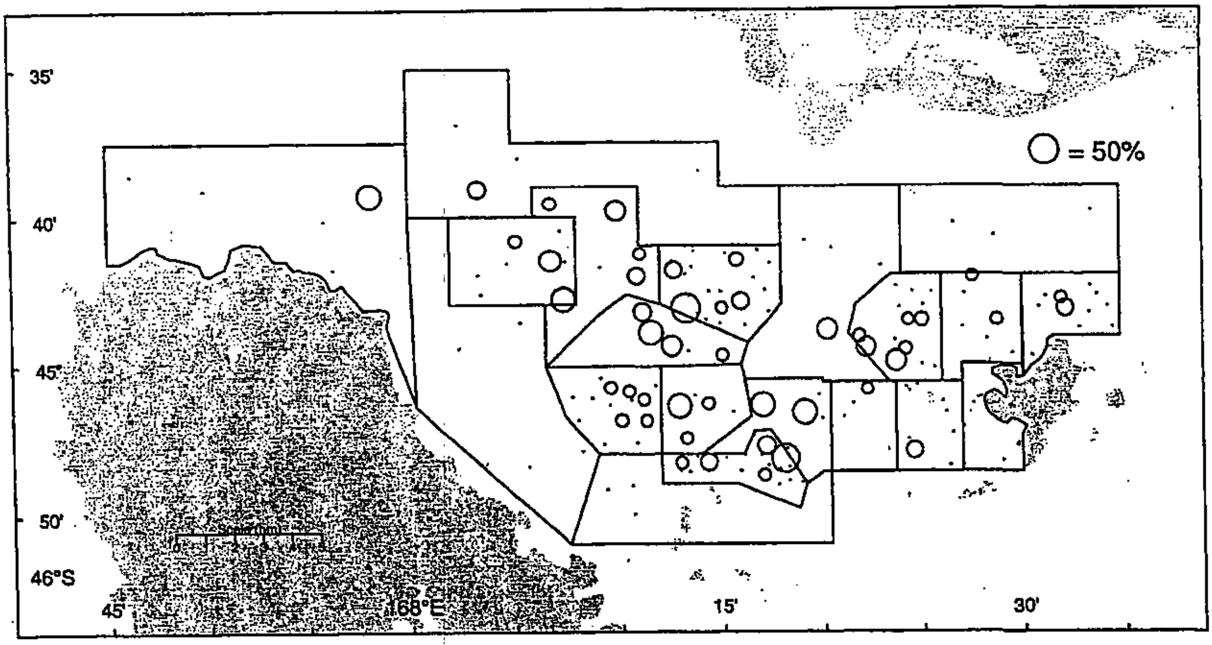

Figure 13: Estimated prevalence of *Bonamia exitiosus* infected live recruits from the October 2002 survey, with symbol area proportional to the prevalence rate. Zero values are marked with a full circle.

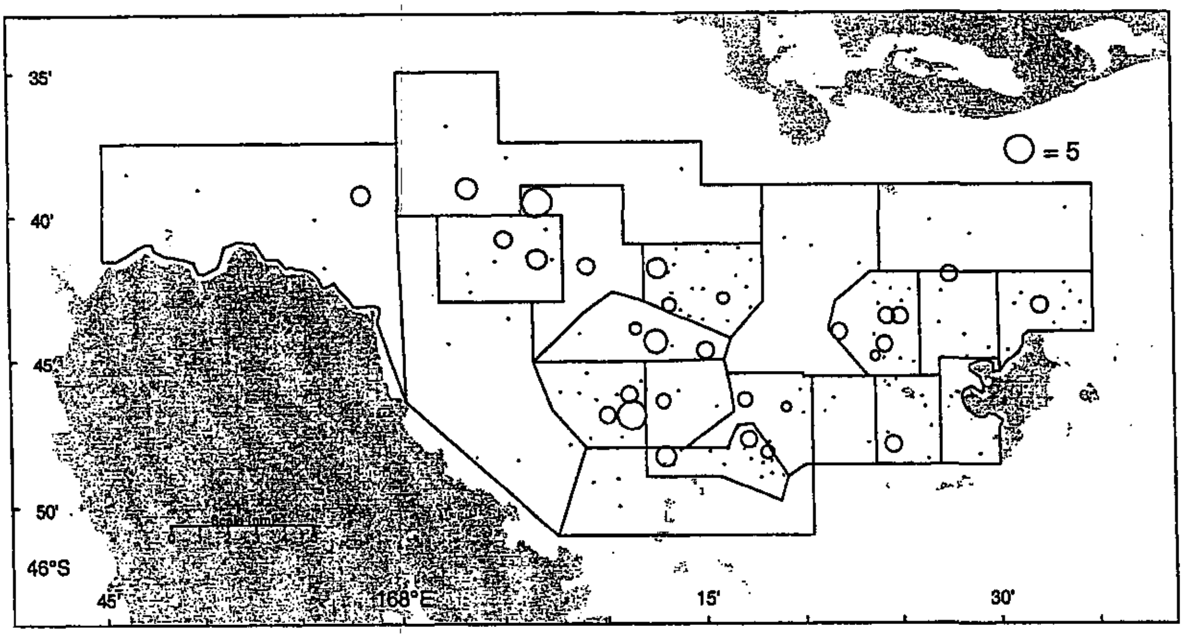

Figure 14: Estimated intensity of *Bonamia exitiosus* infected live recruits from the October 2002 survey (intensity scale 1–5), with symbol area proportional to the intensity. Zero values are marked with a full circle.

The estimated density of recruit-size new clocks, old clocks, and gapers represents a measure of mortality from *B. exitiosus* and is shown in Figure 15. Clocks and gapers were abundant in the west, where mortality from *B. exitiosus* has been high since 1999. There were few clocks in the east, indicating that *B. exitiosus* has not spread significantly into the area and mortality from disease is low.

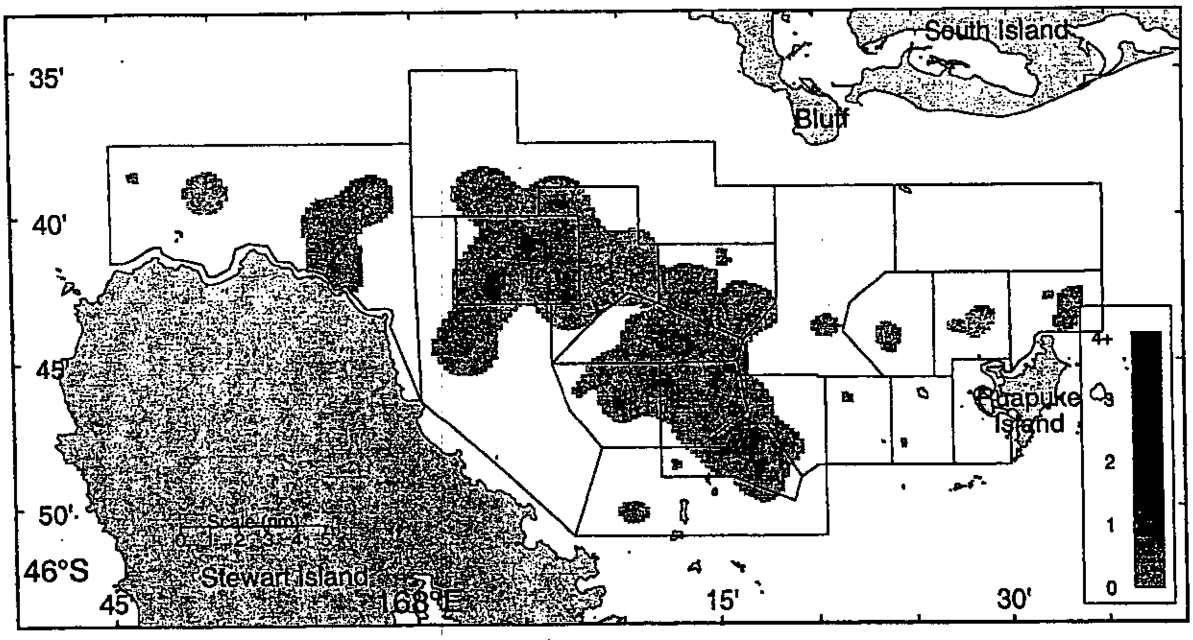

Figure 15: Estimated density of recruit-size new clocks, old clocks, and gapers from the October 2002 survey.

5. DISCUSSION

The survey design, operational procedures, and sampling were comparable to those of previous surveys in 1999–2001. The estimate of the commercial population size of oysters is based on fishery areas designated by fishers from their logbook data and these data give a snapshot of the density and distribution of recruited oysters over the entire fishery area in 2002.

Mortality caused by the *B. exitiosus* epizootic has reduced the population size of recruited and pre-recruit oysters in Foveaux Strait to a third and a half respectively of the 1999 estimates. However, the numbers of small oysters below breeding size (10–50 mm in length) have remained the same, and these oysters may not be as vulnerable to mortality from infection by *B. exitiosus* as breeding size oysters.

The commercial population size of oysters in designated commercial fishery areas has halved since 2001, but, more importantly, the total size of designated commercial fishery areas has increased by half, and the density of oysters within them reduced to a third. The reduction in density of oysters is likely to reduce catch rates in the fishery. The mean catch rate in 2002 was 3.2 sacks per hour, similar to the catch rate in 1992 (3.4 sacks per hour) when the fishery was closed. Catch rates in 2003 are likely to be lower still.

The reduced number of patches of oysters in commercial density available to fishers for the 2003 oyster season may further increase the impact of the likely low catch rate. The 2000–03 *B. exitiosus* epizootic has progressively removed relatively high-density patches of oysters from the fishery. As mortality from the initial focus of infection in the west spread east and south, the fishery has become increasingly more reliant on remaining patches rebuilding in the east. Prevalence and intensity of infection in 2002 had decreased from that in October 2001, but was expected to cause some mortality in 2003. As mortality from *Bonamia* continues to spread east and south, the number of patches available to fishers will continue to diminish. We cannot determine what effect intensive fishing on these patches will have on the prevalence and intensity of infection by *B. exitiosus*, incidental mortality of oysters from dredging, or on the recovery of the oyster population.

The numbers of small oysters below breeding size have not changed during the epizootic and should promote further rebuilding of the oyster population over the next 2–4 years based on available estimates of growth. It is essential that fishers collect detailed logbook data during the 2003 oyster season to investigate the effects of fishing at these low population levels and to actively prospect, especially in the western fishery areas, to identify and monitor fishery areas that may be rebuilding.

6. ACKNOWLEDGMENTS

We thank Brian Hawke and his crew, Jim Foggo, Russell Dixon, Bill Johnston, and Alex Nullinder, and David Fisher and Brian Sanders for the long consecutive days at sea. Thank you to Mike Tait, John Illingworth, and the staff at Greta Point who processed oyster samples.

This investigation was funded by the Ministry of Fisheries under Project OYS2002/01.

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