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A survey of the distribution and absolute abundance of pre-recruit and recruited dredge oysters (*Ostrea chilensis*) in both non-commercial and designated commercial areas of Foveaux Strait, and estimates of the prevalence and intensity of infection by *Bonamia exitiosa*, February 2007

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## EXECUTIVE SUMMARY

**Michael, K.P.; Dunn, A.; Forman, J.; Arlidge, A. (2008). A survey of the distribution and absolute abundance of pre-recruit and recruited dredge oysters (*Ostrea chilensis*) in both non-commercial and designated commercial areas of Foveaux Strait, and estimates of the prevalence and intensity of infection by *Bonamia exitiosa*, February 2007.**

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The February 2007 Foveaux Strait oyster survey was a joint programme between the Bluff Oyster Management Company and NIWA, and continues a series of surveys for OYU 5 stock assessment and determining the status of *Bonamia exitiosa* (bonamia) infection in the oyster population. Sea conditions were good for dredge sampling and operational procedures were comparable to those of previous surveys. A two-phase stratified random survey was successfully completed, along with sampling oysters from two, fine spatial-scale grids, and targeted stations for bonamia infection. Altogether 153 stations were sampled; 90 first-phase, 14 second-phase stations, 9 target stations, and 40 stations from the two grids. All stations were sampled for oyster density and infection by bonamia.

The estimates of mean population size of recruit sized oysters increased from 408 million oysters in January 2005 to 622 million in February 2007, and oyster density over the whole fishery from 0.4 oysters/m<sup>2</sup> to 0.6 /m<sup>2</sup> over the same period. Pre-recruit oysters increased from 414 million oysters to 463 million, but pre-recruit oyster density remained about the same at 0.4 oysters/m<sup>2</sup>. Small oysters decreased from 1344 million oysters to 842 million, and oyster density almost halved from 1.3 oysters/m<sup>2</sup> to 0.8 m<sup>2</sup>. Populations of recruited oysters are rebuilding, pre-recruit are similar to that in 2005, and small oysters have probably declined from 2005. These patterns are similar to those observed in the previous rebuilding phase of the oyster fishery between 1990 and 1999. The population size of small oysters has declined by a third, from a long-term mean of about 1300 million to 842 million oysters. A similar pattern of declining numbers of small oysters two years after low levels of recruit size oysters were recorded was observed in 1993.

The population size of oysters in designated commercial fishery areas has increased from 164 million oysters in 2005 to 196 million oysters in 2007, and oyster density in those areas also increased from 0.44 /m<sup>2</sup> to 0.53 /m<sup>2</sup>. In 2007, mean oyster density is higher in some background areas, especially central and western areas. The population size of oysters above 400 oysters per standard survey tow, a historical indicator of economically acceptable catch rates based on a minimum catch rate of six sacks per hour, has increased from 80 million oysters in 2005 to 104 million in 2007, 14 times the catch limit for the 2007 oyster season.

Oyster populations in central and western areas first affected by mortality from bonamia are rebuilding, and eastern areas have been further reduced by bonamia mortality. Spatial patterns are similar for recruit, pre-recruit, and small oysters.

Few oysters sampled for bonamia had detectable infections, but most of those oysters infected had intense infections likely to kill them. Almost all of this infection was in eastern fishery areas where oyster densities were already low from disease mortality. The estimate of projected mortality, based on category three and greater infections, is not expected to have a significant effect on the rebuilding of the stock.

Mortality from infection by bonamia is the principal driver of oyster population dynamics in Foveaux Strait. In 2007, model estimates of population size were similar to those projections from the 2005 stock assessment (624 million oysters). Projections from the Foveaux Strait oyster stock assessment model indicate that current catch limits are unlikely to have any significant impact on future stock levels. Instead, future disease mortality will determine future stock status. Over the summer of 2007, mortality of oysters with bonamia infections of category three or more was estimated to reduce the oyster population by 43 million oysters (compared to the catch limit of 7.5 million), from 624 to 581 million recruit size oysters, a mean disease mortality of 6.9%. At this level of mortality, the model trajectories showed continued rebuilding of the fishery.

## **1. INTRODUCTION**

### **1.1 General overview**

The Foveaux Strait oyster fishery is a high value, iconic fishery that has been fished for about 140 years. Before 1985, the annual value of this fishery was about \$30 million. Between 1986 and 1992, a *Bonamia exitiosa* (bonamia) epizootic reduced the oyster population to probably less than 10% of the virgin level and in 1993 the fishery was closed to allow the population to rebuild.

The fishery was reopened in 1996 with a catch limit of 15 million oysters, to allow the fishery to continue to rebuild, and has remained unchanged since then. Projections from the OYU 5 stock assessment model indicate this level of harvest is unlikely to have any effect on future stock levels. The recreational and customary fishers take is about 1 million oysters annually in addition to the Total Allowable Commercial Catch (TACC). Since 2003, the Bluff Oyster Management Company (BOMC) has shelved half of the TACC, harvesting about 7.5 million oysters annually.

### **1.2 Oyster population surveys**

Since 1995, the population size of three size classes of oysters, recruited, 58 mm and greater in length; pre-recruits, 50–57 mm in length; and small, 10–49 mm in length, have been estimated from nine biennial dredge surveys [2-10]. The population size of recruited oysters increased from about 640 million in October 1995 to about 1460 million in October 1999. A bonamia epizootic detected at the beginning of the 2000 oyster season (Dunn et al. 2000) caused widespread mortality of oysters, reducing the population size to the levels of the early 1990s, 502 million in October 2002 (Michael et al. 2004a). A January 2004 survey was not able to detect changes in oyster density or population size compared to those estimated from the October 2002 survey. Another two-yearly survey of the oyster population was scheduled for October 2004, but given the low oyster population levels in the fishery, and the continuing need to monitor the prevalence and intensity of infection by bonamia, the Shellfish Working Group recommended the October 2004 survey be deferred and combined with bonamia sampling in January 2005. The estimate of recruited population size in January 2005 was about 408 million. Pre-recruit oysters had declined in similar proportions to recruited oysters, suggesting this size group may be equally vulnerable to bonamia mortality. Since 1999, the numbers of small oysters had remained the same and recruitment did not appear to be affected by the high recruit and pre-recruit oyster mortalities and decreasing oyster densities. The distribution and density of small oysters in January 2005 suggested some rebuilding in central and western fishery areas. The next biennial survey of the oyster population was scheduled for February 2007 combining the population survey with bonamia sampling.

Survey estimates of recruit, pre-recruit, and small oyster population size, and of infection levels in February 2007 are to update the OYU 5 stock assessment model to make projections of recruit-sized stock abundance for the period 2008–10.

### **1.3 Commercial population size**

From 1999 to 2004, yields were calculated using estimates of commercial population size, the recruited population size of oysters from “commercial” fishery areas designated by oyster skippers from biennial October surveys (Michael et al. 2001). The commercial population size declined from about 275 million oysters in 1999 to about 145 million in October 2002, and remained similar at about 165 million in 2005. The designated commercial areas increased in size from 103 km<sup>2</sup> in 1999 to 367 km<sup>2</sup> in 2005. The mean oyster density within those areas declined from 2.4 oysters/m<sup>2</sup> to 0.4/m<sup>2</sup> over the same period, mainly from continuing bonamia mortality (Michael et al. 2005). Since 2004, stock assessments have not used estimates of

yield, but commercial population size is estimated as part of the data available to the Shellfish Working Group. These data, along with the comprehensive coverage of catch and effort as a proxy for oyster density in the fishery, recorded in fishers' logbooks could be used to assess the status of commercial oyster populations.

#### **1.4 Status of bonamia**

Mortality from infection by bonamia is the principal driver of oyster population abundance in Foveaux Strait during epizootics. Since 2000, widespread mortality from the haplosporidian parasite bonamia has reduced oyster density to historically low levels of the early 1990s. Seven surveys of bonamia and the oyster population found mortality had significantly reduced both the size and number of commercial fishery areas, reduced oyster density within them, and changed the distribution of oysters (Dunn et al. 2000, 2002, 2003, Michael et al. 2004a, 2004b, 2005). A survey of bonamia infection in oysters in January 2005 found the prevalence and intensity of infection had decreased significantly from those in January 2004 (Michael et al. 2005). Very few new clocks or gaping oysters were sampled in January 2005, indicating low mortality. Based on the small numbers of oysters with category 3 or greater infections little disease mortality was expected over that summer. However, infection was more widespread in the fishery in February 2006 compared with that in January 2005 (Michael et al. 2005). The prevalence of infection was similar; however, the intensity of infection was much higher and may be due to the time of sampling or seasonal variation in the patterns of infection. This high intensity of infection had caused some mortality at the time of sampling and, based on the number of oysters with category 3 or greater infections, mortality from bonamia could have reduced the recruited oyster population from about 240 million oysters to about 230 million by the beginning of the 2006 oyster season, more than the catch limit.

#### **1.5 Stock assessment**

Since October 1995, two-yearly October surveys of Foveaux Strait oysters have estimated commercial population sizes and yields. In 1995, commercial population size was the proportion of the recruited oyster population over 400 oysters per survey tow (Cranfield et al. 1996). CAYs (Current Annual Yields) were estimated using Method 1 of Annala et al. (2002). From 1999, yields were estimated from a new definition of commercial population size; the population size of all recruit-sized oysters in fishery areas designated as commercial by oyster skippers (Michael et al. 2001). In 2004, the Shellfish Working Group agreed to change from CAY to projections of recruit-sized stock abundance from a length-based stock assessment model developed by Dunn (2005). Projections of recruit-sized stock abundance for different levels of harvest and bonamia mortality are compared.

In 2005, model estimates of population size were similar to those from the population survey. Projections from this model indicate that current catch limits of 15 million oysters are unlikely to have any significant effect on future stock levels. Instead, future disease mortality will determine future stock status if recruitment remains similar. Depending on the level of assumed disease mortality, projected status in 2008 ranged from about 80% more than the 2005 level (with nil disease mortality) to about 80% of the current level (assuming disease mortality of 0.4/y). At the level of bonamia mortality estimated from the February 2006 survey, the model projections show continued rebuilding of the fishery, given the current catch limits.

## 1.6 Recruitment

Previous surveys to estimate the size of the commercial oyster population (Michael et al. 2001, 2004a, 2004b, 2005, 2006) focused sampling effort in designated commercial fishery areas that had shifted east between 1999 and 2006. These surveys did not provide sufficient information on the densities of small oysters (less than 50 mm in length) to assess the rebuilding of fishery areas where mortality from bonamia infection had significantly reduced recruit-sized oyster density. Likewise, fishers' logbooks (Dunn & Michael 2001, Dunn 2002) had not provided sufficient information to assess the extent of any rebuilding of these fishery areas. The January 2004 and 2005 surveys estimated numbers of small oysters in the 1999–2005 commercial fishery areas to assess recruitment. These surveys found densities of small oysters were similar or had increased slightly in all areas between October 2002 and January 2005, and had continued to rebuild in January 2006. The February 2007 survey sampled these areas again.

## 1.7 Research overview

Recent research has concentrated on oyster population and bonamia infection, and on understanding bonamiosis in oysters (Diggles & Hine 2002, Diggles et al. 2003, Diggles 2004) and developing length-based models as a means of improving scientific advice for the management of the fishery (Dunn 2005). A draft strategic research plan developed to underpin management goals in the Bluff Oyster Management Company Limited (BOMC) Fisheries Plan (Michael & Dunn unpublished report), and linked to a wider case study of an ecosystem approach to fisheries management in Foveaux Strait, has provided a focus for shaping future research. However, few fishery data are available to determine the status of commercial fishery areas devastated by mortality from bonamia infection, whether infection continued to cause mortality over the summer of 2006–07, and whether oyster population in commercial fishery areas where mortality from bonamia had heavily reduced oyster density early in the epizootic are rebuilding to commercial densities.

A Foveaux Strait oyster fishery plan being developed by stakeholders and facilitated by MFish is developing strategies (underpinned by a draft strategic research plan) to maximise the value and production of oysters. These strategies will be dependent on data from the fishery recorded in fishers' logbooks. During the (2006) oyster season, fishery data were recorded at a spatial-scale of one nautical mile square by all vessels in the oyster fleet. Further, BOMC are sampling the commercial catch for catch-at-length data and are expanding a pilot trial to monitor the distribution and density of oyster spat settlement in relation to source populations in Foveaux Strait to provide data for managed fishing of the stock.

Until the Foveaux Strait oyster fisheries plan is approved, the Ministry will continue with the current stock strategies for the OYU 5 fishery (Allen Frazer, Ministry of Fisheries, pers. comm.). This report documents a collaborative, biennial stock assessment survey between NIWA and BOMC of the oyster population size and status of infection by bonamia, and in part fulfils Milestone 4, Reporting Requirement 3 of the Ministry of Fisheries project OYS2006/01, objective 1: To carry out a survey in late January 2007 to determine the distribution and absolute abundance of pre-recruit, and recruited oysters in both non-commercial and designated commercial areas of Foveaux Strait, to estimate the prevalence and intensity of infection by bonamia, and to update the Foveaux Strait oyster stock assessment model to predict recruit-sized stock abundance. A two-phase random stratified survey, comprising 106 stations, was completed in February 2007, and this report includes survey estimates of population size and commercial population size for stock assessment from these data. Additional target stations and two fine-scale grids were also sampled to determine the status of infection over small spatial scales, and changes over time. Estimates of prevalence of infection among oysters and the intensity of bonamia infection within individual oysters are presented along with data on the density and distribution of live recruit,

pre-recruit, and small oysters. We discuss how these estimates have changed between October 2002 and February 2007.

## 2. METHODS

### 2.1 Sampling design

The February 2007 survey continued a time series of surveys using the 1999 Foveaux Strait oyster survey area (1054 km<sup>2</sup>) with one additional new area (B1a) outside the standard survey boundary requested by oyster skippers (Figure 1). The survey essentially retained the October 2005 survey strata (Michael et al. 2008). Some strata were partitioned to better define the commercial fishery and new commercial strata were added, based on information from skippers' logbooks for the 2006 oyster season that represented almost 100% of fishing by the entire fleet and skippers' input. The survey employed a two-phase stratified random design.

A total of 153 stations was sampled, but only the randomly allocated stations were used to estimate population size. Ninety-one sample stations were allocated to the first-phase sampling; 53 to commercial strata, 32 to background strata, and 6 to exploratory. Allocations to individual stratum were based on stratum area (Table 1, Figure 1). A further 15 stations were allocated as second-phase stations. Two grids, 5 cells oriented along the tidal flow by 4 cells across, with sample stations positioned 0.25 nautical miles apart were sampled to investigate the small spatial scale distribution of oyster density and bonamia infection. The western grid was centred on position 167 57.000 E 46 39.000 S and the eastern grid on position 168 30.100 E 46 41.500 S. These were sampled with a quarter the standard tow length (straight-line tow down tide tow) of 0.05 nautical miles. Nine targeted stations repeated survey tows from 1999, 2001, 2002, and 2005 in areas where bonamia mortality had reduced high densities of oysters to low levels to investigate whether these areas were rebuilding.

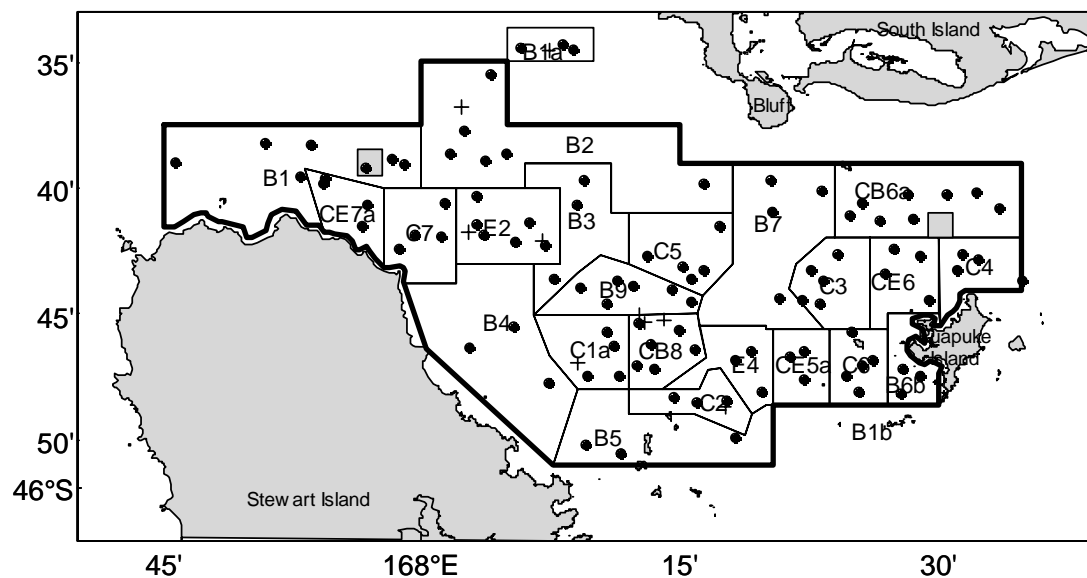


Figure 1: The 1999 survey area (heavy line), and strata surveyed (light lines) and the first-phase station allocation (points) used in the February 2007 survey. Strata designated commercial by oyster boat skippers are those with a “C” prefix. Exploratory strata have an “E” prefix and background strata “B”. B1a is a new stratum added in 2007 survey. Target stations for bonamia investigations shown as crosses and grids as grey squares.

**Table 1: Number of samples per stratum in the first and second phases for the February 2007 oyster survey. Strata designated commercial are prefixed “C”; exploratory strata prefixed “E”; background strata prefixed “B”.**

Stratum	No. stns		Stratum	No. stns		Stratum	No. stns	
	first	second		first	second		first	second
B1	3	5	C3	6	0	B1b	3	0
B2	4	2	C4	4	0	B6b	3	0
B3	3	0	C5	5	0	C1a	4	0
B4	3	0	C6	4	0	C-B8	4	2
B5	3	0	C7	4	0	C-E6	4	0
B7	4	1	E2	3	3	CE7a	3	0
B9	3	2	E4	3	0	C-B6a	8	0
C2	4	0	B1a	3	0	C-E5a	3	0

## 2.2 Operational procedure

Sampling followed similar procedures to those in the surveys in October 2002 (Michael et al. 2004a), February 2003 (Dunn et al. 2003), January 2004 (Michael et al. 2005), January 2005 (Michael et al. 2006), and February 2006 (Michael et al. unpublished data). FV *Golden Lea*, a commercial oyster vessel skippered by Brian Hawke, has been used for these surveys since 2001 and sampled survey stations with a standard commercial dredge (3.35 m wide, 430 kg). NIWA staff ensured consistency of procedures.

## 2.3 Navigation

The survey used standalone GPS position fixing (Furuno GP-31) with positions downloaded to the vessel’s computer running OLEX navigation software. Start and finish tow positions were recorded both manually and electronically as waypoints.

## 2.4 Survey tows

Survey tows were started on station position 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 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 site. 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 GPS 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 released, and the dredge 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; later they were saved to file to provide a backup.

Tows that could not be dredged because of foul ground were replaced with spare sites in the same stratum. Tows were repeated with the same site number when the dredge became tangled or the dredge did not fish properly. Tows were not repeated when the dredge was landed less than 75% full, but mainly filled with kaeos (*Pyura pachydermatina*) or algae, or when the dredge came fast after 0.1 of a nautical mile.

All survey data were recorded on the Foveaux Strait oyster survey form (Appendix 1).

## 2.5 Sorting the catch

Only the aft dredge of the two commercial dredges was used for sampling during the survey. Dredge samples were landed onto the aft culching (sorting) bench without washing (i.e., without dipping the dredge) to avoid the loss of small oysters and benthic fauna. The fullness of the dredge was visually estimated while the dredge was suspended above the bench during landing.

The catches of oysters and bycatch were photographed with a digital camera from each survey tow before the catch was sorted into live oysters, gapers (live, but moribund oysters containing the whole oyster and valves remaining apart after the adductor muscle has lost its ability to contract), and clocks (the articulated shells of recently dead oysters with the ligament attaching the two valves intact) to estimate mortality. New clocks are usually defined, in October surveys, as those shells that have clean inner valves and have retained their lustre without any sign of fouling (fouling organisms are thought to settle over the late spring and summer). In this February survey, new clocks were defined as those that had clean inner valves that had retained their lustre, but may have had some minor speckling of fouling organisms (Figure 2). New clocks are usually assumed to be the shells of those oysters that died since the settlement of fouling organisms in the previous summer, within the previous year. The shells of oysters that are fouled or in which the inner valves have lost their lustre are termed old clocks (Figures 3 and 4). Old clocks can be covered in fouling organisms on both external and internal surfaces, and as the ligaments of oysters are thought to break down over a three-year period, old clocks represent oysters that died between 1 and 3 years previous by Cranfield et al. (1991). The classification of old clocks may vary depending on habitat. Old clocks from sand habitats may be older as they may be filled with sand preventing the settlement of fouling organisms and reducing physical forces on the hinge prolonging the time both valves are attached beyond three years. Gravel habitats are usually shallower with stronger tidal currents and higher swell energy, and the valves of old clocks there may be disconnected much more quickly than three years or the old clocks transported out of the fishery area by the strong tides.

For analysis, we assumed that new clocks were only those oysters that have died since the summer mortality from bonamia began, and that oysters that died before that were categorised as old clocks.

The catch was further sorted into two size groups: recruit (unable to pass through a 58 mm internal diameter ring), and 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 and 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.

Samples of up to 30 randomly selected recruit-sized oysters from each site were collected for the heart imprints and histology to estimate levels of bonamia infection. When there were insufficient recruit-size oysters in the catch, pre-recruit and small oysters were used to fill the sample size, or the whole catch was retained for processing. Samples were bagged, labelled with site 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 NIWA, Wellington, for processing.

The data recorded at each site included start and finish location of the tow; depth, speed of tow, numbers of oysters, new clocks, and gapers caught; percentage fullness of the dredge; wind force (Beaufort scale); sites where live bryozoans (*Cinictipora elegans*) were observed and sediment type. Previous surveys recorded bycatch data from digital images of the catch. In 2007, these data were recorded directly from the bycatch.



**Figure 2: New clock (with hinge intact), glossy inner valve with no fouling except a few white coralline specks.**



**Figure 3: Recent old clock (with hinge intact), glossy inner valve with light fouling.**



**Figure 4: Old clock with hinge intact. No gloss on inner valve and heavy fouling.**

## **2.6 Processing of samples, heart imprints, and histology protocols**

Oyster samples generally arrived in Wellington within 36 hours of capture, and were processed that day. 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.

Site and sample data were recorded on bonamia sampling forms (Appendix 2), and the total numbers of live and dead oysters in the samples noted. A subsample of up to 25 recruit-sized oysters from each site was taken for heart imprints to estimate the prevalence among oysters and intensity within individual oysters of bonamia infection. Each oyster was assigned a number from 1 to 25, a size category assigned using oyster size rings, and measured for length and height (Figure 5) to the nearest millimetre down using callipers. If samples contained insufficient recruit-sized oysters, pre-recruits were used in preference to small oysters. Recruit-size oysters were denoted with an R, pre-recruit oysters with P, and small oysters with an O. Gaping oysters with valves of the shell apart, but closed when tapped, were marked with an asterisk alongside the corresponding oyster number. Oysters incubating larvae were assigned “W” for white early-stage larvae, “G” late-stage grey larvae, and “N” for no larvae present.

Heart imprints were made by removing the heart (dark organ adjacent to adductor muscle, see Figure 6) with fine forceps, draining excess water and fluid on filter paper, and lightly dabbing the heart on a slide to deposit a small amount of haemolymph. 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.

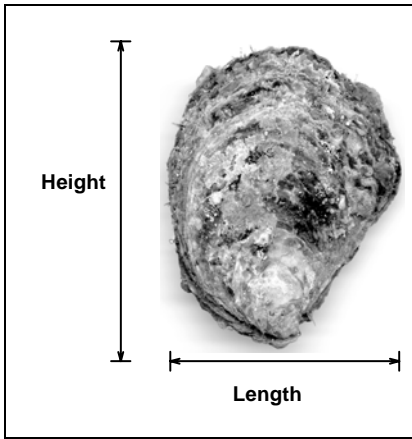
Histological samples were taken from the first five oysters processed for heart imprints. A section was taken through the digestive gland (Figure 6) and fixed in a quantity of 10% formalin in seawater equal to at least five times the tissue volume of the sample. All histology samples were archived at NIWA.

## **2.7 Analysis**

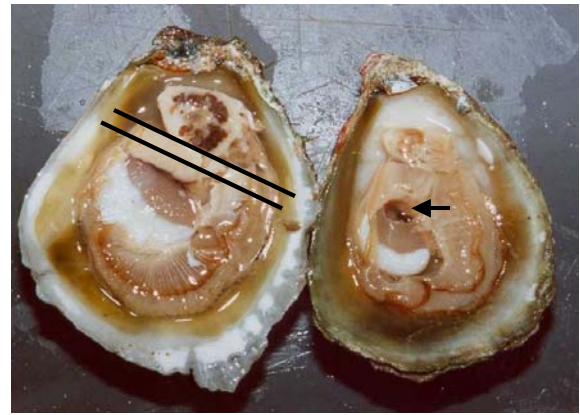
### **2.7.1 Analysis of oyster heart imprint data**

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. Correlation studies with in-situ hybridisation have shown the prevalence of bonamia estimated from heart imprints can underestimate the true infection rate by about 20% (Diggles et al. 2003).

The prevalence and intensity of bonamia were determined from heart imprints taken from 150 sites. 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 2. Three good heart imprints containing oyster haemocytes were located and examined on each slide, and the number of bonamia cells counted for each. If no bonamia cells were found, further imprints were examined to confirm the absence of bonamia.



**Figure 5:** An oyster showing length (anterior-posterior axis) and height (dorsal-ventral axis) dimensions.



**Figure 6:** 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.

**Table 2: Criteria used to stage intensity of infection from bonamia in oysters.**

Stage	Criteria
0	No bonamia observed
1	One bonamia observed after examining an imprint
2	More than 1, but fewer than 10, bonamia observed after examining an imprint
3	More than 10 bonamia present in the imprint, but few in each haemocyte
4	Bonamia present in many haemocytes of each imprint and many in each haemocyte
5	Bonamia present in nearly all haemocytes of each imprint and many in each haemocyte, and extracellularly

Previous studies (NIWA, unpublished data) suggest that stages 1 and 2 are relatively light infections and do not appear to affect 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.

For each site, prevalence is defined as the proportion of oysters in a sample with at least one bonamia 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 bonamia 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 as oysters of decreasing size are increasingly less vulnerable to infections and mortality. 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  $\pi$ , where  $\pi = r/n$  (where  $r$  is the number of oysters infected with bonamia and  $n$  the number of oysters in the sample), the 95% confidence interval is determined by:

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

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

## 2.7.2 Estimates of oyster density and population size

The February 2007 survey of Foveaux Strait provided estimates of the total oyster population (recruit, pre-recruit, and small oysters), and the commercial population (recruit-sized oysters in designated commercial areas). Estimates of the commercial population should be considered with caution given the low sample sizes, but may provide comparative estimates. Estimates of absolute abundance and variance from stratified random sampling theory (Jolly & Hampton 1990) assumed a mean dredge efficiency, re-estimated from the 1990 data, of 0.17 (95% confidence intervals 0.13–0.22). We assume that areas of commercial densities are known without error, and we present estimates of population size for the designated commercial and non-commercial areas separately (see Figure 1).

Survey estimates of the numbers of recruits, pre-recruits, and small oysters 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.

## 2.7.3 Patterns of recruitment

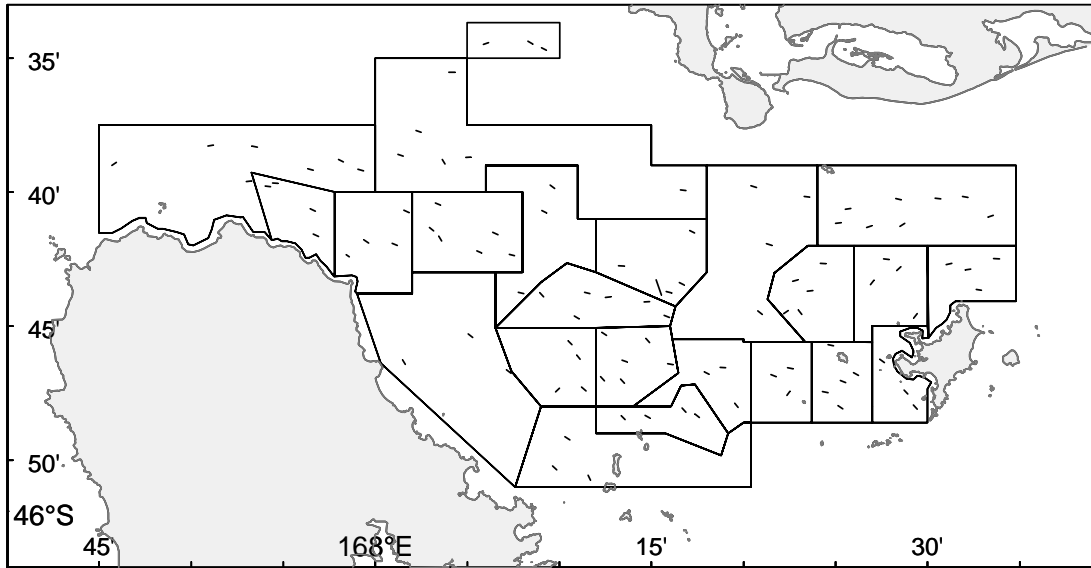
Recruitment to the fishery is investigated from changes in the estimated numbers of small oysters, and from changes in patterns of distribution of small oyster densities, between the October 2002 and February 2007 surveys.

# 3. RESULTS

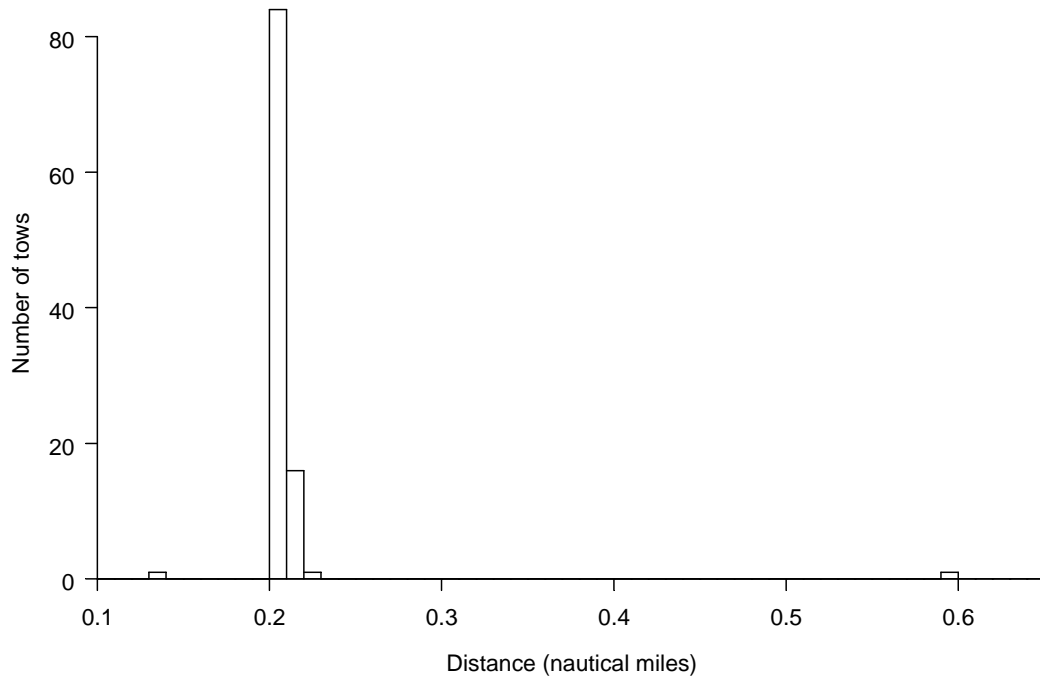
## 3.1 Survey operational detail

The oyster vessel *Golden Lea* successfully sampled 150 stations on 12 days between 7 February and 22 February 2007. Two days were completely lost due to rough weather and sea conditions. Three of the first-phase stations were not sampled. Oyster samples were collected from all stations. Survey strata are shown in Figure 1 and dredge tow positions for randomly allocated stations in Figure 7. The survey data are held on the Foveaux Strait dredge oyster database at NIWA, Greta Point, Wellington.

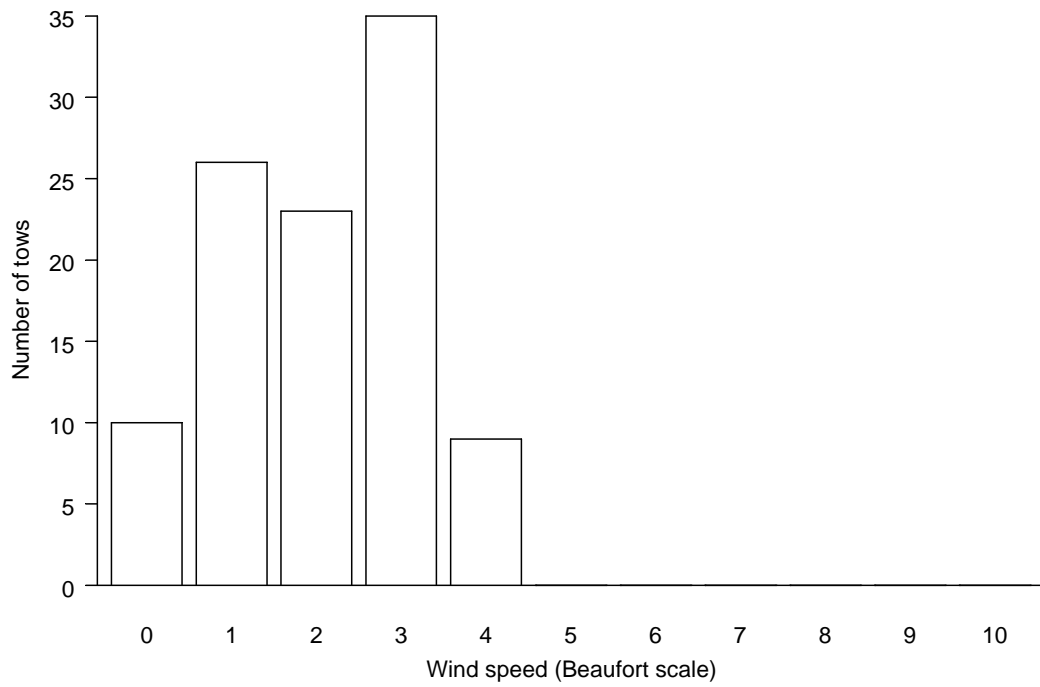
Dredge tow lengths were closely clustered around the 0.2 nautical mile (370 m) standard tow length (Figure 8), except for 1 tow. Most of the survey stations were sampled in light wind conditions; the median wind force was 1 on the Beaufort scale (1–3 knots), with 5 and 95 percentiles of Beaufort scale 0 (calm) and 4 (11–16 knots) respectively (Figure 9). These wind and resulting sea conditions were similar to sampling conditions on previous surveys, and 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. All dredge tows were landed less than 80% full (Figure 10), suggesting that dredge saturation had a minimal effect on sampling effectiveness. While 80% fullness is assumed to be the level at which dredge saturation occurs, the actual level may be lower as few dredges are landed more than 80% full, resulting in underestimates of oyster density and clocks.



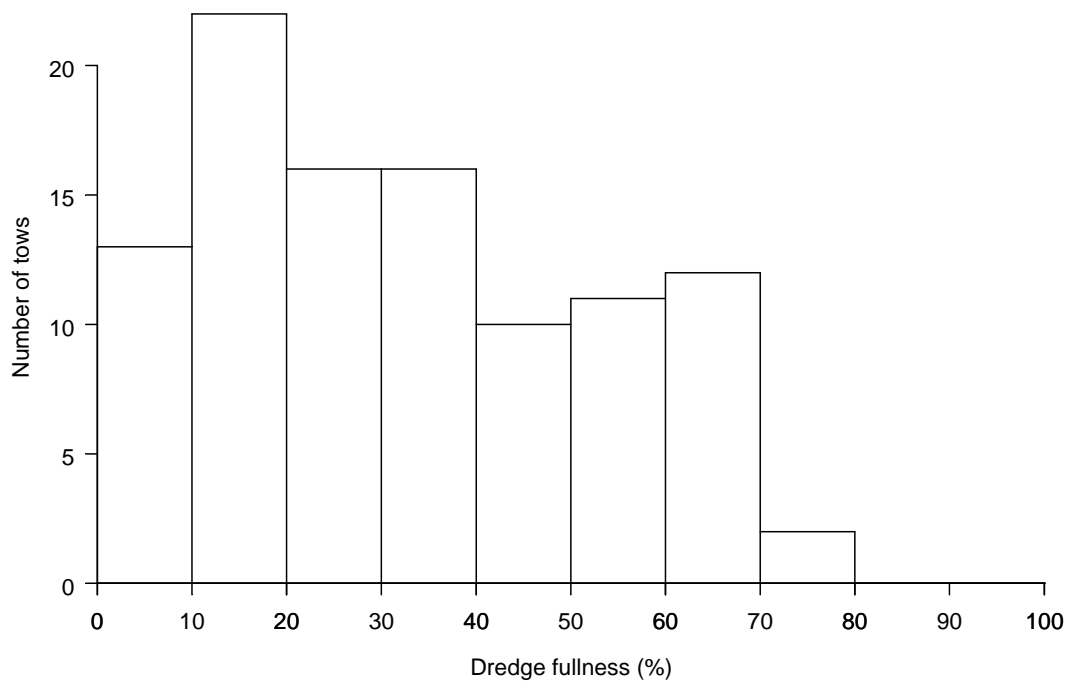
**Figure 7: The random survey tows sampled in February 2007. Target and grid tows not shown.**



**Figure 8: Distribution of tow lengths from the February 2007 survey. The standard tow length was 0.2 nautical mile (370 m).**



**Figure 9: Distribution of wind speed (Beaufort scale) recorded during survey tows in the February 2007.**



**Figure 10: Distribution of dredge fullness recorded for survey tows in February 2007. None of the tows were landed with a fullness of greater than 80%, indicating a low probability that tows were saturated and hence underestimated oyster density.**

### **3.2 Observations from sampling**

Generally low numbers of new clocks and gapers were observed in February 2007, indicating low recent mortality, compared to the slightly larger numbers observed in February 2006. The 2006 survey sampled a smaller number of stations (N = 45) in mainly commercial fishery areas to investigate the status of bonamia infection, and was not as extensive as the 2007 survey. Recruit-sized new clocks were down from 7% in 2006 to 2% in 2007, and pre-recruit sized new clocks 4% to 2% respectively. The proportion of gapers was also down, 0.2% compared to near 0% over the same period.

Dredge contents were randomly sampled to identify benthic fauna providing good surfaces for oyster settlement and survival. Observations from this sampling confirmed fishers' and researchers' earlier observations that most small spat were found on live oysters and the large gastropod *Astraea heliotropium*, known by fishers as "circular saws". Large numbers of small (test size under 20 mm) kina (*Evechinus chloroticus*) were observed in the bycatch at many locations in Foveaux Strait, especially the northeastern fishery area.

### **3.3 Estimates of oyster density and prevalence and intensity of infection by bonamia**

Heart imprint slides from 153 stations were sampled to determine prevalence and intensity of infection by bonamia. Estimated oyster density, number of oysters taken for bonamia sampling, and the number of infected oysters found at each station are summarised in Appendix 3, Table 3A.

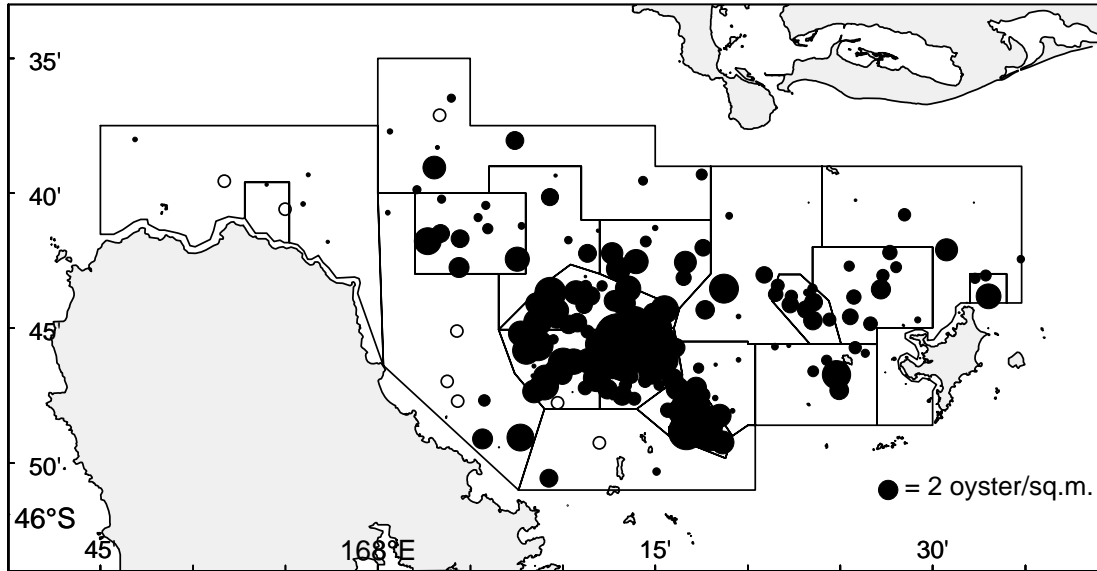
### **3.4 Distribution of live oysters**

The distributions of oyster density for live recruit, pre-recruit, and small oysters are presented from survey data from the October 2001, October 2002, January 2005, and February 2007 surveys, shown in Figures 11–22. These surveys primarily focussed sampling effort on designated commercial fishery areas to estimate commercial population size, and do not provide consistent and total coverage of the fishery area.

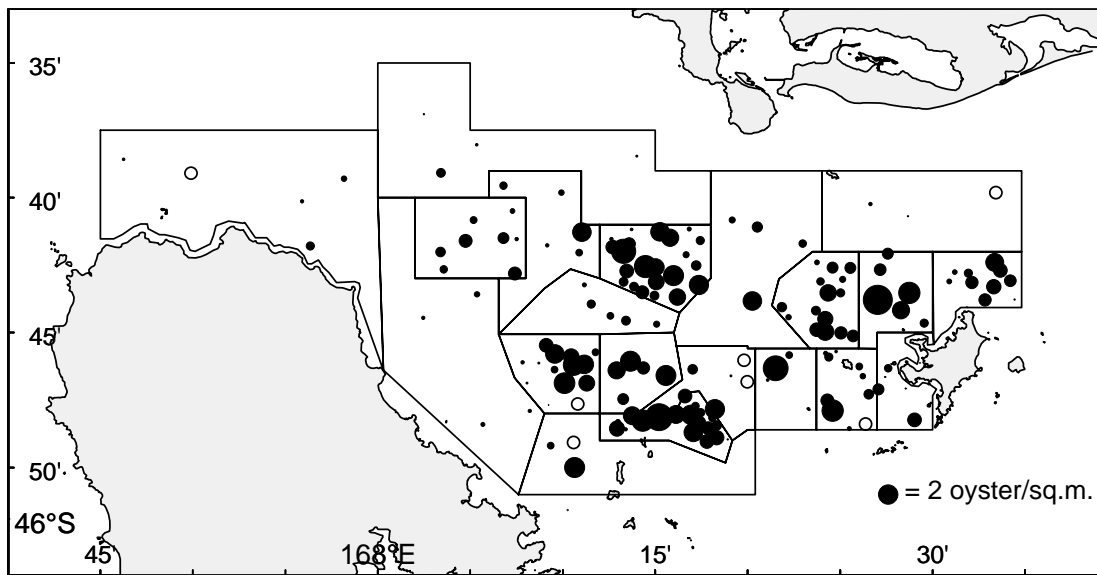
The distributions of recruited oysters (Figures 11–14) show mortality from bonamia reduced oyster density in western and central areas between 1999 (not shown) and 2001, and severely reduced oyster density in central areas between 2001 and 2002. By 2005, all fishery areas were reduced to the low "background" densities. Mortality from bonamia continued to reduce oyster density in eastern areas until 2007, but central and western areas showed continued rebuilding of densities first indicated by the 2005 survey. Western and central areas appear to be in the early stages of rebuilding, at similar densities and distributions to 1995, and are following a similar pattern to that observed between 1992 and 1999. Similar patterns of distribution have been observed for pre-recruit oysters (Figures 15–18), thought to be as vulnerable to bonamia mortality as recruit size oysters. Densities of pre-recruit oysters are increasing in western and central areas, albeit slowly, and the number of areas (patches) are increasing. Fewer stations in the 2005 and 2007 surveys recorded no oysters than the earlier surveys.

Small oysters (Figures 19–22) had relatively high densities over much of the fishery area in 2001, and were especially high in eastern areas, west of Ruapuke I. Densities increased in the east and declined in the west in 2002. By 2005 this pattern of distribution had changed with densities decreasing in the east and increasing in the west, with this trend continuing in 2007. Most of the small oysters sampled in 2001 and 2002 are expected to recruit into the fishery within 2–4 years, and to become increasingly more vulnerable to mortality from bonamia. The patterns of distribution observed between 2001 and 2007 reflect recruitment dynamics combined with the effects of disease mortality, rather than the effects of fishing on the stock.

Oyster density had been reduced by mortality from bonamia to low background levels throughout the fishery area, significantly reducing the size and number of commercial fishery areas and reducing the oyster density within them. Most of this mortality occurred before the October 2002 survey, although bonamia infection was present in mainly eastern areas of the fishery in 2007. The fishery appears to be entering a rebuilding phase where recruitment to fishery is exceeding bonamia mortality.



**Figure 11: Relative density of live recruit oysters in the October 2001 survey. Stations with no oysters are denoted by open circles.**



**Figure 12: Relative density of live recruit oysters in the October 2002 survey. Stations with no oysters are denoted by open circles.**

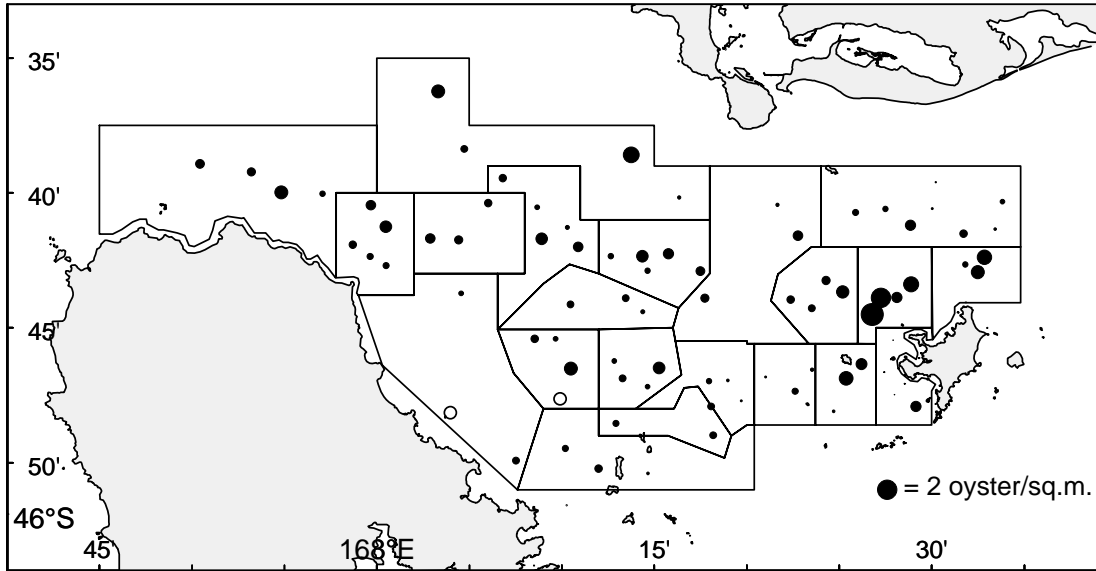


Figure 13: Relative density of live recruit oysters in the January 2005 survey. Stations with no oysters are denoted by open circles.

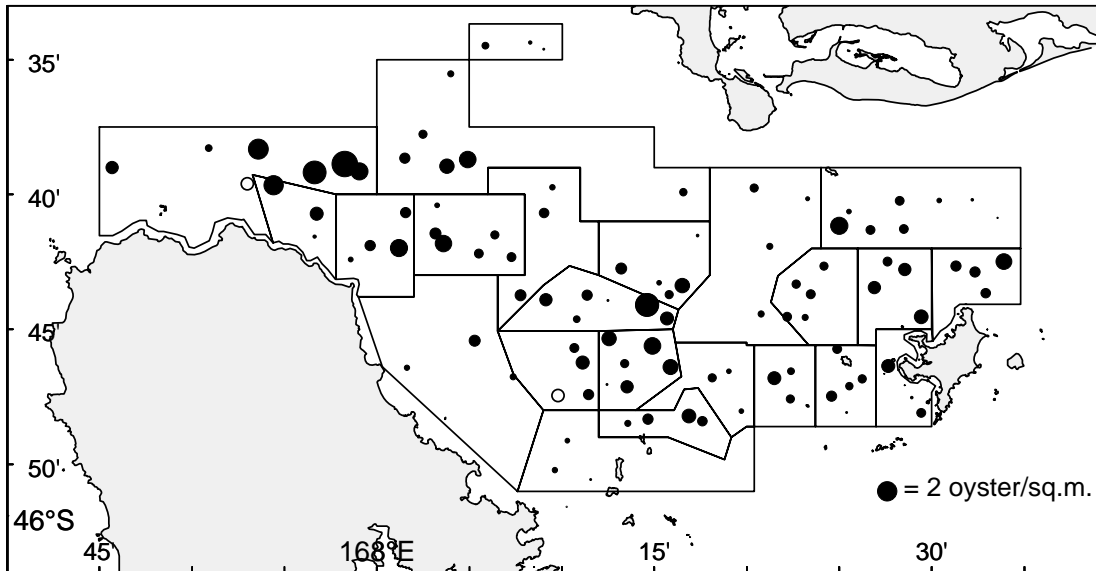


Figure 14: Relative density of live recruit oysters in the February 2007 survey. Stations with no oysters are denoted by open circles.

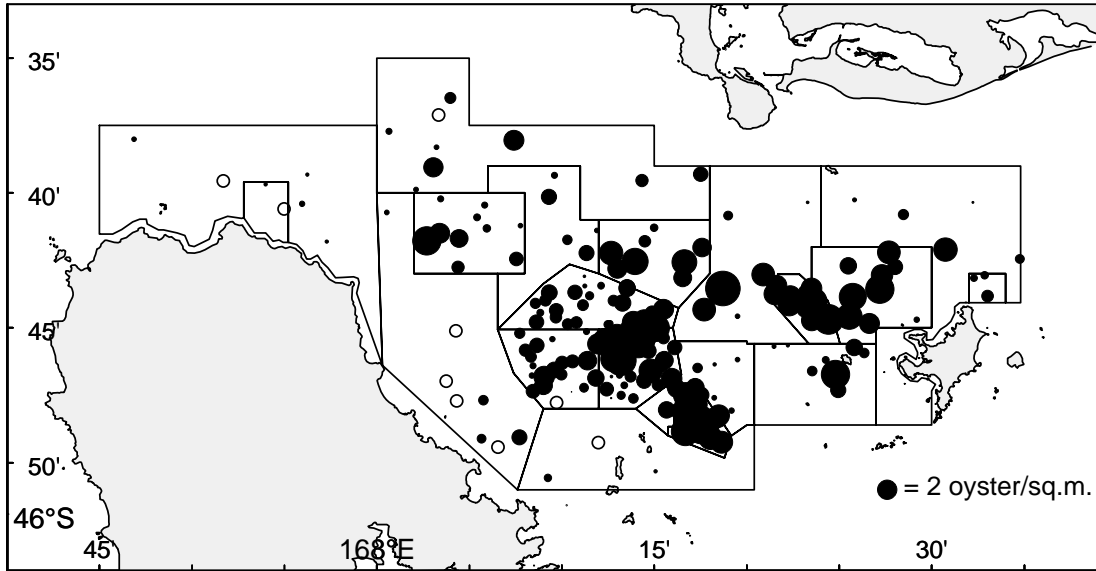


Figure 15: Relative density of live pre-recruit oysters in the October 2001 survey. Stations with no oysters are denoted by open circles.

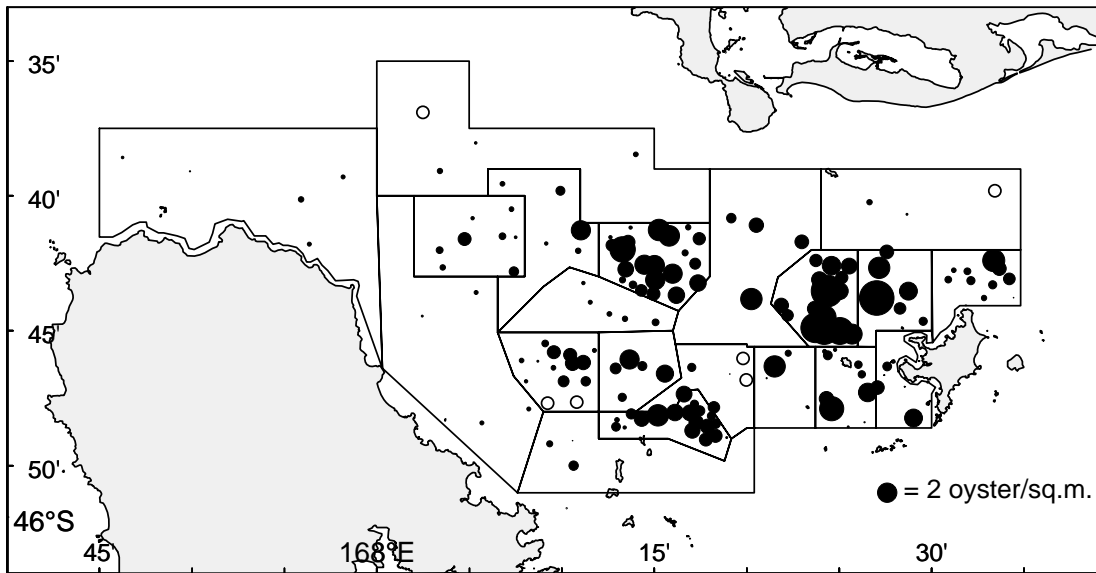


Figure 16: Relative density of live pre-recruit oysters in the October 2002 survey. Stations with no oysters are denoted by open circles.

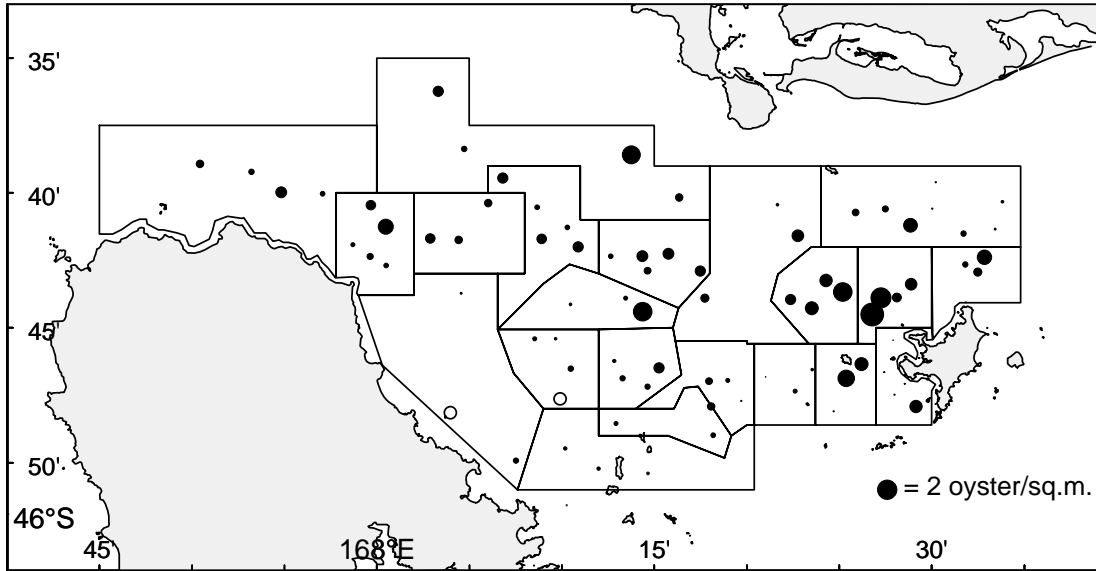


Figure 17: Relative density of live pre-recruit oysters in the January 2005 survey. Stations with no oysters are denoted by open circles.

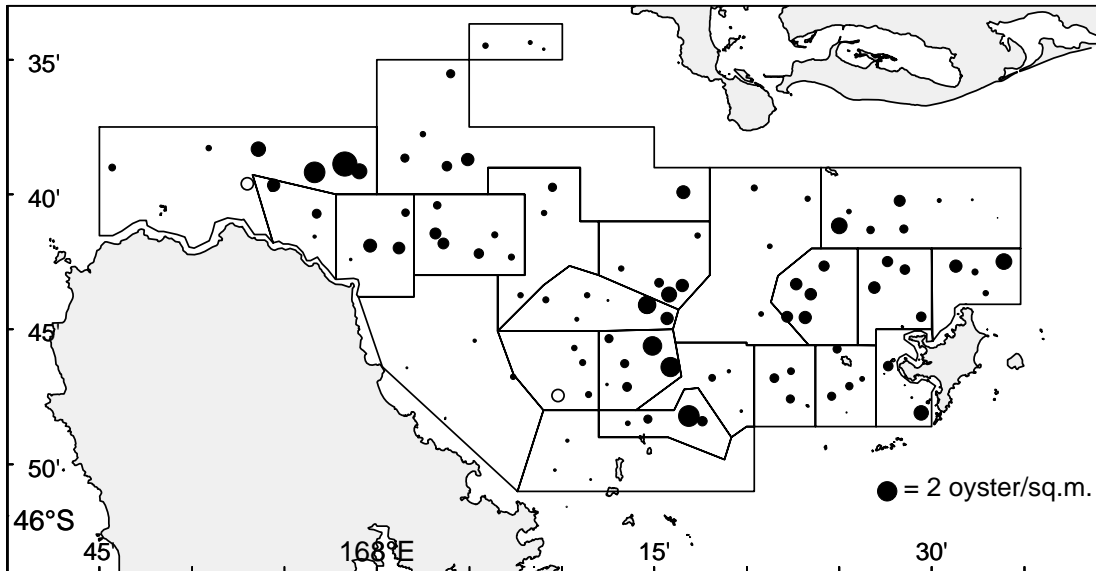


Figure 18: Relative density of live pre-recruit oysters in the February 2007 survey. Stations with no oysters are denoted by open circles.

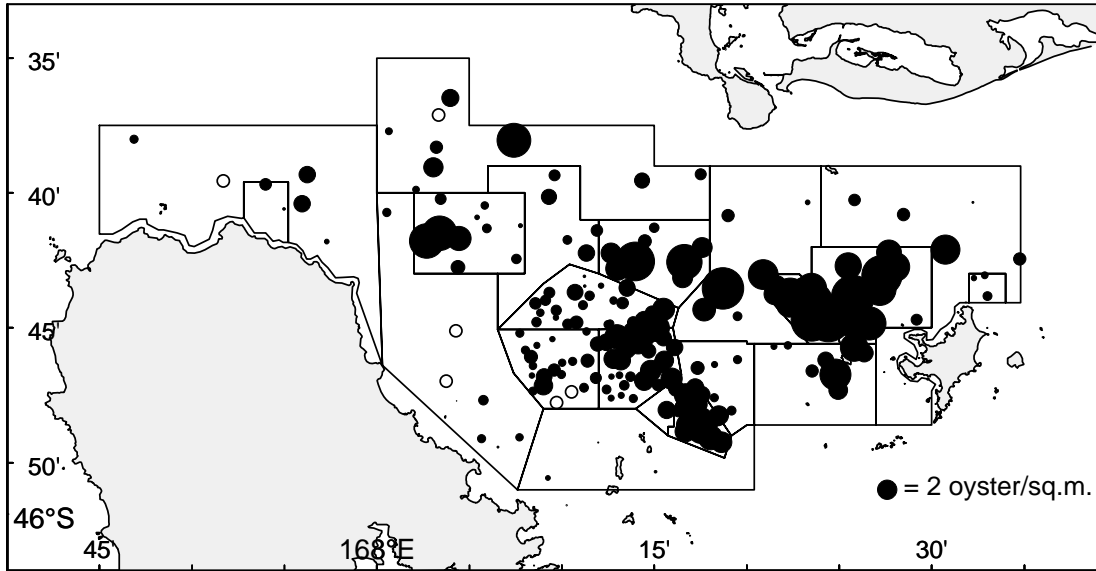


Figure 19: Relative density of live small oysters in the October 2001 survey. Stations with no oysters are denoted by open circles.

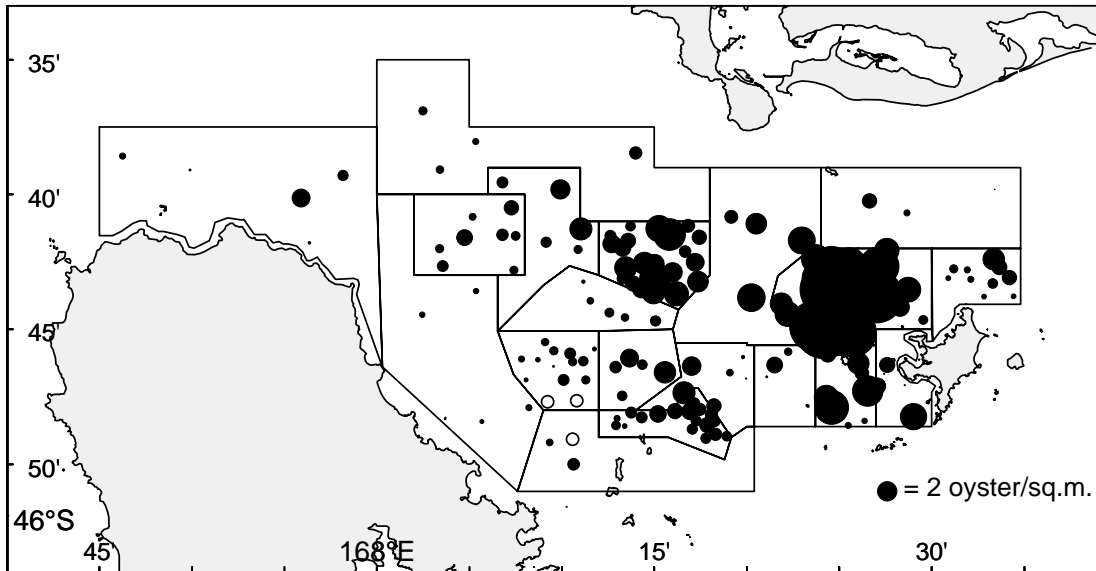


Figure 20: Relative density of live small oysters in the October 2002 survey. Stations with no oysters are denoted by open circles.

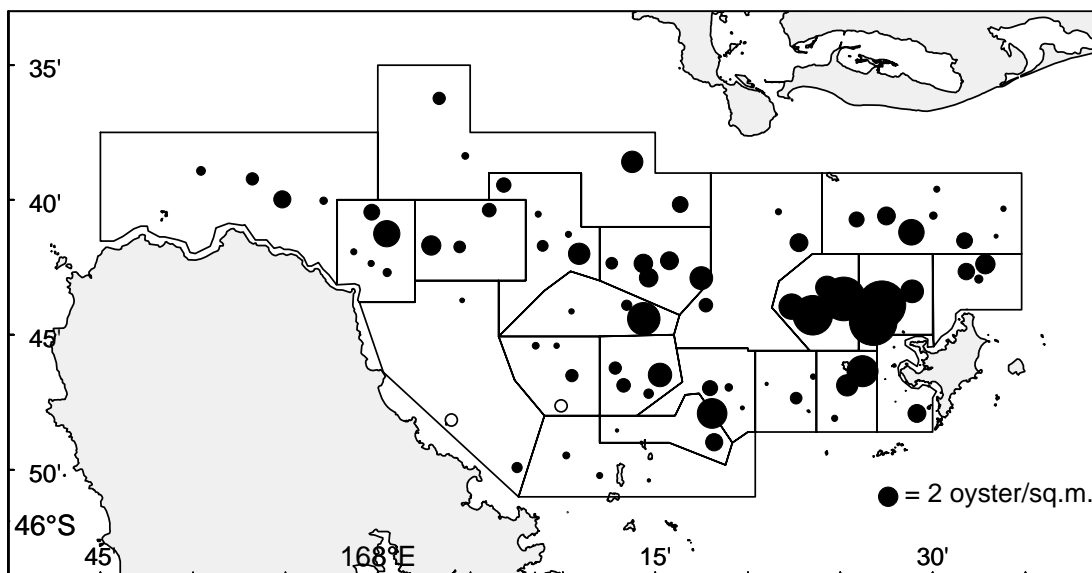


Figure 21: Relative density of live small oysters in the January 2005 survey. Stations with no oysters are denoted by open circles.

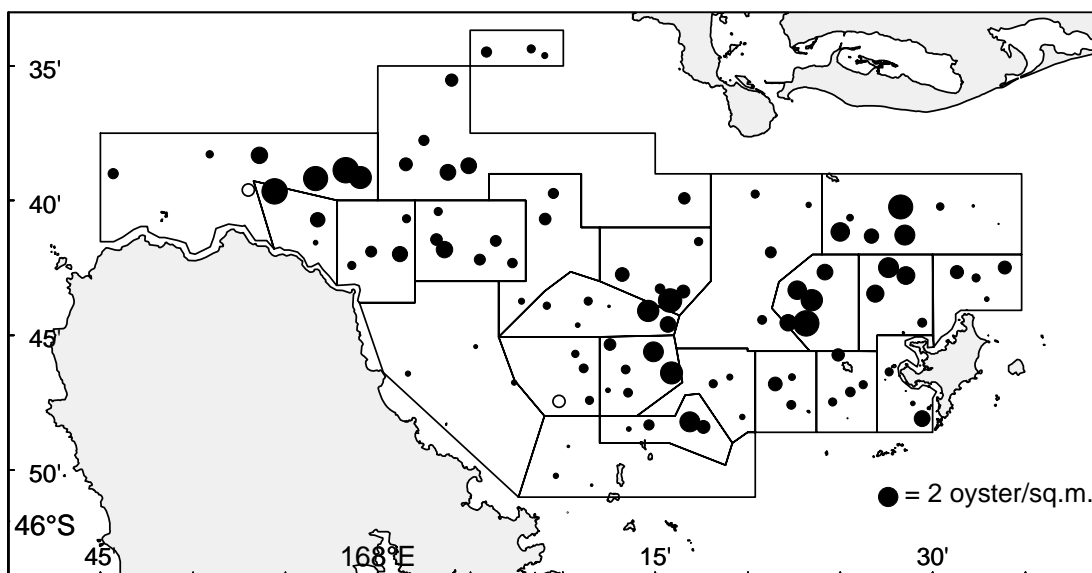


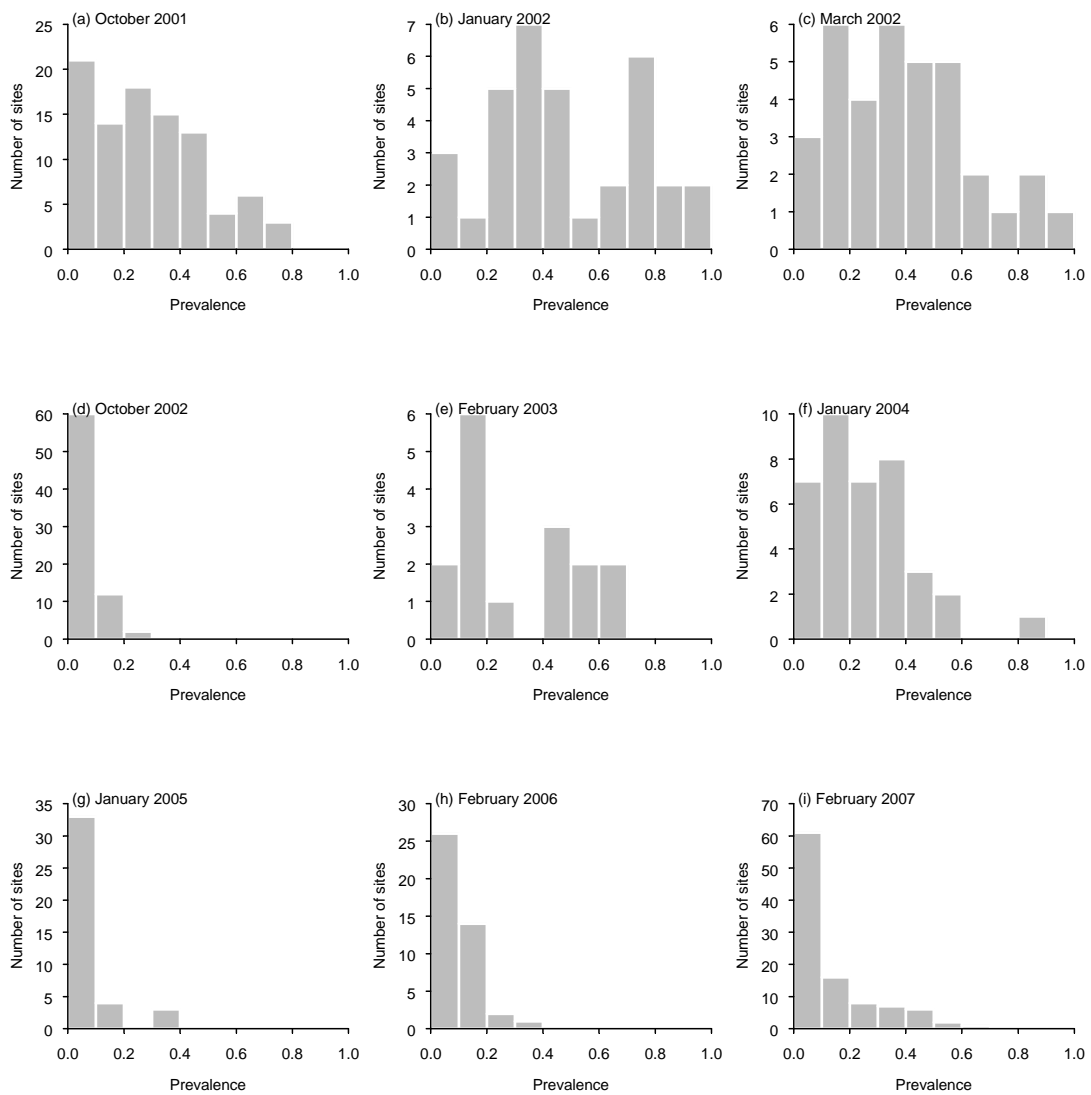
Figure 22: Relative density of live small oysters in the February 2007 survey. Stations with no oysters are denoted by open circles.

### 3.5 Estimated prevalence and intensity of bonamia infection

In general, the prevalence and intensity of infection by bonamia is highest in late summer to early autumn (January to March). Prevalence of infection by station for the October 2001, January 2002, March 2002, October 2002, February 2003, January 2004, January 2005, February 2006, and February 2007 surveys is shown in Figure 23.

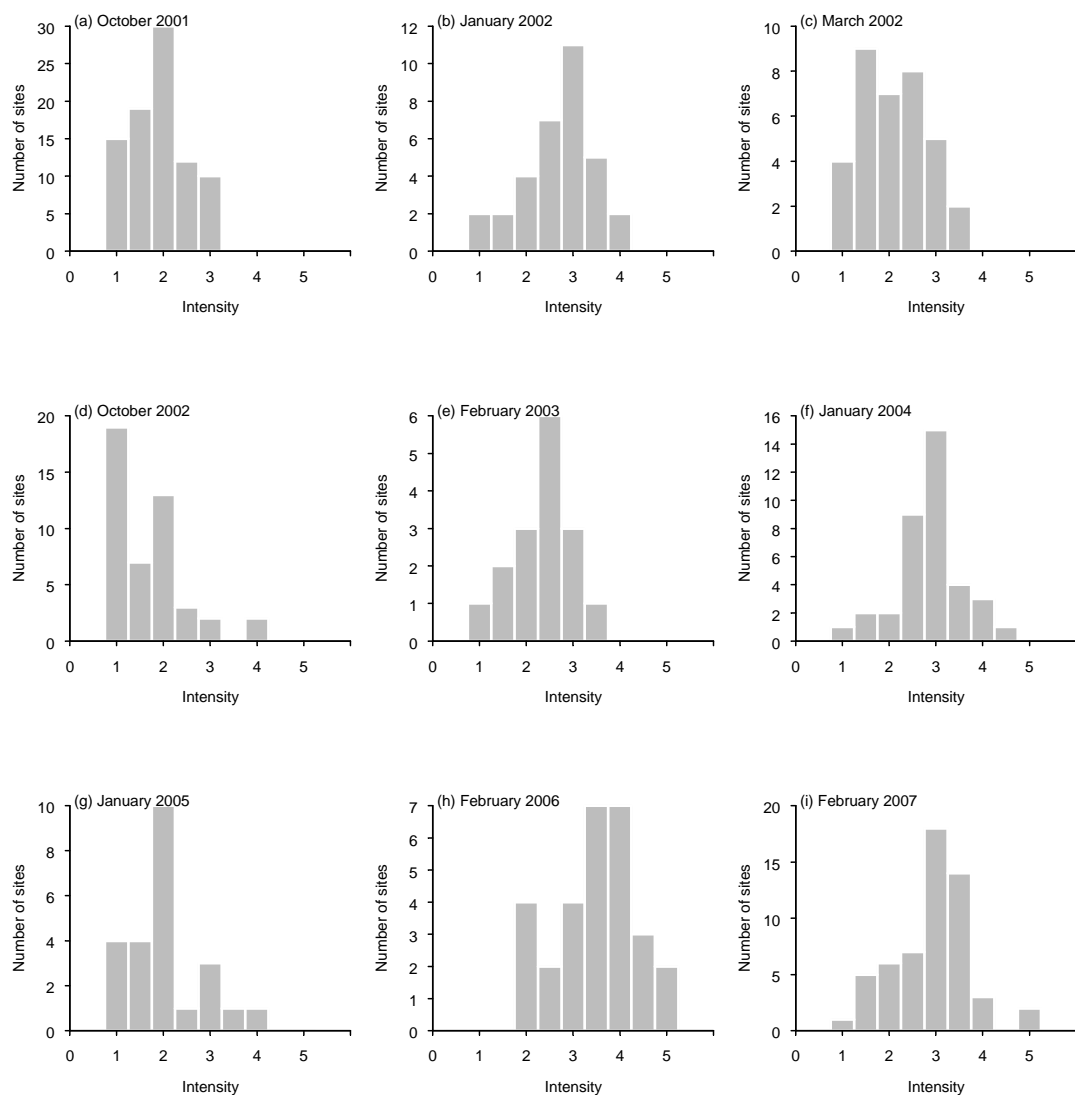
Heart imprints taken in February 2007 could not detect bonamia at 43% of the stations examined (Figure 23, Table 3A). Bonamia infection had a prevalence ranging from 4% to 52%, with more than half of these stations with prevalence of less than 20% (up to five infected oysters per sample of 25). The proportion of uninfected and lowly infected stations in February 2007 was similar to those in February 2006 and January 2005, but the remaining infected stations in 2007 generally had

higher prevalence of infection. However, this contrasts with 10% of stations in January 2004 and 24% in February 2003 with a prevalence of at least 50%.



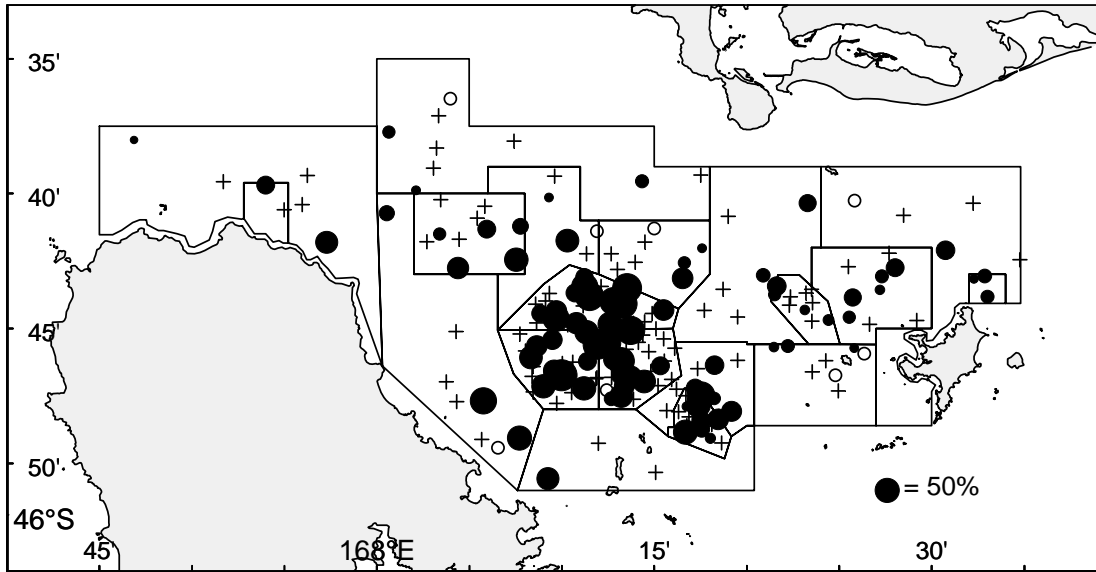
**Figure 23: Prevalence of *bonamia* infection at sites sampled in (a) October 2001, (b) January 2002, (c) March 2002, (d) October 2002, (e) February 2003, (f) January 2004, (g) January 2005, (h) February 2006, and (i) February 2007.**

Intensity of infection by station for the October 2001, January 2002, March 2002, October 2002, February 2003, January 2004, January 2005, February 2006, and February 2007 surveys are shown in Figure 24. Of all the individual oysters sampled, 12.5% had detectable infections (categories 1–5), and 7.9% 3+ infections. The percentage of all stations having a mean intensity of category 3+ infections was 47.0% (Figure 24). Category 3+ infected oysters were projected to reduce the recruited population size from 623.9 million oysters to 580.6 million oysters (Appendix 4 Table 4A).

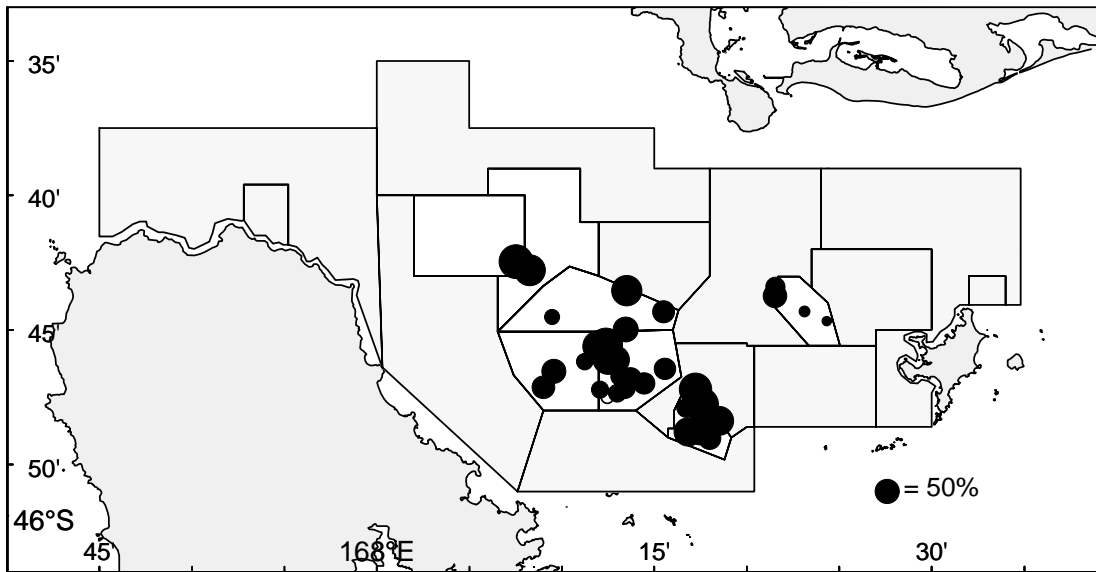


**Figure 24: Mean intensity of bonamia infection at sites sampled in (a) October 2001, (b) January 2002, (c) March 2002, (d) October 2002, (e) February 2003, (f) January 2004, (g) January 2005, (h) February 2006, and (i) February 2007.**

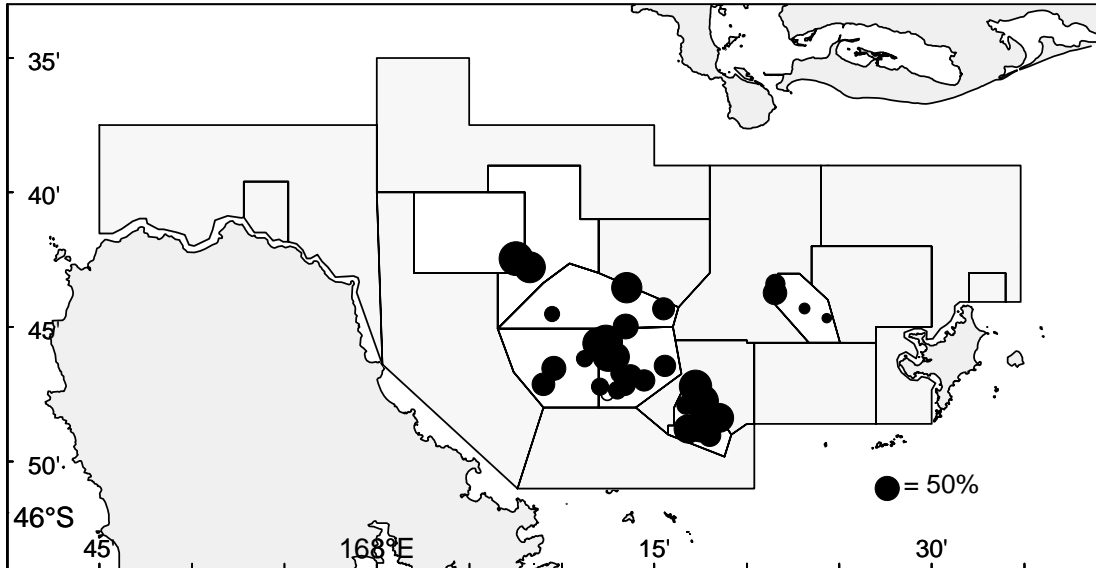
The prevalence from October 2001 to February 2007 is shown in Figures 25–33. By October 2001, high prevalence of infection was found south and east (Figure 25) of the original focus of infection in 1999/2000, where infection had severely reduced oyster density. Although prevalence was high in the same fishery areas in January and March of 2002 (Figures 26 & 27), prevalence was low throughout the fishery in October 2002 (Figure 28), possibly because sampling took place at a time of year when infection levels are generally low and difficult to detect. In 2003 and 2004, sampling was extended to eastern fishery area where oyster density was still relatively high and prevalence of infection widespread and relatively high (Figures 29 & 30). In January 2005, sampling was widespread throughout the fishery, with low numbers of infected stations and prevalence generally low except at some eastern stations with relatively higher oyster densities (Figure 31). A limited survey in February 2006 (Figure 32) and a more extensive survey in 2007 (Figure 33) found widespread infection, with almost all infection east of a line between Bluff Hill and Saddle Point, and the highest prevalence in eastern fishery areas. Because sampling for bonamia focused on commercial oyster fishery areas more likely to show infection, and to provide data to make projections of oyster mortality based on category 3+ infections, it is difficult to determine the distribution of infection over the whole fishery area and how it may have changed over time.



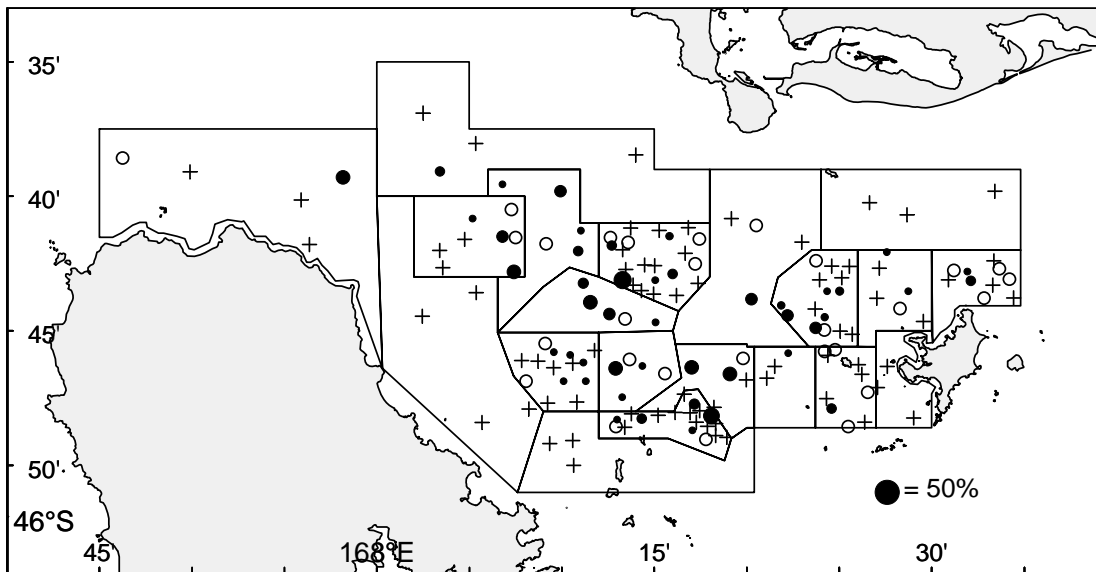
**Figure 25: Prevalence of infection of bonamia for recruit-sized oysters in the October 2001 survey. Stations with zero prevalence are denoted by an open circle, and stations that were not sampled for bonamia are denoted by a cross.**



**Figure 26: Prevalence of infection of bonamia for recruit-sized oysters in the January 2002 survey. Stations with zero prevalence are denoted by an open circle.**



**Figure 27: Prevalence of infection of bonamia for recruit-sized oysters in the March 2022 survey. Stations with zero prevalence are denoted by an open circle.**



**Figure 28: Prevalence of infection of bonamia for recruit-sized oysters in the October 2022 survey. Stations with zero prevalence are denoted by an open circle, and stations that were not sampled for bonamia are denoted by a cross.**

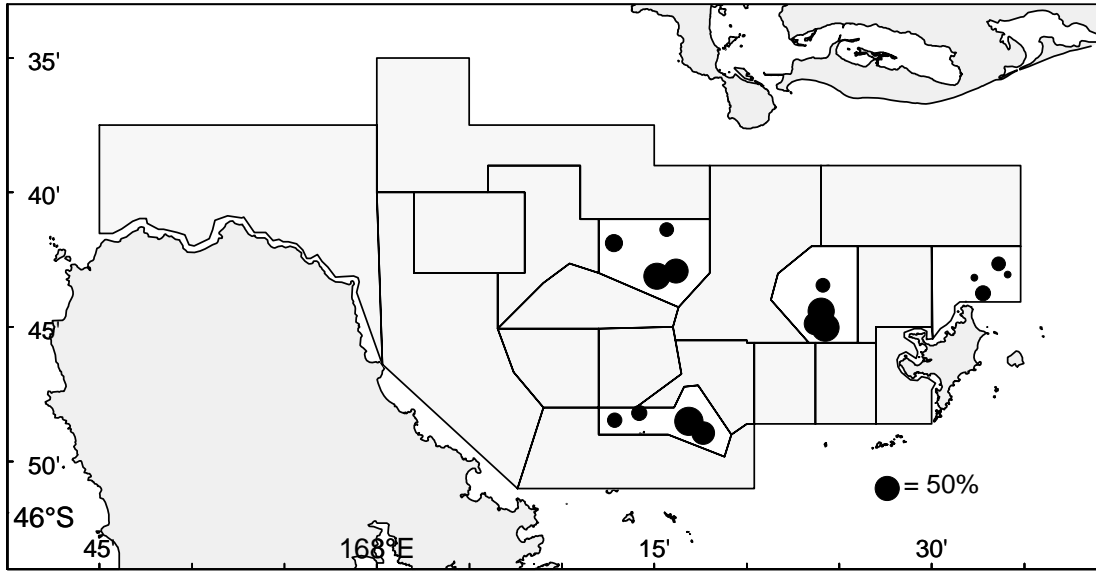


Figure 29: Prevalence of infection of bonamia for recruit-sized oysters in the February 2003 survey.

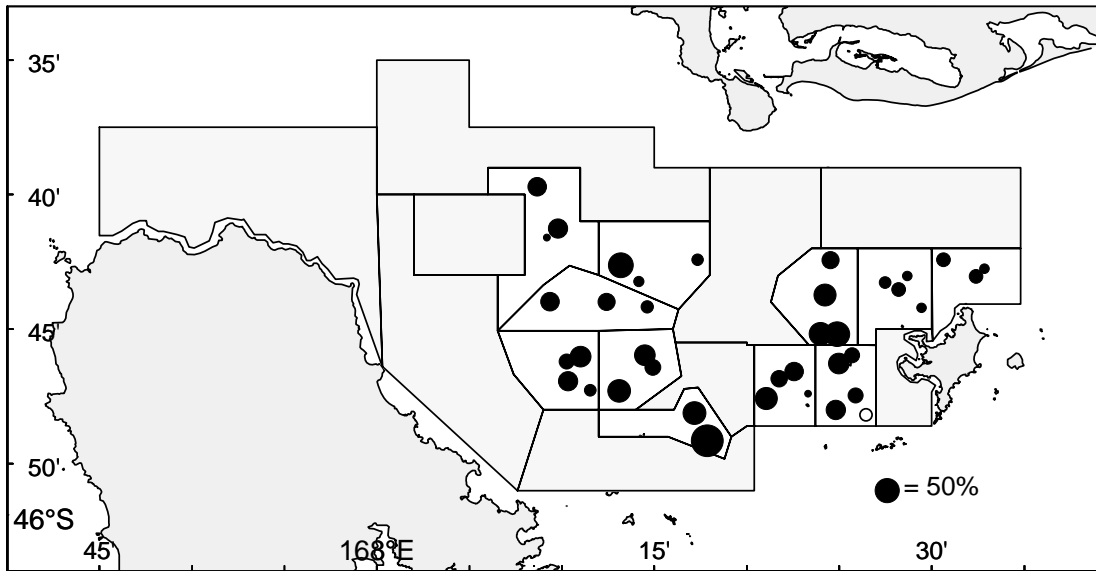
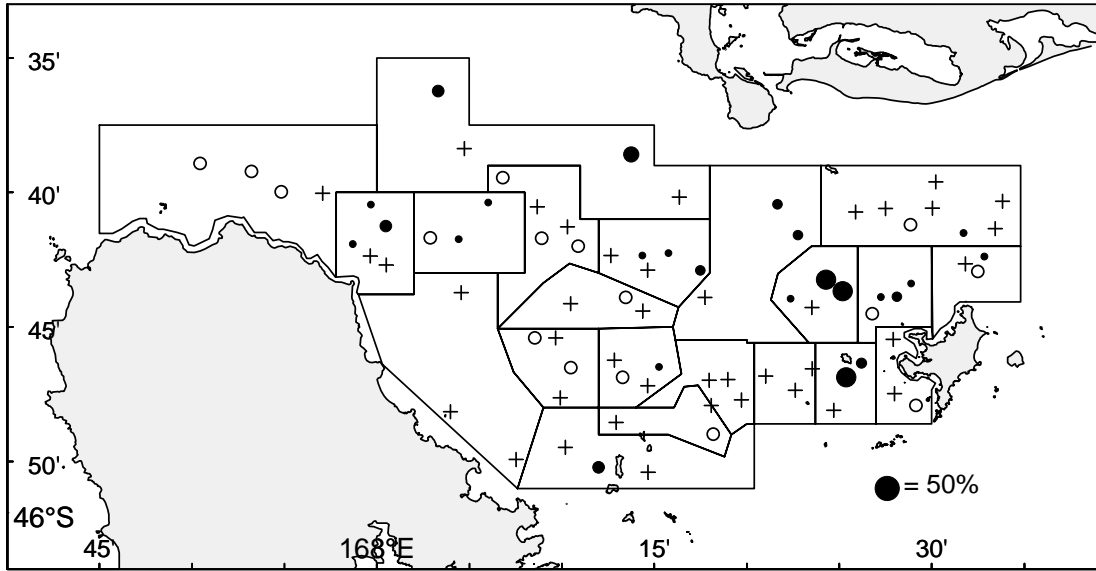
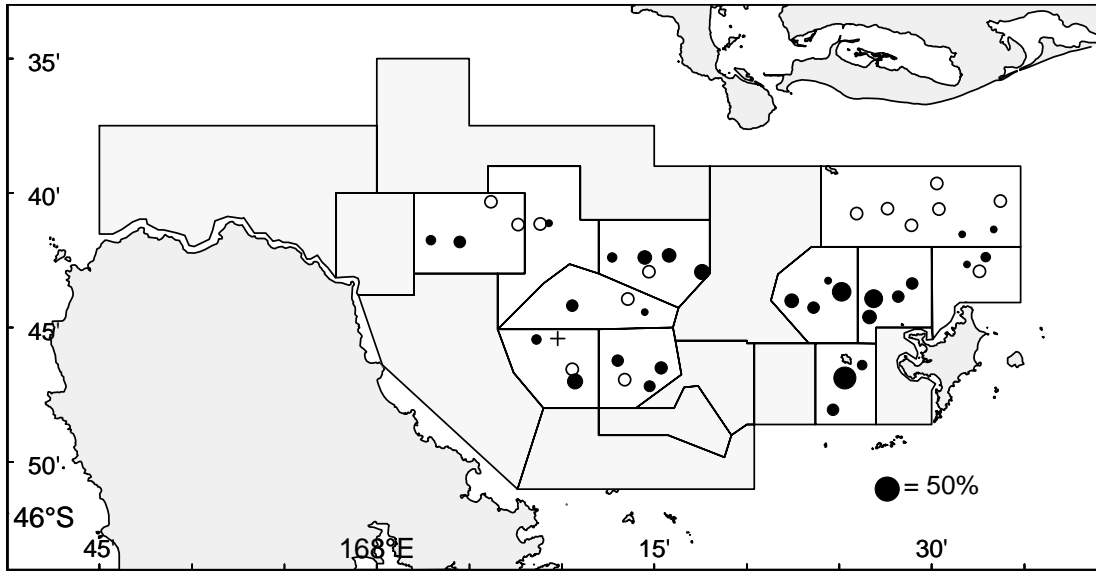


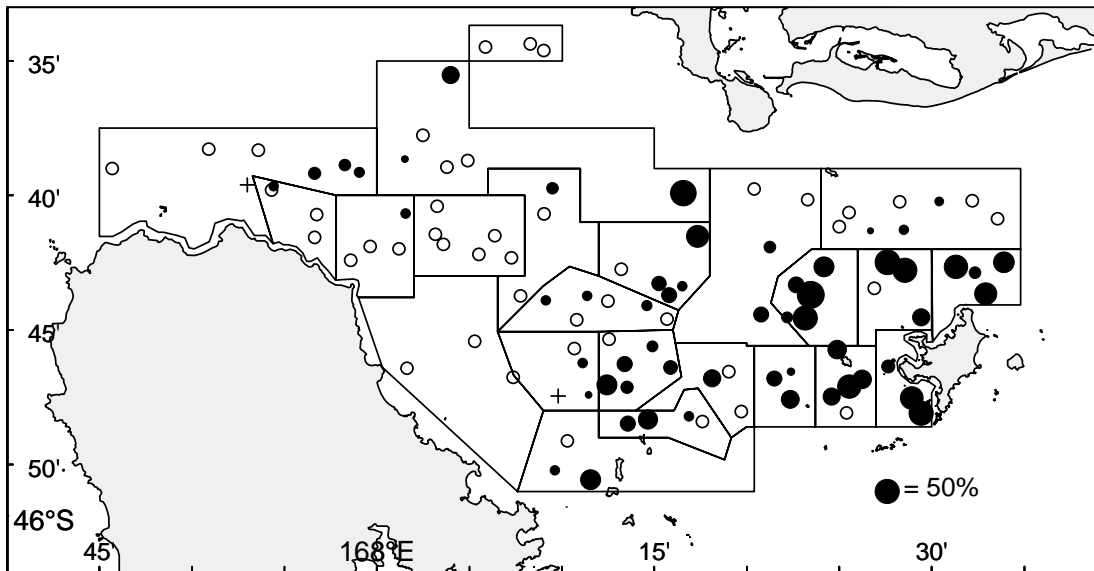
Figure 30: Prevalence of infection of bonamia for recruit-sized oysters in the January 2004 survey. Stations with zero prevalence are denoted by an open circle.



**Figure 31: Prevalence of infection of bonamia for recruit-sized oysters in the January 2005 survey. Stations with zero prevalence are denoted by an open circle, and stations that were not sampled for bonamia are denoted by a cross.**

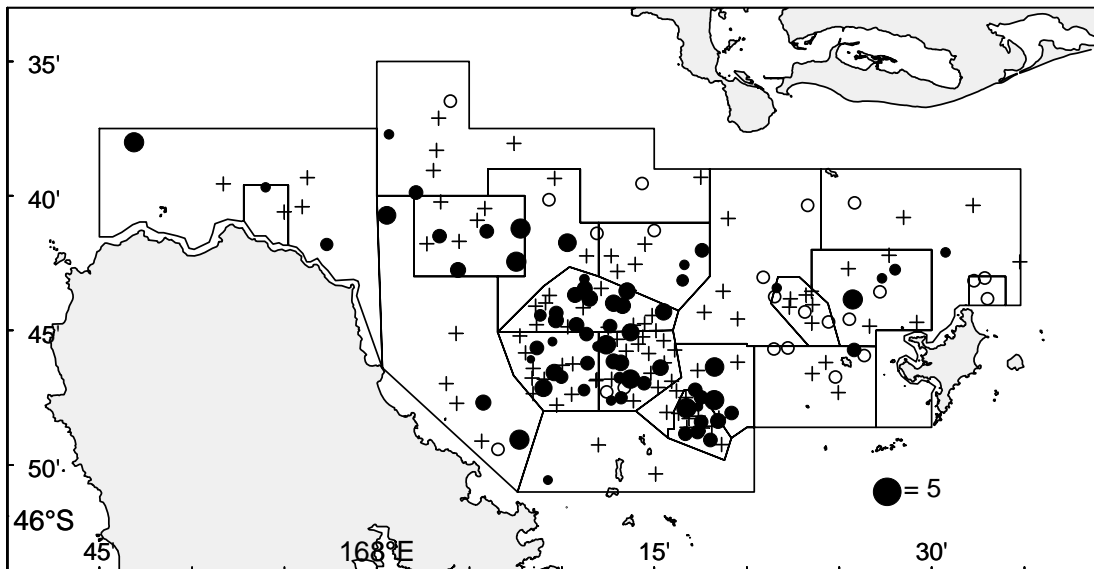


**Figure 32: Prevalence of infection of bonamia for recruit-sized oysters in the February 2006 survey. Stations with zero prevalence are denoted by an open circle, and stations that were not sampled for bonamia are denoted by a cross.**

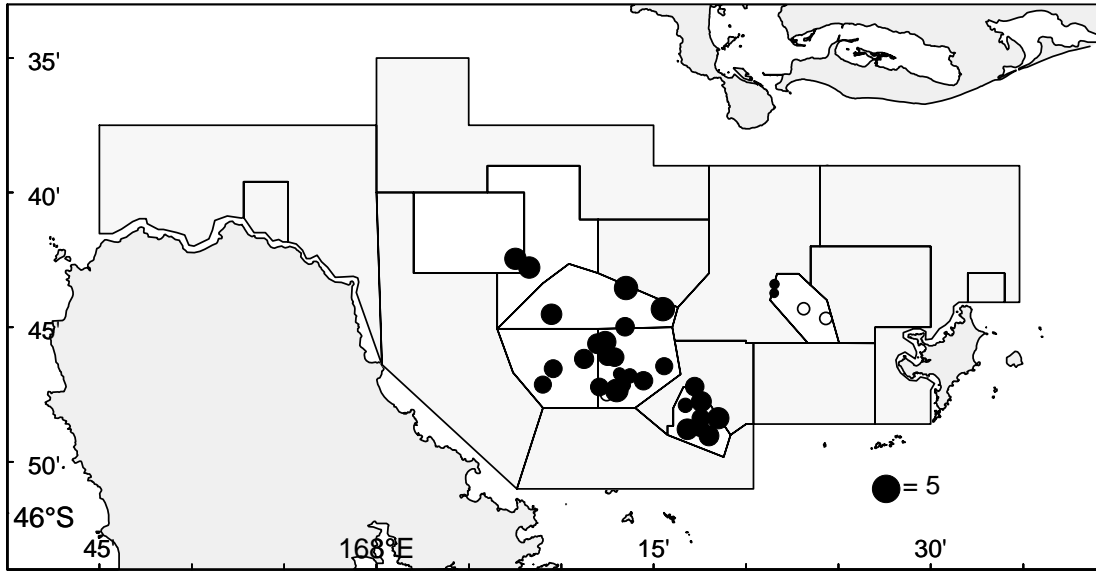


**Figure 33: Prevalence of infection of bonamia for recruit-sized oysters in the February 2007 survey. Stations with zero prevalence are denoted by an open circle, and stations that were not sampled for bonamia are denoted by a cross.**

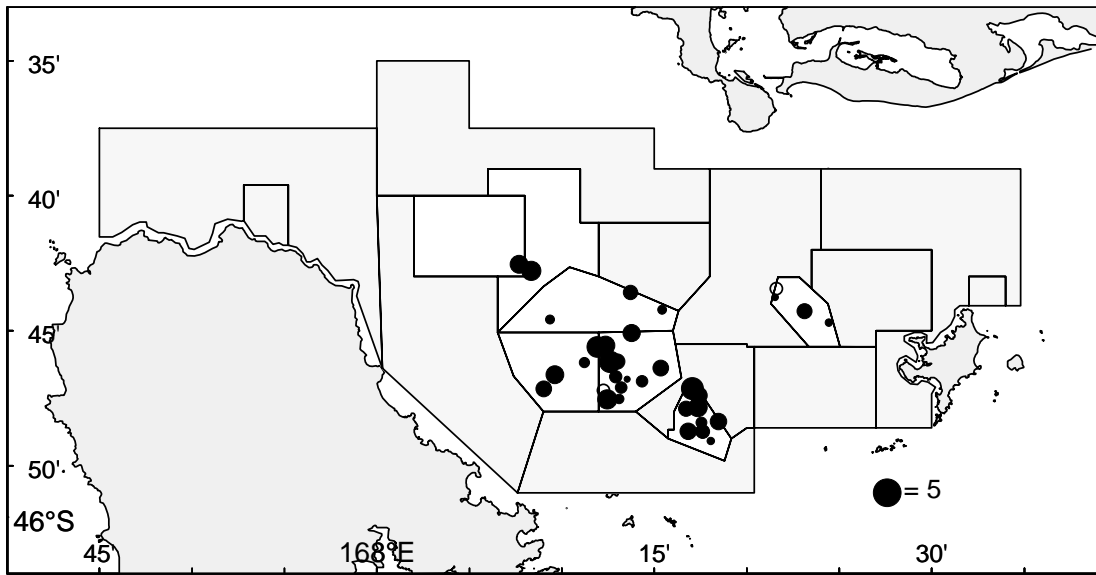
The intensity of infection from October 2001 to February 2007 is shown in Figures 34–42. Intensity of infection was mostly low in October 2001 (Figure 34) at a time of year when infections can be difficult to detect; higher in January 2002 (Figure 35) and March 2002 (Figure 36). In October 2002, intensity of infection was mainly low after oysters with category 3 and greater infection in January and March 2002 had probably died, but there were some relatively high intensity patches still present (Figure 37). The number of high intensity patches increased over 2003 and 2005 (Figures 38–40), and infected oysters had mainly high intensity of infection in 2006 and 2007 (Figures 41 & 42).



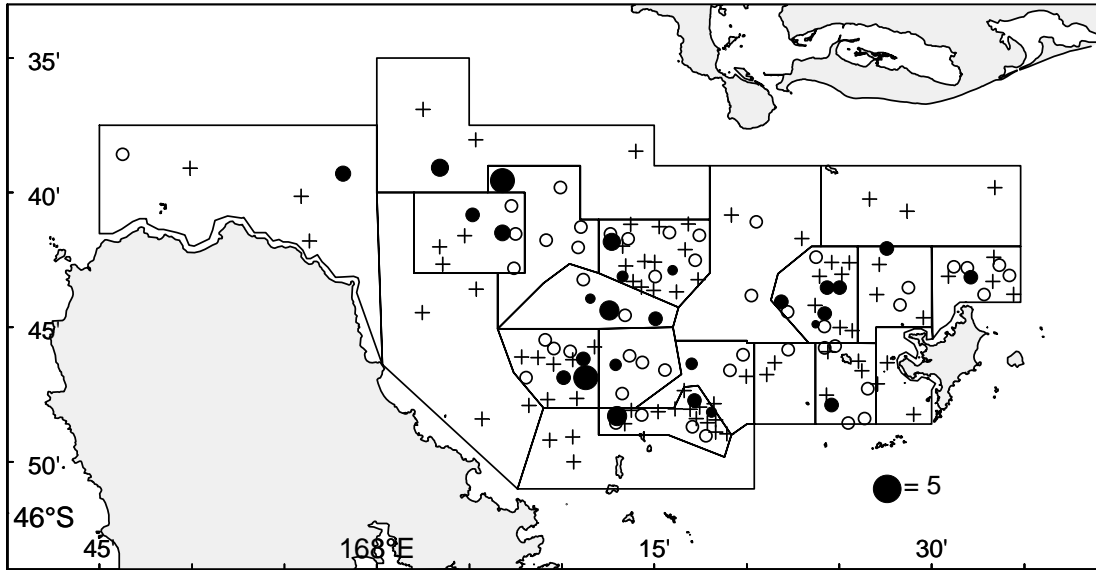
**Figure 34: Intensity of infection of bonamia for recruit-sized oysters in the October 2001 survey. Stations with zero prevalence are denoted by an open circle, and stations that were not sampled for bonamia are denoted by a cross.**



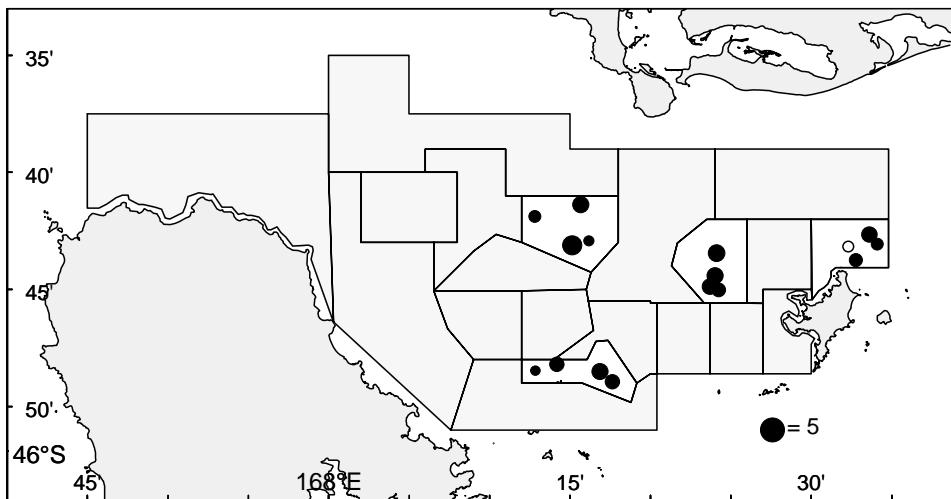
**Figure 35: Intensity of infection of bonamia for recruit-sized oysters in the January 2002 survey. Stations with zero prevalence are denoted by an open circle.**



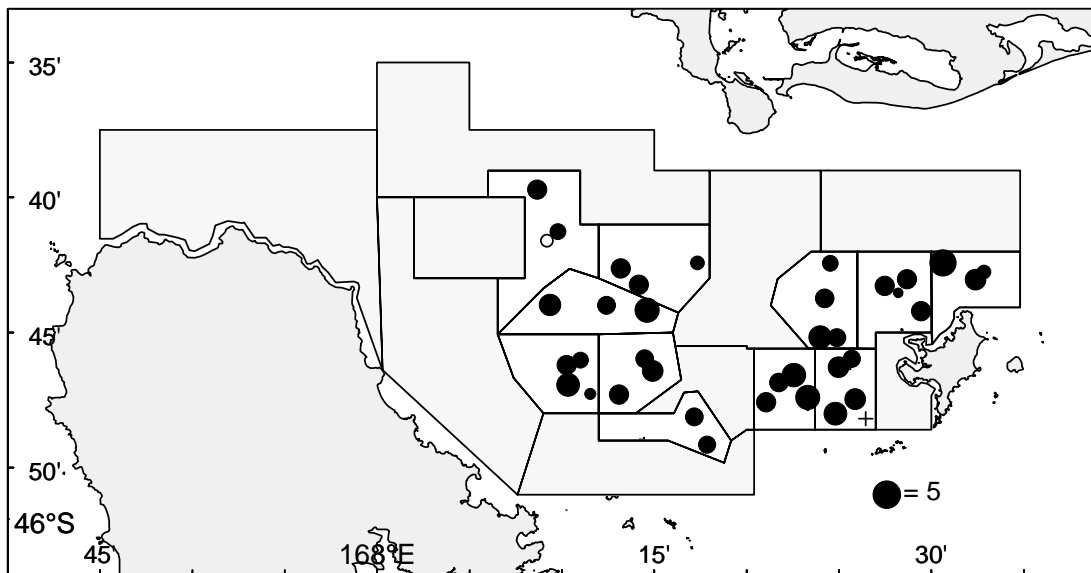
**Figure 36: Intensity of infection of bonamia for recruit-sized oysters in the March 2002 survey. Stations with zero prevalence are denoted by an open circle.**



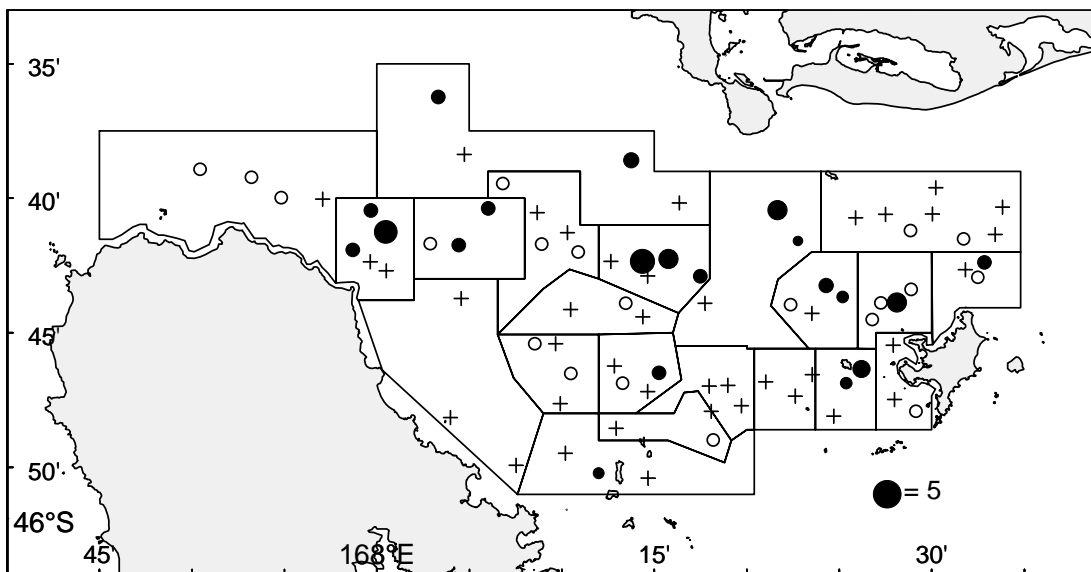
**Figure 37: Intensity of infection of bonamia for recruit-sized oysters in the October 2002 survey. Stations with zero prevalence are denoted by an open circle, and stations that were not sampled for bonamia are denoted by a cross.**



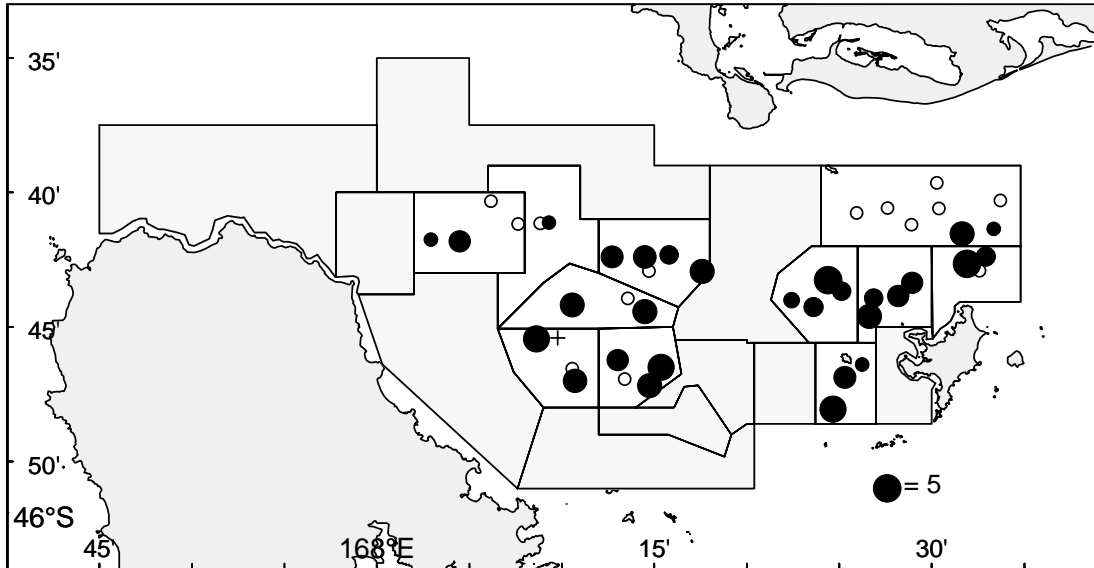
**Figure 38: Intensity of infection of bonamia for recruit-sized oysters in the February 2003 survey. Stations with zero prevalence are denoted by an open circle, and stations that were not sampled for bonamia are denoted by a cross.**



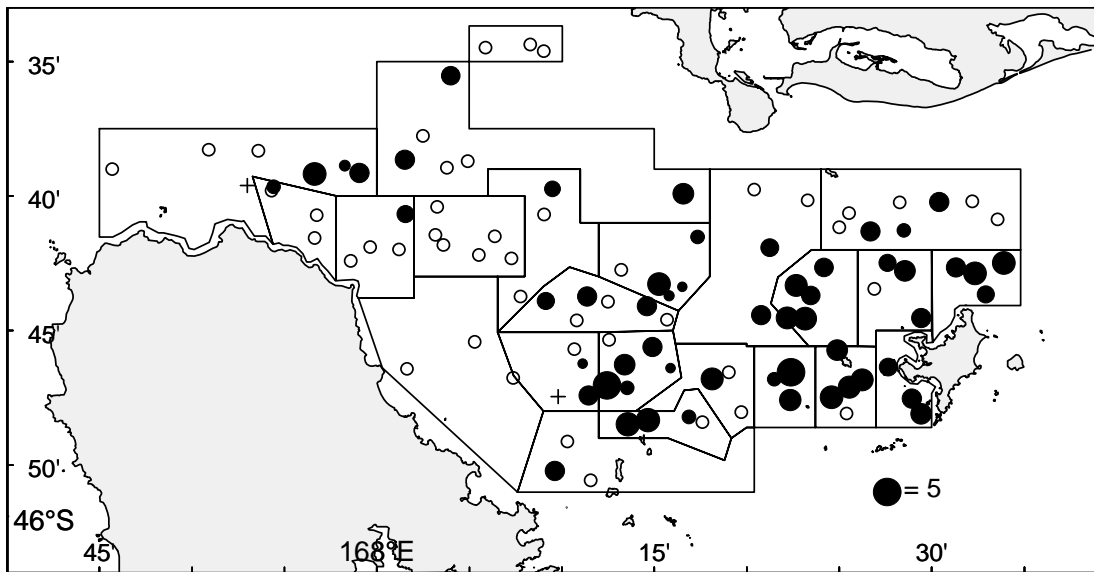
**Figure 39: Intensity of infection of bonamia for recruit-sized oysters in the January 2004 survey. Stations with zero prevalence are denoted by an open circle, and stations that were not sampled for bonamia are denoted by a cross.**



**Figure 40: Intensity of infection of bonamia for recruit-sized oysters in the January 2005 survey. Stations with zero prevalence are denoted by an open circle, and stations that were not sampled for bonamia are denoted by a cross.**



**Figure 41: Intensity of infection of bonamia for recruit-sized oysters in the February 2006 survey. Stations with zero prevalence are denoted by an open circle, and stations that were not sampled for bonamia are denoted by a cross**



**Figure 42: Intensity of infection of bonamia for recruit-sized oysters in the February 2007 survey. Stations with zero prevalence are denoted by an open circle, and stations that were not sampled for bonamia are denoted by a cross.**

### 3.6 Survey estimates of population size

Survey estimates of population size for recruit, pre-recruit, and small oysters from the February 2007 surveys by strata are shown in Tables 3–5. Table 6 compares survey estimates for recruit, pre-recruit, and small oysters from population surveys 1999–2007.

In February 2007, western background strata (B1) had the highest densities of recruit, pre-recruit, and small oysters (1.6–1.8 oysters/m<sup>2</sup>). Stations with relatively high densities (0.6–0.9 oysters/m<sup>2</sup>) of recruited oysters were found throughout the survey area, as were stations with relatively high small oyster densities (0.9–1.9 oysters/m<sup>2</sup>). The higher densities of pre-recruit oysters (0.6–0.8 oyster/m<sup>2</sup>) were mainly found in the central and east areas. Mean densities for recruit, pre-recruit and small oysters were 0.6, 0.5, and 0.8 oysters/m<sup>2</sup> respectively.

The oyster fishery appears to be in an early rebuilding phase, with the absolute population size increasing from 408 million oysters in 2005 to 623 million oysters in 2007. Estimates of recruited and pre-recruit oysters are rebuilding, similar to the trend observed from the October 1995 survey, with the exception of some persistent bonamia infection in 2007. Estimates of small oysters are lower than in 2005.

**Table 3: Absolute population survey estimates for recruited oysters: the number of stations sampled (No. stations), the mean oyster density per m<sup>2</sup> (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 (Area), by stratum for the February 2007 Foveaux Strait oyster survey.**

Stratum	No. Stations	Mean density	Density s.d.	Density c.v.	Mean population	Lower 95% CI	Upper 95% CI	Area (km <sup>2</sup> )
B1	8	1.60	0.42	0.26	183.1	80.5	321.8	114.4
B1A*	3	0.12	0.07	0.62	1.9	0.0	4.6	16.0
B2	6	0.65	0.20	0.30	85.5	32.6	158.6	131.0
B3	3	0.46	0.15	0.34	20.4	6.9	39.0	44.7
B4	3	0.33	0.15	0.45	32.3	3.2	69.1	98.7
B5	3	0.10	0.04	0.42	6.5	1.2	13.5	63.6
B6B	3	0.46	0.25	0.55	9.1	0.0	21.3	19.8
B7	4	0.22	0.06	0.26	18.7	8.6	33.1	86.1
B9	6	0.88	0.38	0.43	30.4	4.5	63.5	34.5
C1A	4	0.49	0.19	0.39	15.3	3.6	30.6	31.3
C2	4	0.57	0.16	0.29	12.5	5.1	22.7	21.9
C3	6	0.39	0.04	0.10	12.8	8.2	19.6	32.7
C4	4	0.72	0.18	0.25	19.0	8.8	33.5	26.3
C5	5	0.47	0.20	0.42	17.6	2.7	36.6	37.7
C6	4	0.32	0.11	0.36	7.5	2.2	14.7	23.5
C7	4	0.69	0.29	0.43	24.9	4.2	51.7	36.1
CB6A	8	0.39	0.18	0.46	30.3	3.0	64.0	77.1
CB8	6	0.83	0.22	0.27	22.4	9.9	40.0	26.8
CE5A	3	0.50	0.20	0.40	11.7	2.4	23.5	23.5
CE6	4	0.74	0.12	0.16	22.3	13.2	36.0	30.0
CE7A	3	0.42	0.24	0.56	9.9	0.0	23.4	23.6
E2	6	0.57	0.18	0.32	24.3	8.4	45.2	42.8
E4	3	0.20	0.07	0.36	5.6	1.6	10.8	28.0
Total	103	0.58	0.06	0.10	623.9	405.2	944.9	1070.3

\* Stratum B1A is outside the boundaries of the 1999 survey area and has been sampled only in 2006 and 2007 surveys.

**Table 4: Absolute population survey estimates for pre-recruit oysters: the number of stations sampled (No. stations), the mean oyster density per m<sup>2</sup> (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 (Area), by stratum for the February 2007 Foveaux Strait oyster survey.**

Stratum	No. Stations	Mean density	s.d.	Density c.v.	Mean population	Lower 95% CI	Upper 95% CI	Area (km <sup>2</sup> )
B1	8	1.12	0.38	0.34	128.2	40.9	242.4	114.4
B1A*	3	0.10	0.03	0.34	1.6	0.5	3.0	16.0
B2	6	0.51	0.11	0.21	67.0	34.5	114.5	131.0
B3	3	0.24	0.07	0.30	10.9	4.4	20.1	44.7
B4	3	0.08	0.05	0.56	8.2	0.0	19.4	98.7
B5	3	0.05	0.01	0.16	3.1	1.8	4.9	63.6
B6B	3	0.53	0.30	0.57	10.4	0.0	24.9	19.8
B7	4	0.15	0.02	0.11	13.2	8.4	20.5	86.1
B9	6	0.48	0.25	0.52	16.6	0.0	37.5	34.5
C1A	4	0.14	0.05	0.35	4.5	1.4	8.7	31.3
C2	4	0.80	0.50	0.62	17.6	0.0	42.9	21.9
C3	6	0.63	0.06	0.10	20.7	13.3	31.7	32.7
C4	4	0.64	0.27	0.42	16.8	3.1	34.8	26.3
C5	5	0.55	0.20	0.36	20.9	5.7	40.6	37.7
C6	4	0.21	0.08	0.41	4.9	1.0	10.0	23.5
C7	4	0.49	0.19	0.39	17.8	4.2	35.6	36.1
CB6A	8	0.36	0.15	0.42	27.6	4.8	56.5	77.1
CB8	6	0.84	0.34	0.41	22.5	4.3	46.3	26.8
CE5A	3	0.36	0.05	0.14	8.4	5.1	13.2	23.5
CE6	4	0.55	0.06	0.11	16.6	10.7	25.7	30.0
CE7A	3	0.21	0.12	0.59	5.0	0.0	12.1	23.6
E2	6	0.42	0.09	0.20	18.2	9.7	30.1	42.8
E4	3	0.13	0.06	0.50	3.5	0.1	7.8	28.0
Total	103	0.43	0.05	0.11	464.2	298.0	710.7	1070.3

\* Stratum B1A is outside the boundaries of the 1999 survey area and has been sampled only in 2006 and 2007 surveys.

**Table 5: Absolute population survey estimates for small oysters: the number of stations sampled (No. stations), the mean oyster density per m<sup>2</sup> (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 (Area), by stratum for the February 2007 Foveaux Strait oyster survey.**

Stratum	No. Stations	Mean density	s.d.	Density c.v.	Mean population	Lower 95% CI	Upper 95% CI	Area (km <sup>2</sup> )
B1	8	1.83	0.51	0.28	209.5	87.7	373.0	114.4
B1A*	3	0.38	0.11	0.29	6.1	2.5	11.2	16.0
B2	6	0.94	0.14	0.15	122.6	74.2	196.2	131.0
B3	3	0.49	0.14	0.28	22.0	9.3	39.9	44.7
B4	3	0.14	0.03	0.19	13.7	7.6	22.9	98.7
B5	3	0.08	0.04	0.52	5.4	0.1	12.2	63.6
B6B	3	0.61	0.38	0.62	12.1	0.0	30.1	19.8
B7	4	0.40	0.09	0.24	34.2	16.8	59.3	86.1
B9	6	0.72	0.34	0.47	24.7	1.7	53.5	34.5
C1A	4	0.28	0.10	0.35	8.7	2.7	16.7	31.3
C2	4	0.91	0.43	0.47	20.0	1.6	43.6	21.9
C3	6	1.88	0.38	0.20	61.4	32.8	102.7	32.7
C4	4	0.57	0.19	0.34	15.0	4.8	28.9	26.3
C5	5	1.12	0.45	0.40	42.2	8.3	85.7	37.7
C6	4	0.32	0.11	0.34	7.4	2.5	14.3	23.5
C7	4	0.65	0.20	0.31	23.6	8.9	43.8	36.1
CB6A	8	1.09	0.40	0.37	84.4	22.7	164.3	77.1
CB8	6	1.07	0.40	0.38	28.6	7.0	57.1	26.8
CE5A	3	0.56	0.24	0.43	13.1	1.9	27.2	23.5
CE6	4	1.46	0.36	0.25	43.9	20.7	77.0	30.0
CE7A	3	0.47	0.30	0.64	11.2	0.0	28.1	23.6
E2	6	0.73	0.15	0.20	31.2	16.7	51.4	42.8
E4	3	0.25	0.05	0.21	7.0	3.6	11.9	28.0
Total	103	0.79	0.07	0.09	848.1	555.4	1277.8	1070.3

\* Stratum B1A is outside the boundaries of the 1999 survey area and has been sampled only in 2006 and 2007 surveys.

**Table 6: Absolute population survey estimates for recruited, pre-recruit, and small oysters 1999–2007; mean population size (millions of oysters) with upper and lower 95 % confidence intervals in parenthesis. Estimates exclude stratum B1A.**

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)
2005 (January)	408 (253–628)	414 (247–652)	1 344 (845–2 056)
2007 (February)	622 (398–947)	463 (293–708)	842 (546–1273)

### 3.7 Survey estimates of the commercial population size

Survey estimates for recruit-sized oysters in designated commercial fishery areas from population surveys in 1999–2007 are compared in Table 7. Oyster densities in designated commercial fishery areas ranged from 0.4–0.7 oysters/m<sup>2</sup> in 2007. The mean density over all designated commercial fishery areas was 0.53 oysters/m<sup>2</sup>, similar to most exploratory and background areas in 2007.

Estimates of population size of recruited oysters in designated commercial areas have increased from 144 million in October 2002 to 196 million in February 2007.

**Table 7: Population estimates for recruited oysters in designated commercial areas, 1999–2007; 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 (Area).**

Year	No.	Mean	Density			Mean	Area
	stations	density	s.d.	c.v.	population	km <sup>2</sup>	
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
2005	80	0.44	0.05	0.12	164	(103–252)	366
2007	52	0.53	0.06	0.12	196	(124–300)	367

In 1995 and 1997, the commercial population used to estimate yield 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 areas. Although this method is no longer used for stock assessment, the Shellfish Working Group requested that these estimates are included in this report (Table 8) to allow some comparison with previous years.

**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).**

Stratum	No.	Mean	Density			Mean	Lower	Upper	Area
	stations	density	s.d.	c.v.	population	95% CI	95% CI	(km <sup>2</sup> )	
B1	8	1.27	0.51	0.40	145.5	32.0	290.8	114.4	
B9	6	0.44	0.44	1.00	15.3	0.0	49.3	34.5	
Total	103	0.15	0.06	0.37	160.8	38.2	316.7	1054.2	

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 historical threshold level) was 161 million oysters in 2007 compared to 118 million in 1999 and 109 million in 1997. In 1997–99, the catch limit was 14.95 million oysters. The 2007 estimate is higher with a same TACC, but a catch limit of 7.5 million oysters.

### 3.8 Recruitment

Recruitment did not appear to be affected by the high recruit and pre-recruit oyster mortalities and decreasing oyster densities between 1999 and 2005. The population size of small oysters had not changed from about 1300 million oysters in 1999, but the 2007 survey found a decrease in the population size of small oysters to 885 million oysters. Several factors could have caused this decline or affected the estimate; a time lag between the decline in densities of recruited oysters and the 2–3 years of low population levels, changes in the distribution of oyster densities to western areas where fewer spat and wings are normally attached to large oysters, or it could part of the normal variation in recruitment in the fishery.

## **4. DISCUSSION**

### **4.1 The 2007 survey**

Mortality of oysters from infection by bonamia is thought to occur between January and May (Hine 1991). We do not know if this period of mortality varies in timing and duration seasonally during epizootics. Sampling in late January to early February has proved to be the most reliable for detecting bonamia infections. The February 2007 survey gave the best opportunity to investigate the prevalence and intensity of infection in oysters by bonamia, and to provide estimates of mortality that may contribute to better management of the fishery. The small numbers of new clocks sampled and the presence of some gapers suggested recent and ongoing mortality from disease and a high likelihood of sampling representing the true status of infection.

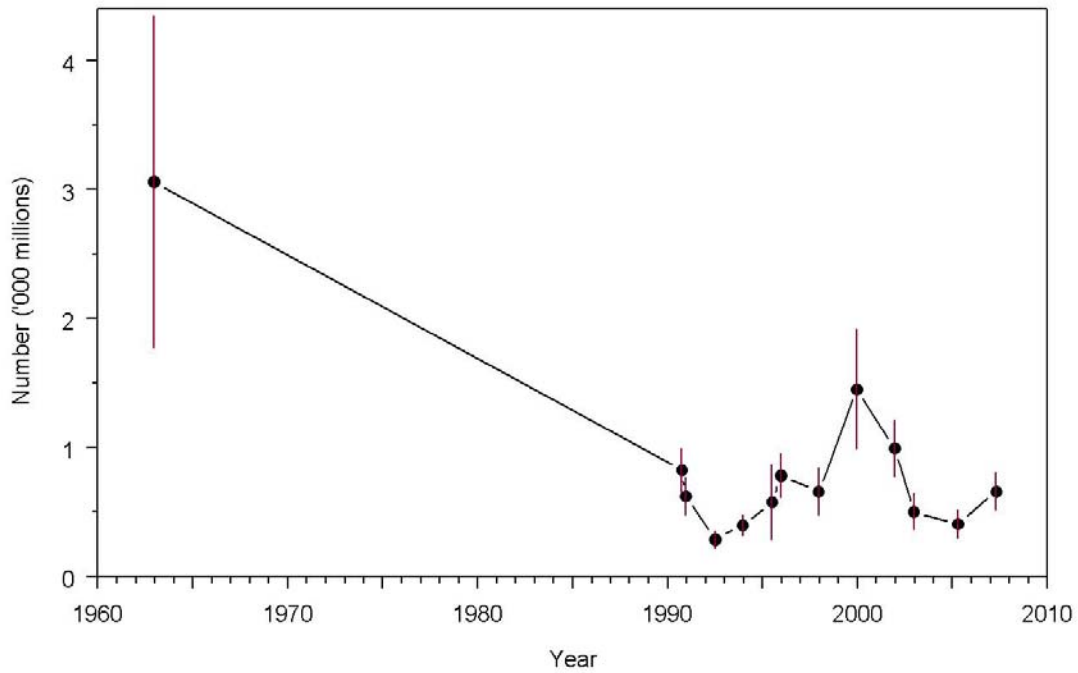
There is no information available to suggest that dredge efficiency has changed since it was last estimated in 1990 (Doonan et al. 1994). However, dredge saturation will affect dredge efficiency and underestimate densities of oysters and clocks. Dredges are assumed to have saturated at some part of the sample tow if they are landed more than 80% full. It is rare for dredge shots to be landed more than 70% full, and the 80% threshold may need to be revised, as saturation may occur at a lower level of dredge fullness.

The survey used the same GPS, sampling vessel, skipper, and operational procedures as for all surveys since October 2001. The results of this survey represent part of a series of snapshots of the changes in prevalence and intensity of infection, and resulting mortality, in the oyster population from bonamia since October 2001, and changes to the population size of oysters. Because these surveys tend to target commercial fishery areas with higher oyster densities and do not regularly sample the whole fishery area, the distribution of the three size groups of oysters is estimated with less certainty. As the survey retained the same strata as the October 2002 survey, oyster densities can be effectively compared in the same strata. The c.v.s for estimates of oyster population size were 10%, 11%, and 9% for recruit, pre-recruit, and small oysters respectively, lower than previous years.

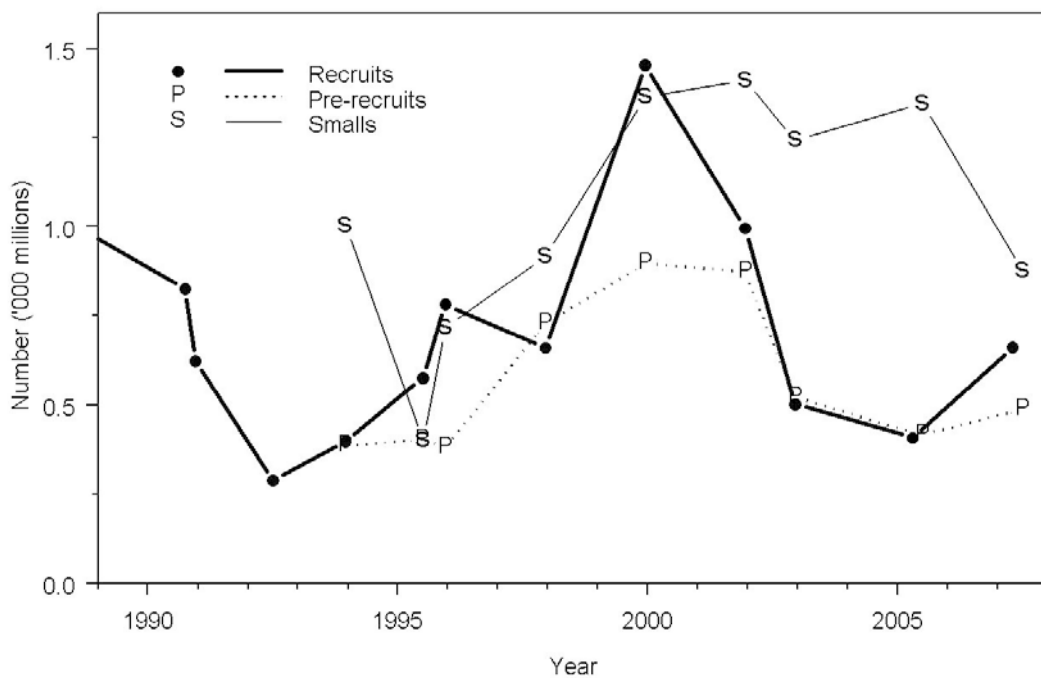
### **4.2 Estimates of population size**

The 2007 survey was not able to detect statistically significant changes in oyster population size of recruited, pre-recruit, or small oysters compared to those estimated from the October 2002 survey. However, the estimates of mean population size of recruit sized oysters show an increase from 408 (253–628) million oysters in January 2005 to 622 (398–947) million oysters in February 2007 (Figure 43) and is consistent with the projected recruit size stock abundance from the 2005 stock assessment. Overall, oyster densities are still low in the fishery compared to pre-disease levels, but localised rebuilding of commercial areas in the central and western fishery detected in 2005 and 2006 is continuing in 2007. Mean recruit size oyster density over the whole fishery ( $0.6/\text{m}^2$ ) in 2007 has increased from that in 2005 ( $0.4$  oysters/ $\text{m}^2$ ).

Populations of recruited oysters are rebuilding, pre-recruit are similar, and small oysters have probably declined from 2005. These patterns are similar to those observed in the previous rebuilding phase of the oyster fishery in 1990–99 (Figure 44). The decline in small oysters could reflect a time lag between low recruit densities (2002–05) and low production, and may also reflect the change in the distribution of oyster densities to western areas where fewer spat and wings normally occur on oysters. Recruitment to the fishery is currently exceeding bonamia mortality.



**Figure 43: Estimates of recruit sized oyster population in Foveaux Strait 1963–2007.**



**Figure 44: Estimates of mean population size for recruited, pre-recruit, and small oysters 1990–2007.**

The population size of oysters in designated commercial fishery areas has increased from 164 million oysters (103–252) in 2005 to 196 million oysters (124–300) in 2007. The area of the designated commercial areas increased from 173 km<sup>2</sup> in 2002 to 367 km<sup>2</sup> in 2005, and remained the same in 2007. Oyster density was halved from 0.83 oysters/m<sup>2</sup> to 0.44/m<sup>2</sup> in 2005, but slightly increased to 0.53 /m<sup>2</sup> in 2007. Mean oyster density is higher in some background areas; the highest densities of recruit-sized oysters were from central and western areas (strata B1, B9, CB8, B5, C4, C7, B2, C2, and E2).

A commercial catch rate of 6–8 sacks per hour provided a reasonable economic return to fishers (paid by how much they caught) in the 1970s and 1980s; this rate corresponds to 400 oysters per standard survey tow. Although it has no biological basis, it has been used as an indicator of commercial densities. Estimates of the proportion of oysters above 400 oysters per standard survey tow over the entire fishery area 2001–07 are given in Table 9. Only background strata B1 and B9 that collectively cover about 15% of the entire fishery area had mean catch rates above 400 oysters per standard survey tow.

**Table 9: Estimates of the proportion of oysters above 400 oysters per standard survey tow over the entire fishery area 2001–07; the number of stations sampled (No. stations), the mean oyster density per m<sup>2</sup> (Mean density), standard deviation (s.d.) of the density estimate, coefficient of variation (CV) of the population estimate, mean population size (Mean population with upper and lower 95 % confidence intervals in parenthesis), and the area of each survey (Area).**

Year	No. stations	Mean density	s.d.	c.v.	Mean population	population 95% CI	Area km <sup>2</sup>
2001	192	0.59	0.10	0.17	624	(359–1012)	1054
2002	155	0.17	0.06	0.33	178	(57–331)	1054
2005	80	0.03	0.02	0.58	33	(0–78)	1054
2007	104	0.19	0.07	0.36	204	(60–403)	1070

### 4.3 Distribution of oysters

The survey shows oyster populations in the central and western areas first affected by mortality from bonamia are rebuilding, and eastern areas have been further reduced by bonamia mortality. Spatial patterns are similar for all three size groups of oysters. The longer temporal pattern of oyster density distribution is similar to that observed between 1986 and 1999. There was no sampling for bonamia infection between October 1995 and 1999, and there are no data on the status of infection over that period to confirm whether that rebuilding event occurred in the absence of disease mortality.

### 4.4 Recruitment

Although there is no evidence of a stock recruit relationship, low oyster densities may have an effect on recruitment processes, both in terms of larval production and limiting surfaces for larval settlement and survival. Numbers of small oysters used to index recruitment were not affected by the high recruit and pre-recruit oyster mortalities and decreasing oyster densities until 2007. The population size of small oysters has declined by a third, from a long-term mean of about 1 300 million to 842 million oysters. A similar pattern of declining numbers of small oysters two years after low levels of recruit size oysters were recorded was observed in 1993. The distributions of small oysters in 2007 suggest continued rebuilding of oyster populations in western and central fishery areas.

### 4.5 Status of infection

The February 2007 survey of the status of bonamia infection found few oysters sampled had detectable infections, but most of those oysters infected had intense infections likely to kill them. Almost all of this infection was in eastern fishery areas where oyster densities were already low from disease mortality. The estimate of projected mortality based on category 3 and greater infections is not expected to have a significant effect on the rebuilding of the stock.

## 4.6 Status of the OYU 5 fishery

Mortality from infection by bonamia is the principal driver of oyster population dynamics in Foveaux Strait. Since 2004, model projections of recruit-sized stock abundance under different catch limits and mortality levels (from bonamia) have been used for the Foveaux Strait oyster stock assessment. In 2007, model estimates of population size were similar to projections from the 2005 stock assessment (624 million oysters). While uncertainty exists in levels of future recruitment and continued bonamia related mortality, projections from the Foveaux Strait oyster stock assessment model indicate that current catch limits are unlikely to have any significant impact on future stock levels. Instead, future disease mortality will determine future stock status. Depending on the level of assumed disease mortality, the median projected status in 2010 ranged from about 60% more than the current level (with nil disease mortality) to about the same as the current level (assuming disease mortality of 0.2/y). Over the summer of 2007, mortality from bonamia in category 3 or greater infections in oysters was estimated to reduce the oyster population by 43 million oysters (compared to the catch limit of 7.5 million) to 581 million recruit size oysters, a mean disease mortality of 6.9%. At this level of mortality, the model trajectories showed continued rebuilding of the fishery.

## 5. ACKNOWLEDGMENTS

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# APPENDIX 1: STATION DATA RECORD FORM

## FOVEAUX STRAIT OYSTER SURVEY, STATION DATA RECORD

Vessel name					Recorder					
<input style="width: 100%;" type="text"/>					.....					
Date	Day	Month	Year	Time NZST	Station no.	Stratum				
	<input style="width: 20px;" type="text"/>	<input style="width: 20px;" type="text"/>	<input style="width: 20px;" type="text"/>	<input style="width: 20px;" type="text"/>	<input style="width: 20px;" type="text"/>	<input style="width: 20px;" type="text"/>				
Start position	Latitude			Longitude			Depth (m)	Speed (knots)		
	<input style="width: 20px;" type="text"/>	<input style="width: 20px;" type="text"/>	<input style="width: 20px;" type="text"/>	S	<input style="width: 20px;" type="text"/>	<input style="width: 20px;" type="text"/>	<input style="width: 20px;" type="text"/>	<input style="width: 20px;" type="text"/>	<input style="width: 20px;" type="text"/>	
Finish position	Latitude			Longitude						
	<input style="width: 20px;" type="text"/>	<input style="width: 20px;" type="text"/>	<input style="width: 20px;" type="text"/>	S	<input style="width: 20px;" type="text"/>	<input style="width: 20px;" type="text"/>				
Number of Oysters ≥58 mm	Live	Gapers	New clocks*	Old clocks**						
	<input style="width: 20px;" type="text"/>	<input style="width: 20px;" type="text"/>	<input style="width: 20px;" type="text"/>	<input style="width: 20px;" type="text"/>						
Number of Oysters 50-57 mm	Live	Gapers	New clocks*	Old clocks**		Number of live oysters 10-50 mm				
	<input style="width: 20px;" type="text"/>	<input style="width: 20px;" type="text"/>	<input style="width: 20px;" type="text"/>	<input style="width: 20px;" type="text"/>		<input style="width: 20px;" type="text"/>				
% fullness of dredge including sediment			Live Bryozoa	Bycatch photo numbers						
<input style="width: 40px;" type="text"/>			<input style="width: 20px;" type="text"/>	<input style="width: 40px;" type="text"/>						
Wind force, beaufort		Did the dredge fish well? Y=1 or N=2		Bonamia sample?		Comments?				
<input style="width: 20px;" type="text"/>		<input style="width: 20px;" type="text"/>		<input style="width: 20px;" type="text"/>		<input style="width: 20px;" type="text"/>				

If N please repeat tow and record both tows. Strike out repeated tow with diagonal line across page

### Sediment type

Circle the main type (one only)

Weed	Shell	Shell/sand	Shell/gravel	Pea gravel	Sand	Silt	Sponges	Bryozoa
<input style="width: 20px; text-align: center;" type="text"/>	<input style="width: 20px; text-align: center;" type="text"/>	<input style="width: 20px; text-align: center;" type="text"/>	<input style="width: 20px; text-align: center;" type="text"/>	<input style="width: 20px; text-align: center;" type="text"/>	<input style="width: 20px; text-align: center;" type="text"/>	<input style="width: 20px; text-align: center;" type="text"/>	<input style="width: 20px; text-align: center;" type="text"/>	<input style="width: 20px; text-align: center;" type="text"/>

Comments: \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

1 Nautical mile = 1.853 km

\* New clocks are hinged shells of recently dead oysters, inner shell glossy with no fouling except the odd speck of coralline

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

Counts of oysters and clocks to include samples taken for population size and *Bomania*



### APPENDIX 3

**Table 3A: Estimated prevalence and intensity of infection by bonamia, February 2007 by stratum and station. For each station, where  $r$  is the number of oysters infected with bonamia and  $n$  the number of oysters in the sample, density is the density of recruit-sized oysters, prevalence is defined as the proportion of oysters in a sample with at least one bonamia cell observed (i.e., the number of stage 1–5 oysters divided by the number of all oysters examined in the sample), and 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 bonamia cell observed). Two stations could not be sampled.**

Stratum	Station	$r$	NA	Prevalence	Density	Intensity
B1	7	3	25	00.12 (00.30-00.31)	3.42	1.67
B1	9	3	24	00.12 (00.30-00.32)	2.75	3.67
B1	109	0	25	00.00 (00.00-00.14)	0.28	0
B1	202	NA	NA	(-)	0	NA
B1	203	2	21	00.10 (00.10-00.30)	1.52	3
B1	204	0	25	00.00 (00.00-00.14)	0.83	0
B1	205	2	25	00.80 (00.10-00.26)	1.93	2
B1	208	0	25	00.00 (00.00-00.14)	2.08	0
B1A	10	0	23	00.00 (00.00-00.15)	0.26	0
B1A	11	0	14	00.00 (00.00-00.23)	0.07	0
B1A	12	0	3	00.00 (00.00-00.71)	0.02	0
B2	16	0	25	00.00 (00.00-00.14)	1.08	0
B2	17	7	13	00.54 (00.25-00.81)	0.29	3.29
B2	18	0	25	00.00 (00.00-00.14)	0.38	0
B2	19	1	24	00.40 (00.00-00.21)	0.55	3
B2	116	6	25	00.24 (00.90-00.45)	0.21	2.83
B2	117	0	25	00.00 (00.00-00.14)	1.41	0
B3	20	3	25	00.12 (00.30-00.31)	0.17	2.33
B3	21	0	25	00.00 (00.00-00.14)	0.69	0
B3	22	0	25	00.00 (00.00-00.14)	0.52	0
B4	23	0	23	00.00 (00.00-00.15)	0.22	0
B4	24	0	25	00.00 (00.00-00.14)	0.62	0
B4	123	0	25	00.00 (00.00-00.14)	0.15	0
B5	26	1	3	00.33 (00.10-00.91)	0.02	1
B5	27	2	25	00.80 (00.10-00.26)	0.16	3
B5	126	0	22	00.00 (00.00-00.15)	0.13	0
B6B	30	3	7	00.43 (00.10-00.82)	0.05	3
B6B	129	10	20	00.50 (00.27-00.73)	0.4	3.3
B6B	130	3	21	00.14 (00.30-00.36)	0.92	2.67
B7	32	0	25	00.00 (00.00-00.14)	0.36	0
B7	33	0	21	00.00 (00.00-00.16)	0.08	0
B7	35	5	25	00.20 (00.70-00.41)	0.21	3
B7	132	3	25	00.12 (00.30-00.31)	0.22	2.67
B9	36	2	22	00.90 (00.10-00.28)	2.66	3
B9	37	0	5	00.00 (00.00-00.52)	0.03	0
B9	38	2	25	00.80 (00.10-00.26)	0.8	2.5
B9	136	2	25	00.80 (00.10-00.26)	0.58	3
B9	137	0	10	00.00 (00.00-00.31)	0.28	0
B9	138	0	25	00.00 (00.00-00.14)	0.95	0
C1A	58	NA	NA	(-)	0	NA
C1A	59	0	24	00.00 (00.00-00.14)	0.46	0
C1A	60	2	25	00.80 (00.10-00.26)	0.93	1.5
C1A	61	1	25	00.40 (00.00-00.20)	0.56	3
C2	62	7	22	00.32 (00.14-00.55)	0.55	3.86

Stratm	Station	r	NA	Prevalance	Density	Intensity
C2	63	0	23	00.00 (00.00-00.15)	0.5	0
C2	162	5	25	00.20 (00.70-00.41)	0.21	3.8
C2	264	2	24	00.80 (00.10-00.27)	1.01	2
C3	66	8	13	00.62 (00.32-00.86)	0.45	2.87
C3	67	2	19	00.11 (00.10-00.33)	0.46	3.5
C3	68	5	23	00.22 (00.70-00.44)	0.39	3.6
C3	69	5	15	00.33 (00.12-00.62)	0.38	2.8
C3	70	4	8	00.50 (00.16-00.84)	0.2	3.75
C3	71	7	25	00.28 (00.12-00.49)	0.46	3.29
C4	72	11	24	00.46 (00.26-00.67)	0.55	3
C4	74	3	25	00.12 (00.30-00.31)	0.55	3.67
C4	172	9	25	00.36 (00.18-00.56)	1.27	3.78
C4	173	10	25	00.40 (00.21-00.61)	0.52	2.5
C5	76	4	22	00.18 (00.50-00.40)	0.15	3.75
C5	77	2	25	00.80 (00.10-00.26)	1.15	1.5
C5	78	5	25	00.20 (00.70-00.41)	0.37	1.6
C5	79	2	5	00.40 (00.50-00.85)	0.04	2
C5	80	0	25	00.00 (00.00-00.14)	0.62	0
C6	81	7	25	00.28 (00.12-00.49)	0.36	3.57
C6	82	0	5	00.00 (00.00-00.52)	0.03	0
C6	83	6	25	00.24 (00.90-00.45)	0.59	3.67
C6	84	8	17	00.47 (00.23-00.72)	0.29	3.5
C7	85	0	16	00.00 (00.00-00.21)	0.13	0
C7	86	2	25	00.80 (00.10-00.26)	0.55	2.5
C7	87	0	25	00.00 (00.00-00.14)	1.52	0
C7	88	0	24	00.00 (00.00-00.14)	0.57	0
CB6A	39	0	3	00.00 (00.00-00.71)	0.01	0
CB6A	40	2	25	00.80 (00.10-00.26)	0.43	2
CB6A	41	1	14	00.70 (00.00-00.34)	0.12	3
CB6A	42	0	25	00.00 (00.00-00.14)	0.43	0
CB6A	43	0	2	00.00 (00.00-00.84)	0.12	0
CB6A	44	0	23	00.00 (00.00-00.15)	1.58	0
CB6A	45	1	27	00.40 (00.00-00.19)	0.4	3
CB6A	46	0	8	00.00 (00.00-00.37)	0.04	0
CB8	47	0	21	00.00 (00.00-00.16)	1.14	0
CB8	48	1	3	00.33 (00.10-00.91)	0.03	5
CB8	49	3	23	00.13 (00.30-00.34)	0.81	2
CB8	50	2	19	00.11 (00.10-00.33)	1.45	3
CB8	147	5	25	00.20 (00.70-00.41)	0.35	3.2
CB8	148	4	25	00.16 (00.50-00.36)	1.22	1.5
CE5A	51	1	19	00.50 (00.00-00.26)	0.26	5
CE5A	52	5	25	00.20 (00.70-00.41)	0.89	2
CE5A	53	5	18	00.28 (00.10-00.53)	0.34	3.4
CE6	54	12	23	00.52 (00.31-00.73)	0.4	2.58
CE6	55	12	25	00.48 (00.28-00.69)	0.79	3.17
CE6	56	6	25	00.24 (00.90-00.45)	0.97	3
CE6	57	0	3	00.00 (00.00-00.71)	0.82	0
CE7A	89	0	7	00.00 (00.00-00.41)	0.08	0
CE7A	90	0	25	00.00 (00.00-00.14)	0.31	0
CE7A	91	0	25	00.00 (00.00-00.14)	0.87	0
E2	1	0	25	00.00 (00.00-00.14)	0.4	0
E2	2	0	23	00.00 (00.00-00.15)	0.62	0
E2	3	0	25	00.00 (00.00-00.14)	1.4	0

Stratm	Station	r	NA	Prevalance	Density	Intensity
E2	101	0	25	00.00 (00.00-00.14)	0.45	0
E2	102	0	25	00.00 (00.00-00.14)	0.41	0
E2	103	0	17	00.00 (00.00-00.20)	0.12	0
E4	4	0	25	00.00 (00.00-00.14)	0.12	0
E4	5	0	25	00.00 (00.00-00.14)	0.14	0
E4	6	6	25	00.24 (00.90-00.45)	0.34	3.5

## APPENDIX 4

**Table 4A: Population size estimates by stratum corrected for oysters with category 3 and greater infections expected to die before the beginning of the oyster season. For each station, where  $r$  is the number of oysters infected with bonamia and  $n$  the number of oysters in the sample, removed is the number of small oyster removed, factor is the scaling applied to stratum densities based on oysters with category 3 and greater infections, mean density is the density of recruit-sized oysters, density s.d. is the standard deviation and c.v. coefficient of variation. Population is the estimate of mean population size in millions of oysters and Lower and Upper CI 95% confidence limits, and the area of each stratum Area km<sup>2</sup>.**

Stratum	N	Removed	factor	Density			c.v.	Population	Lower.CI	Upper.CI	Area.km <sup>2</sup>
				mean	s.d.	mean					
B1	8	0	0.99	1.5884828	0.4165468	0.2622293	181.71402	79.88081	319.4052	114.3947	
B1A	3	0	1.00	0.1166012	0.0725636	0.6223231	1.8683713	0	4.6005792	16.0236	
B2	6	0	0.81	0.5291537	0.1592688	0.3009878	69.335212	26.403771	128.59859	131.03038	
B3	3	0	0.97	0.4423521	0.1483587	0.3353859	19.764692	6.6509817	37.753784	44.68091	
B4	3	0	1.00	0.3274067	0.1468387	0.4484904	32.314329	3.232994	69.100358	98.69784	
B5	3	0	0.95	0.0973579	0.0408979	0.4200774	6.1955346	1.1733437	12.801765	63.63666	
B6B	3	0	0.75	0.343037	0.1902616	0.5546388	6.8003902	0	15.971871	19.82407	
B7	4	0	0.92	0.2003178	0.0515025	0.257104	17.249588	7.9784803	30.533409	86.11111	
B9	6	0	0.98	0.8656601	0.3739509	0.4319836	29.827392	4.4301619	62.233211	34.45624	
C1A	4	0	0.97	0.4747415	0.1865365	0.3929224	14.836197	3.4885639	29.780565	31.25111	
C2	4	0	0.79	0.4467288	0.1296389	0.2901961	9.8019004	3.995668	17.827529	21.9415	
C3	6	0	0.83	0.3229865	0.033073	0.1023976	10.563571	6.7902994	16.19402	32.70592	
C4	4	0	0.78	0.5630311	0.1426243	0.2533152	14.803269	6.8864758	26.052149	26.2921	
C5	5	0	1.00	0.4663537	0.1974012	0.4232864	17.573532	2.7374367	36.469501	37.68284	
C6	4	0	0.80	0.2557666	0.0923018	0.3608828	6.0148733	1.7710938	11.780947	23.51704	
C7	4	0	0.99	0.6845764	0.291703	0.4261072	24.699121	4.1694557	51.237325	36.07942	
CB6A	8	0	0.98	0.3866195	0.178219	0.4609674	29.815763	2.9351964	63.011089	77.11914	
CB8	6	0	0.90	0.7528737	0.2019299	0.2682122	20.207702	8.9874133	36.116335	26.84076	
CE5A	3	0	0.85	0.4203978	0.1685608	0.4009554	9.8865108	2.02334	19.95899	23.51704	
CE6	4	0	0.82	0.6096242	0.0985514	0.1616592	18.282777	10.781358	29.465137	29.99024	
CE7A	3	0	1.00	0.4199706	0.2354087	0.5605362	9.9132556	0	23.418858	23.60464	
E2	6	0	1.00	0.5663553	0.1798579	0.3175707	24.257548	8.352005	45.22977	42.83097	
E4	3	0	0.87	0.1735313	0.0618461	0.3563973	4.8662699	1.3894716	9.4685019	28.04261	
All	103	0		0.5424719	0.0570806	0.1052232	580.59182	375.64668	881.62088	1070.2708	