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## EXECUTIVE SUMMARY

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The Bluff Oyster Management Company and NIWA completed a joint survey of Foveaux Strait oysters in February 2009. This survey continues a series of surveys in OYU 5 for stock assessment and determining the status of *Bonamia exitiosa* (bonamia) infection in the oyster population. A two-phase stratified random survey was undertaken, along with sampling additional target stations. Altogether 130 stations were sampled; 100 first-phase stations, 15 second-phase stations, 6 target stations for bonamia infection, 6 stations in the recreational fishery area, and 3 (2006) video sites. Oyster samples were collected from all first-phase, target, and video stations to determine the status of bonamia infection. Sampling and operational procedures were comparable to those of previous surveys.

The estimates of mean population size of recruit-sized oysters in the 1999 survey area increased from 408 million oysters in January 2005 to 622 million in February 2007, and 720 million in February 2009. Mean oyster density over the whole fishery also increased from 0.39 oysters/m$^2$ to 0.68 /m$^2$ over the same period. Although pre-recruit oysters increased from 414 million oysters in 2005 to 463 million in 2007, the population declined to 354 million oysters in 2009. Pre-recruit oyster densities were similar from 0.39 oysters/m$^2$ in 2005 to 0.33 oysters/m$^2$ in 2009. Small oysters decreased from 1344 million oysters in 2005 to 842 million in 2007 and increased to 889 million oysters in 2009. Mean small oyster density was lower in 2009 (0.85 m$^2$) than in 2005 (1.28 oysters/m$^2$). Although the increase in the recruited oyster population from the low point in 2005 is similar to the level of rebuilding between 1993 and 1997, the future levels of rebuilding may be slower than in 1997 to 2001 as the numbers of pre-recruits and small oysters are lower and bonamia mortality is present in the fishery at low levels (there was no heightened mortality apparent between 1997 and 2001). The low numbers of pre-recruit and small oysters may represent temporal lags from low recruit numbers in 2005, and suggest a stock recruit relationship between numbers of recruits and settlement and survival of small oysters.

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 361 million oysters in 2009. Mean oyster density in those areas also increased from 0.44 /m$^2$ to 0.97/m$^2$. In 2009, mean oyster density is highest in the central fishery area (strata B3, CB8, E2, and E4, 1.4–2.1/m$^2$). The population size of oysters above 400 oysters per standard survey tow, an historical indicator of economically acceptable catch rates based on a minimum catch rate of six sacks per hour, has increased from 33 million oysters in 2005, to 204 million in 2007, and 257 million in 2009.

Oyster populations in the central and western areas first affected by mortality from bonamia are continuing to rebuild, and eastern areas have been further reduced by bonamia mortality. The distributions of oyster densities are similar for recruit and pre-recruit oysters. In 2001, high densities of small oysters were found throughout the fishery, but the highest densities were east of a line between Bluff Hill and Garden Point. Between 2001 and 2007, small oyster densities were greatly reduced, especially in the eastern fishery areas. In 2009, small oyster densities are still low in eastern areas, but increasing in western, central, and southern fishery areas.

An extensive survey in 2007 found widespread infection, but most infected stations were east of a line between Bluff Hill and Saddle Point. In February 2008, central fishery areas showed lower prevalence of infection, but eastern areas continued to have relatively high prevalence despite their reduced oyster densities. In February 2009, 92.0% of oysters and 34% of stations sampled didn't have detectable infections, a further 40% of stations had a prevalence of infection less than 10%, and remaining stations a prevalence of 12–64%. The intensity of infection varied considerably within individual sample stations and most stations had a mean

intensity of infection higher than category 3. The prevalence of infection is similar to that in 2008, but intensity of infection has increased. Mean mortality from higher than category 3 infections over the summer of 2009 was estimated at 6.25%, reducing the oyster population from 725 million oysters to 679 million.

The densities of oysters sampled in the recreational fishery area were low (0–0.05 recruited oysters/m$^2$) compared to the commercial fishery area. Habitats varied from sand to complex macrobenthic assemblages. Densities of pre-recruit and small oysters were also low, but no historical data on oyster densities at sample sites are available for comparison.

## 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 the recent *Bonamia exitiosa* (bonamia) epizootics that began in 1985, the annual value of this fishery was about $30 million. This value has fallen to about $10 million due to reduced catch limits as the first of two bonamia epizootic between 1986 and 1992 reduced the oyster population to probably less than 10% of the pre-disease level. 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 (Sullivan et al. 2005).

### 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 eight biennial dredge surveys (Cranfield et al. 1996, 1999, Michael et al. 2001, 2004a, 2004b, 2006, 2008a, 2008b, 2008c), and from surveys of the status of bonamia infection (see Table 6, Dunn 2007). These data provide some ability to predict future stock levels. The population 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). Pre-recruit oysters had declined in similar proportions to recruited oysters, suggesting this size group may be equally vulnerable to bonamia mortality. 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 biennial 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 in January 2005 was about 408 million, increasing to 622 million in February 2007. Recruited oyster densities almost doubled over this period. Pre-recruit oysters increased from 414 million oysters in 2005 to 463 million in 2007.

Since 1999, the numbers of small oysters have remained the same and recruitment does 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 (Michael et al. 2006). A survey in February 2007 found oyster populations in central and western areas first affected by mortality from bonamia were rebuilding, and those in eastern areas had been further reduced by bonamia mortality. The distributions of oysters were similar for all three size groups of oysters. However, the population 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 while larger oyster were increasing was observed in 1993, two years after the lowest population of recruit size oysters was recorded.

The next biennial survey of the oyster population was scheduled for February 2009, combining the population survey with bonamia sampling. Survey estimates of recruit, pre-recruit, and small oyster population size, and of infection levels in February 2009 are used to update the OYU 5 stock assessment model to make projections of recruit-sized stock abundance for 2010–12.

## 1.3 Commercial population size

From 1999 to 2004, yields were calculated using estimates of commercial population, the recruited population of oysters from “commercial” fishery areas designated by oyster skippers from biennial surveys (Michael et al. 2001). The commercial population declined from about 275 million oysters in 1999 to about 144 million in October 2002, remained similar at about 164 million in 2005, but increased to 196 million oysters in 2007. The designated commercial areas increased from 103 $km^2$ in 1999 to 366 $km^2$ in 2005 and remained the same in 2007. The mean oyster density within those areas declined from 2.4 oysters/$m^2$ in 1999 to 0.4/$m^2$ in 2005, mainly from continuing bonamia mortality (Michael et al. 2005) before increasing to 0.53 /$m^2$ in 2007.

Before the 1986 bonamia epizootic, the portion of the recruited oyster population represented by the number of oysters above 400 oysters per standard survey tow was an historical indicator of economically acceptable catch rates, and used as a proxy for the commercial population size. The estimate of the portion of the oyster population above this threshold has increased from 33 million oysters in 2005 to 204 million oysters in 2007.

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 bonamia is the principal driver of oyster population abundance in Foveaux Strait during epizootics. Since 2000, widespread mortality from the haplosporidian parasite bonamia (*B. exitiosa*) has reduced oyster density to historically low levels of the early 1990s. Seven surveys of bonamia infection 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 (number of infected oysters per sample) and intensity of infection (mean level of infection in infected oysters only, based on a categorical scale, see Table 2) had decreased significantly from those in January 2004 (Michael et al. 2005). 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 higher infections little disease mortality was expected over that summer. However, infection was more widespread in the fishery in February 2006 than in January 2005 (Michael et al. 2005). The prevalence of infection was similar, and the intensity of infection was higher than in 2006. The status of infection in February 2007 was similar to that in February 2006. Few oysters sampled for bonamia had detectable infections, but most of the infected oysters 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.

Based on the numbers of oysters with category 3 or higher infections, mortality from bonamia could have reduced the recruited oyster population by about 14 million oysters in 2006, 43 million oysters in 2007, and 23 million in 2008. The survey in February 2008 found the central fishery areas showed lower prevalence, but eastern areas continued to have relatively high prevalence of infection despite reduced oyster densities there. Infected oysters had mainly high intensity of infection in 2006, 2007, and 2008, and intensity of infection in February 2008 varied considerably within individual sample stations. Category 3+ infected oysters were projected to reduce the recruited oyster population from 694 million in February 2008 to 671.2 million oysters (3.3%) by early March. This level of disease mortality alone is unlikely to have an effect on future recruit size stock abundance.

## 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 affect 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 and a catch limit of 7.5 million oysters, the 2007 stock assessment projected status for 2009 ranged from about 137% more than the 2007 level (with nil disease mortality) to about the same (107%) of the 2006 level (assuming disease mortality of 0.2 $y^{-1}$). At the levels of bonamia mortality estimated in recent years, the model projections suggest continued rebuilding of the fishery, given the current catch limits, but the effects of reduced numbers of small oysters may slow the rate of rebuilding in the oyster population.

The proportion of oysters above 400 oysters per standard survey tow has been retained as an indicator of how well the fishery is rebuilding compared to pre-epizootic population levels.

## 1.6 Recruitment

Surveys to estimate the size of the commercial oyster population (Michael et al. 2001, 2004a, 2004b, 2005, 2006, 2008a) focused sampling effort in designated commercial fishery areas that had shifted east between 1999 and 2006, and sampled the entire fishery in February 2009. 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, February 2005, and February 2007 surveys estimated numbers of small oysters in the 1999–2007 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 (1.28 oysters/$m^2$), but had decreased by February 2007 to (0.58 $m^2$). These areas were sampled again in February 2009.

## 1.7 Research overview

Research has concentrated on surveys of the 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 2007). A draft strategic research plan (Michael & Dunn, unpublished report) developed to underpin management goals in the Bluff Oyster Management Company Limited (BOMC) Fisheries Plan, 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 2008–09, and whether oyster populations 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 the research in a draft strategic research plan) to maximise the value and production of oysters. These strategies will be dependent on data recorded in fishers' logbooks. During the 2006, 2007, and 2008 oyster seasons, fishery data were recorded at a spatial-scale of nautical mile squares 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 and improve the range of data available to the stock assessment model.

## 1.8 Research objectives

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 survey between NIWA and BOMC of the status of infection by bonamia and of oyster densities, and in part fulfils milestone 8, reporting requirement 3 of the Ministry of Fisheries project OYS2008/01, objective 1: To carry out a survey in late January 2009 to determine the distribution, prevalence and intensity of infection by *Bonamia exitiosa*, and the distribution, and population size of recruit, pre-recruit, and small oysters in designated commercial fishery areas for 2009, and in previously designated commercial fishery areas between 2000 and 2008 to investigate rebuilding of oyster populations. To update model projections of recruit-sized stock abundance under different catch limits and bonamia mortality levels from the OYU 5 stock assessment model (reported separately).

The survey sampled randomly allocated stations in two phases to estimate oyster densities; target stations to monitor the rebuilding of localised populations reduced by high levels of mortality from bonamia; sites sampled by benthic drift video to compare bycatch to video data; and stations within the recreational fishery area to assess oyster densities. 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 January 2005 and February 2009, the effects of projected disease mortality on future stock status, and implications for the fishery.

## 2. METHODS

### 2.1 Sampling design

The February 2009 survey continued a time series of surveys using the 1999 Foveaux Strait oyster survey area (1054 $km^2$) with one additional new area (B1a) outside the standard survey boundary requested by oyster skippers in 2007 (Figure 1, Table 1). Surveys since October 1999 have retained the same survey strata, although they have been partitioned and their designation as commercial, exploratory, and background areas changed to reflect changes in the distributions of oyster densities. Strata for the February 2009 survey are based on the 2008 survey (Michael et al. 2008b), and commercial strata designated from information in skippers' logbooks for the 2008 oyster season representing 100% of fishing by the fleet, skippers' input, and historical survey data. One stratum (B2) from 2008 was partitioned into two (B2a and B2b) to better define the commercial fishery and a new commercial stratum (B2b). Ten of 24 strata were designated as commercial, 4 as exploratory, and 10 as background strata. These strata were sampled with a two-phase stratified random survey design. The designations of survey strata are shown in Figure 1 and Table 1.

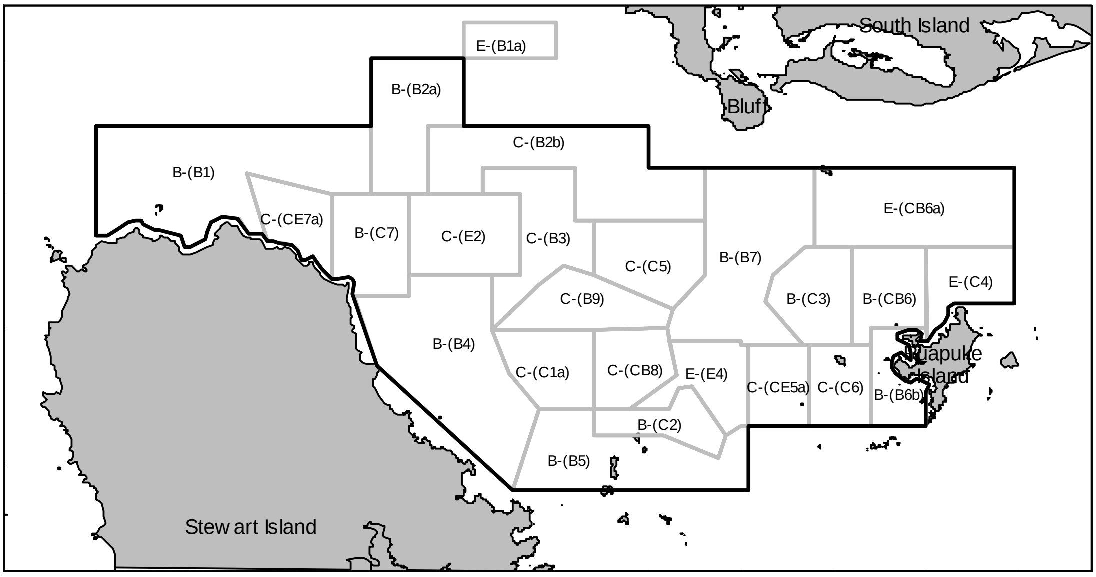


**Figure 1: The 1999 survey area and survey strata (black lines) sampled in February 2009. Strata designated commercial by oyster skippers have a "C" prefix. Exploratory strata have an "E" prefix and background strata "B". B1a is a new stratum added in the 2007 survey and the stratum previously B2 partitioned into two (B2a and B2b) to better delineate oyster densities. Original stratum names in parentheses.**

Target stations were based on survey stations 1999–2002 that recorded high densities of oysters and were severely reduced by bonamia mortality. Video stations were selected outside the survey boundaries to provide additional sites from different habitats to correlate bycatch data (reported separately). No data on the location of recreational dive sites within the recreational fishery area along the Stewart Island coast were available. Sample stations were chosen casually and at locations where a standard dredge tow could be employed without encountering reefs or sand banks.

The oyster vessels *Golden Lea* and *Golden Quest*, skippered by Brian Hawke, successfully sampled 130 stations, comprising 100 first-phase stations, 15 second-phase stations (6 in B1, 3 in B3 and E2, 2 in C7, and 1 in each of C2 and E4), 6 target, 6 recreational, and 3 video stations. Oyster samples were collected from all first-phase, target, and video stations to determine the status of bonamia infection. The numbers of first and second-phase stations sampled in each stratum and stratum areas are shown in Table 1 and the location of all stations sampled by category in Figure 2.

**Table 1: The number of random first and second-phase stations sampled during the February 2009 oyster survey by stratum and the stratum areas. Strata that were designated by oyster skippers as commercial are prefixed "C"; exploratory strata "E"; background strata "B".**

| Stratum | No. stations | Area ($km^2$) | Stratum | No. stations | Area ($km^2$) | Stratum | No. stations | Area ($km^2$) |
|---|---|---|---|---|---|---|---|---|
| B (B1) | 11 | 114.4 | B (B7) | 3 | 86.1 | B (C7) | 5 | 36.1 |
| E (B1A) | 4 | 16.0 | C (B9) | 5 | 34.5 | E (CB6A) | 6 | 77.1 |
| B (B2A) | 3 | 47.7 | C (C1A) | 6 | 31.3 | C (CB8) | 4 | 26.8 |
| C (B2B) | 5 | 83.3 | B (C2) | 3 | 21.9 | C (CE5A) | 5 | 23.5 |
| C (B3) | 10 | 44.7 | B (C3) | 4 | 32.7 | B (CE6) | 3 | 30.0 |
| B (B4) | 3 | 98.7 | E (C4) | 3 | 26.3 | C (CE7A) | 4 | 23.6 |
| B (B5) | 3 | 63.6 | C (C5) | 5 | 37.7 | C (E2) | 9 | 42.8 |
| B (B6B) | 3 | 19.8 | C (C6) | 4 | 23.5 | E (E4) | 4 | 28.0 |

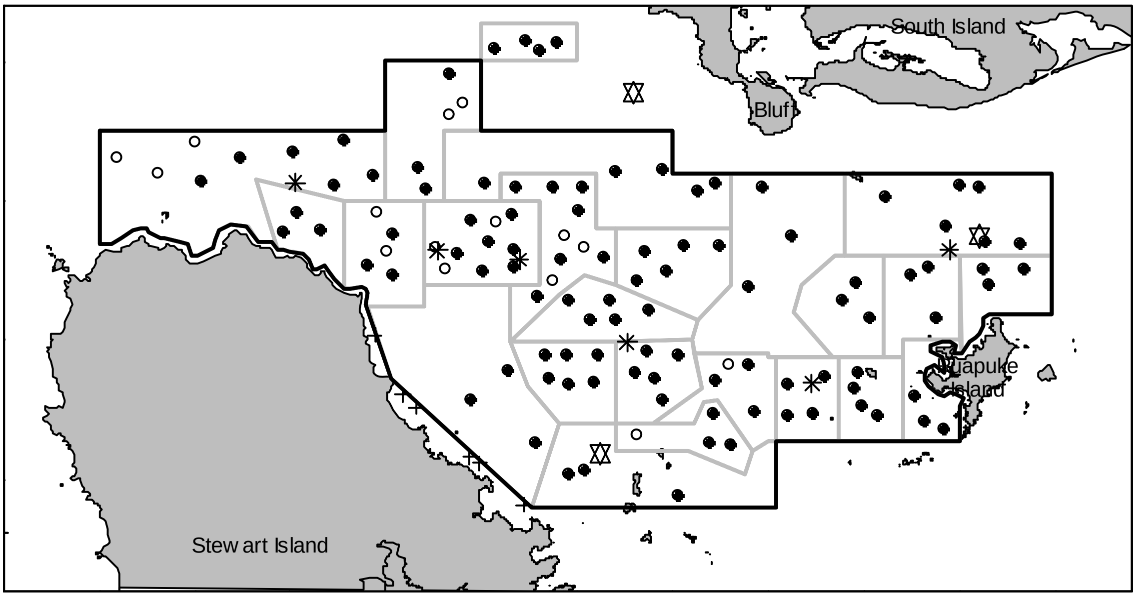


**Figure 2: The random survey stations sampled in February 2009. Filled circles represent first-phase stations where the catch was sampled for both oyster population size and bonamia infection, and open circles represent second-phase stations that were not sampled for bonamia infection. Asterisks show target stations, crosses recreational stations, and double inverted diamonds video stations.**

## 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), February 2006 (Michael et al. 2008a), and February 2007 (Michael et al. 2008b). FV *Golden Lea*, a commercial oyster vessel skippered by Brian Hawke, has been used for these surveys since 2001 and FV *Golden Quest* in 2008. These vessels sampled survey stations with a standard commercial dredge (3.35 m wide, 530 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 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 3). 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 4 and 5). 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 (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 well within 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 were 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, 2008, and 2009 these data were recorded directly from the bycatch.


Figure 3: New clock (with hinge intact), glossy inner valve with no fouling except a few white coralline specks.


Figure 4: Recent old clock (with hinge intact), glossy inner valve with light fouling.


Figure 5: 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 using oyster size rings, and was measured for length and height (Figure 6) to the nearest millimetre down using callipers. If samples contained insufficient recruit-sized oysters, pre-recruits were used in preference to small oysters. Recruit-sized 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 7) 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 7) and fixed in a quantity of 10% formalin in seawater equal to at least five times the tissue volume of the sample. Samples of hearts and gills from each of the oysters sampled for heart imprints were stored in alcohol for future DNA analysis. All histology and DNA 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 that estimating bonamia prevalence 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 108 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 in each. If no bonamia cells were found, further imprints were examined to confirm the absence of bonamia.

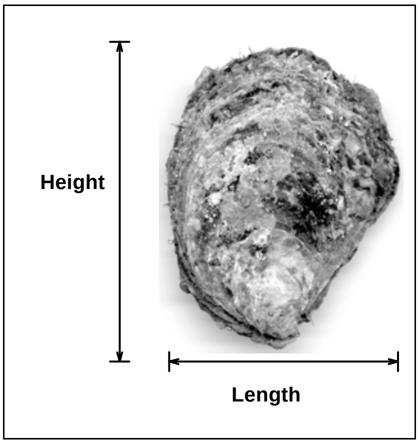


**Figure 6: An oyster showing length (anterior-posterior axis) and height (dorsal-ventral axis) dimensions.**

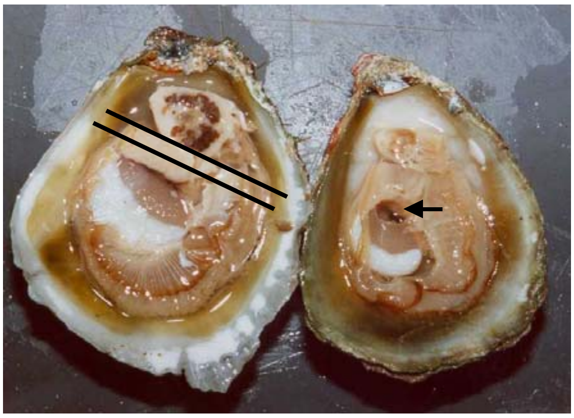

**Figure 7: Lines on left oyster show location of 5 mm thick standard section taken for histology. The arrow on the oyster on the right shows the heart, a black organ adjacent to the adductor muscle.**

**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 smaller oysters 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:

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

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

### 2.7.2 Estimates of oyster density and population size

The February 2009 survey of Foveaux Strait provided estimates of the total oyster population (recruit, pre-recruit, and small oysters), and two estimates of the commercial population (recruit-sized oysters in designated commercial areas and the proportion of the population represented by oyster densities in excess of 400 oysters per standard survey tow). 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 2009 surveys.

## 3. RESULTS

### 3.1 Survey operational detail

The oyster vessels *Golden Lea* and *Golden quest* successfully sampled 130 stations on 12 days between 7 February and 26 February 2009. *Golden Lea* was used for sampling until a breakdown on 18 February, after which *Golden Quest* was used with the same skipper and crews until the end of the survey. Eight stations could not be sampled because of foul ground or sand banks and were replaced (Table 3). Survey strata are shown in Figure 1 and dredge tow positions for randomly allocated stations in Figure 8. The survey data are held on the Foveaux Strait dredge oyster database at NIWA, Greta Point, Wellington.

**Table 3: Station numbers that could not be sampled (original station) and their replacement station numbers.**

| Original station | Replacement station |
|---|---|
| 5 | 101 |
| 11 | 110 |
| 14 | 121 |
| 16 | 123 |
| 17 | 124 |
| 46 | 150 |
| 78 | 177 |
| 91 | 193 |

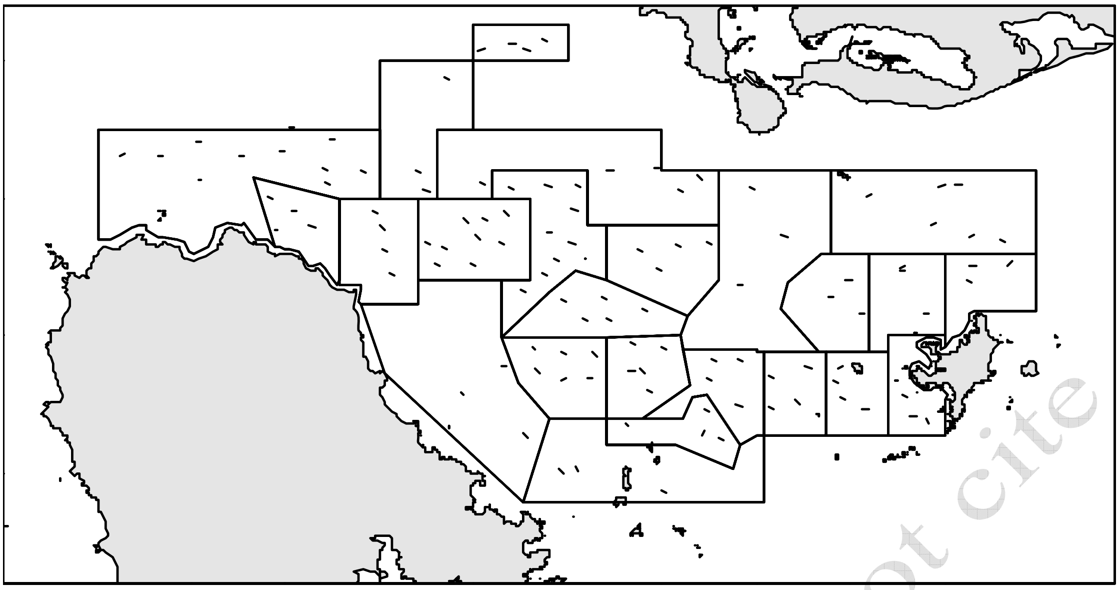

**Figure 8: The random survey tows sampled in February 2009. Target, recreational, and video tows not shown.**

Dredge tow lengths were mostly clustered around the 0.2 nautical mile (370 m) standard tow length (Figure 9). Short tows were terminated early because of foul ground or sand banks. Tows with lengths greater than 0.1 nautical mile were retained and scaled-up and tows shorter than 0.1 nautical mile were discarded and replaced with the next tow number on the list for that stratum. Where a station couldn't be sampled at all, it was also replaced with the next available station.

Most of the survey stations were sampled in light wind conditions; the median wind force was 3 on the Beaufort scale (7–10 knots), with 5 and 95 percentiles of Beaufort scale 0 (calm) and 4 (11–15 knots) respectively (Figure 10). These wind and resulting sea conditions were similar to sampling conditions on previous surveys and 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. No dredge tows were landed over 80% full, suggesting dredge saturation is not likely to have had an effect on sampling effectiveness (Figure 11). However, dredges were rarely landed more than 70% full and dredge contents were unevenly, but symmetrically, spread with contents lower in the middle of the dredge. These observations suggest dredge saturation may occur below 80% dredge fullness. Video observations of dredges saturating on the seabed show dredges can become saturated within 3–4 minutes (standard tow duration is 5–7 minutes) and the dredge contents settle into the dredge bag during hauling, removing signs of the dredge saturation that occurred on the seabed.

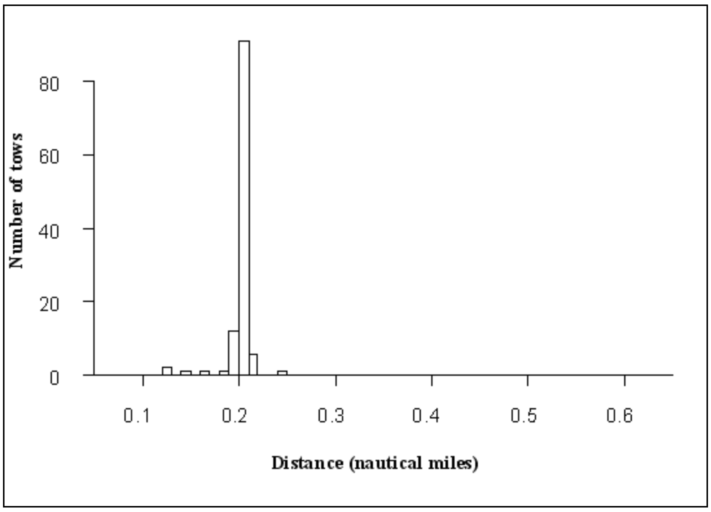


**Figure 9: Distribution of tow lengths from the February 2009 survey. The standard tow length was 0.2 nautical mile (370 m).**

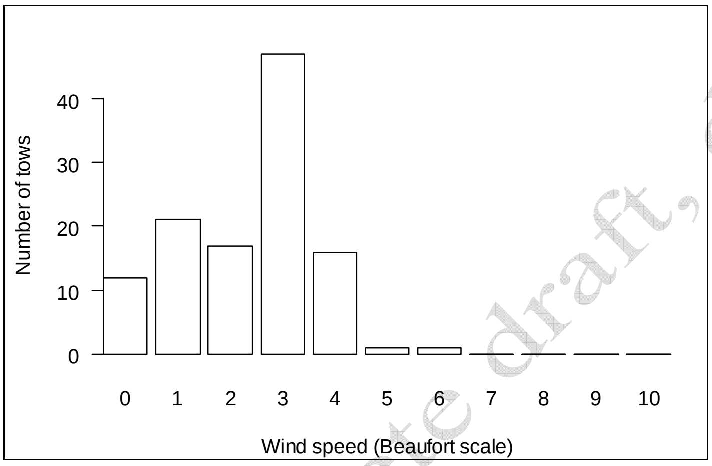


**Figure 10: Distribution of wind speed (Beaufort scale) recorded during survey tows on the February 2009 survey.**

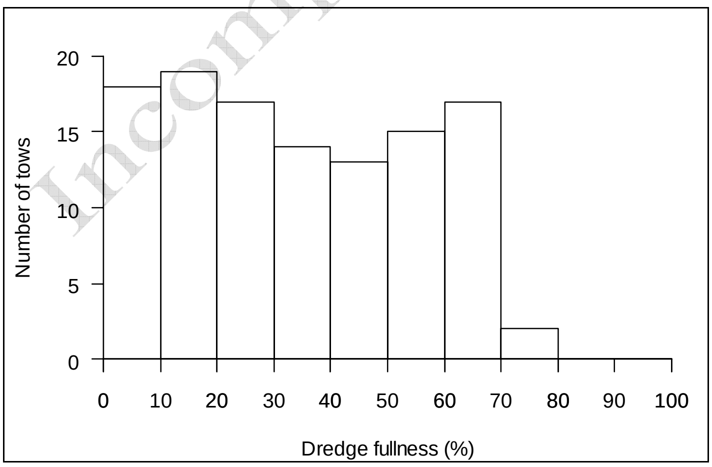


**Figure 11: Distribution of dredge fullness recorded for survey tows on the February 2009 survey. None of the tows were landed with a fullness of more than 80%, indicating a low probability that tows were saturated and hence underestimated oyster density.**

## 3.2 Observations from sampling

The distribution of recruit-sized oyster mortality in February 2009 is shown as a percentage of new clocks to new clocks and live oysters combined, (Figure 12). The distribution of mortality was similar to the distribution of bonamia infection in 2008 (Figure 13). Isolated patches of high mortality were distributed throughout the fishery area, as were patches of low and no mortality. Moderate mortality was confined to east of a line from Bluff Hill to Garden Point. Mortality and infection varied at small spatial-scales. Sites with high prevalence of bonamia infection over the summer of 2008 resulted in mortality and high prevalence and intensity of infection in 2009. These data suggest areas with oysters that have low level infections that progress to fatal infections could be detected a year prior with annual monitoring, and provide an opportunity for managed fishing to minimise losses from disease mortality and spread of infection.

The February 2009 survey sampled unusually large numbers of scallops (*Pecten novaezealandiae*), mostly 50–80 mm in length. These observations suggest good settlement and survival the previous summer (2007–08). Stations where scallops were caught are shown in Figure 14.

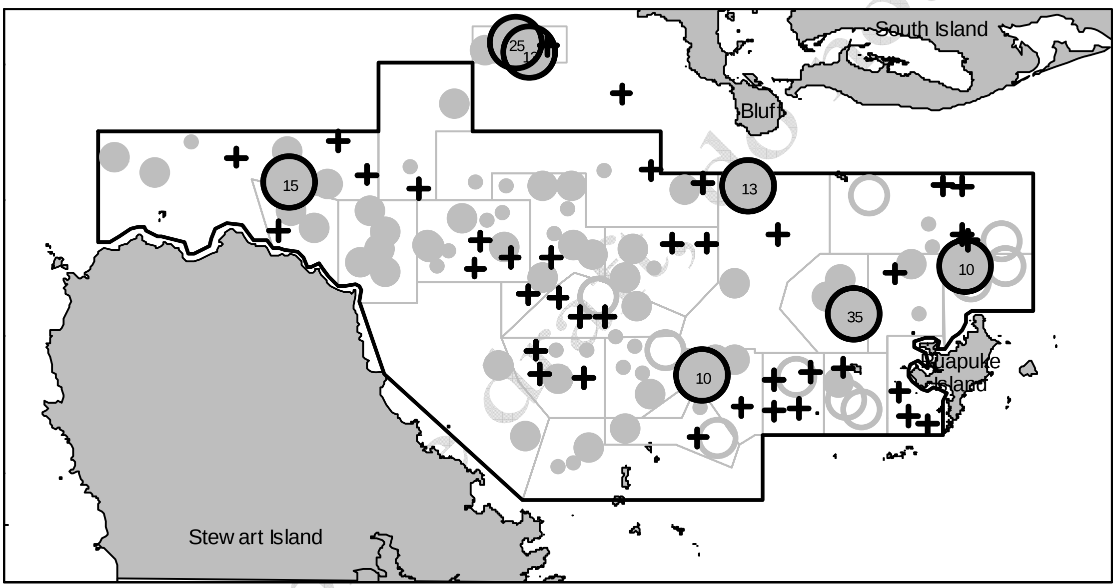


**Figure 12: Summer oyster mortality, February 2009, as indicated by recruit-sized new clock ratios. Black borders around filled grey circles 10–35% with % mortality shown in white text; large grey circles 5–10%; medium filled grey circles 1–5%; small filled grey circles less than 1%; and black crosses no mortality.**

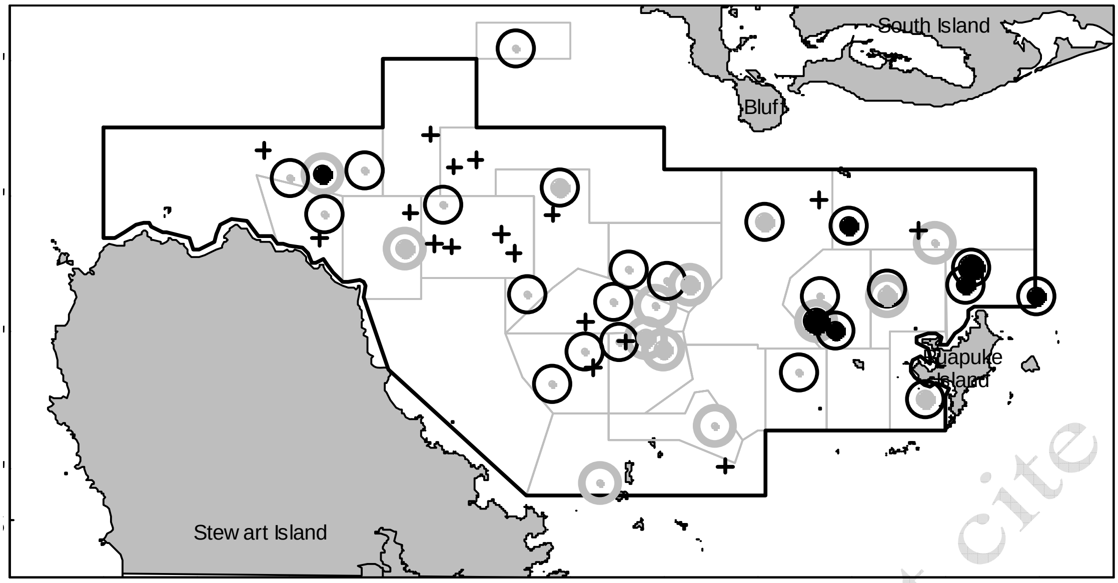


**Figure 13: Status of bonamia infection in February 2008. Stations with no bonamia are shown as black crosses, prevalence (the proportion of oysters infected in the sample) shown as small, grey, filled circles from less than 10%; and large, grey, filled circles for 11–20%; small, black, filled circles 21–30%; and large, black, filled circles more than 30%. Mean intensity of infection for categories 1–2 shown as grey open circles, and likely fatal infections from categories 3–5 in black.**

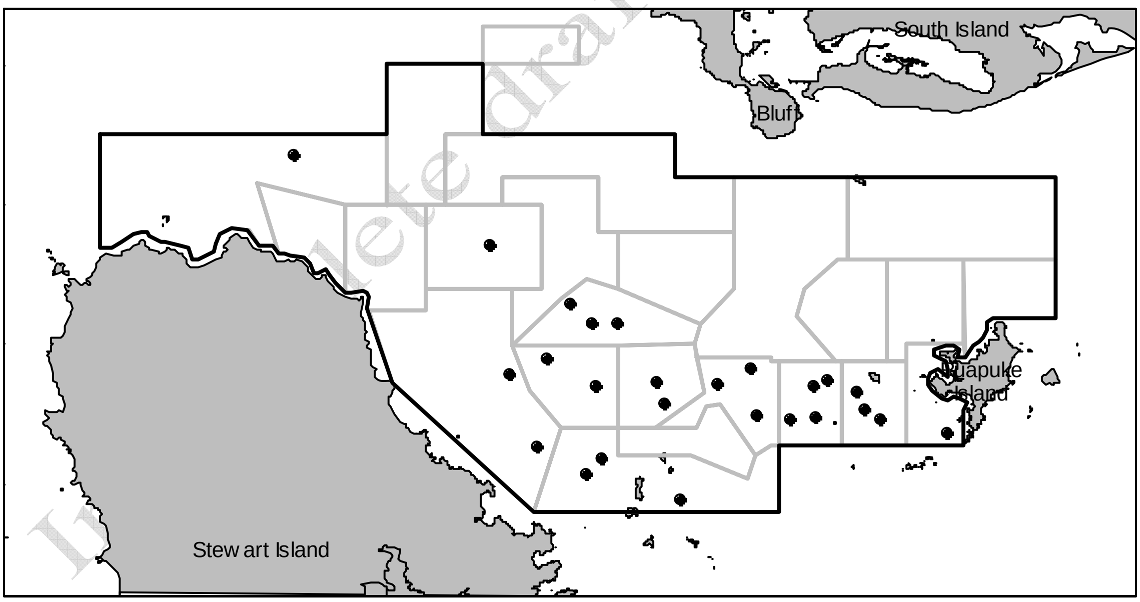


**Figure 14: The distribution of stations (filled black circles) where scallops were caught in February 2009.**



## 3.3 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, 2002, January 2005, and February 2007 and 2009 surveys Figures 15–29. These surveys primarily focussed sampling effort on designated commercial fishery areas to estimate commercial population size, and do not provide consistent and comprehensive coverage of the fishery area.

The distributions of recruited oysters (Figures 15–19) 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 is continuing to reduce oyster density in eastern areas in 2009, but central and western areas showed a continued rebuilding of oyster densities first indicated by the 2005 survey.

Similar patterns of distribution have been observed for pre-recruit oysters (Figures 20–24), thought to be as vulnerable to bonamia mortality as recruit size oysters. Densities of pre-recruit oysters are continuing to decline in eastern fishery areas from bonamia mortality and are increasing in western and central areas, albeit slowly and patchily.

Small oysters (Figures 25–29) had relatively high densities over much of the fishery area in 2001, and were especially high in eastern areas, west of Ruapuke Island. 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 2009. Most of the small oysters sampled in 2001 and 2002 were 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 2009 reflect recruitment dynamics combined with the effects of disease mortality, rather than the effects of fishing on the stock.

Mortality from bonamia between 1999 and 2005 reduced oyster density 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. The mortality of oysters, indicated by new clocks and intense bonamia infections, is widely spread over the commercial fishery area. Recruitment to eastern fishery areas is low and bonamia mortality still high.



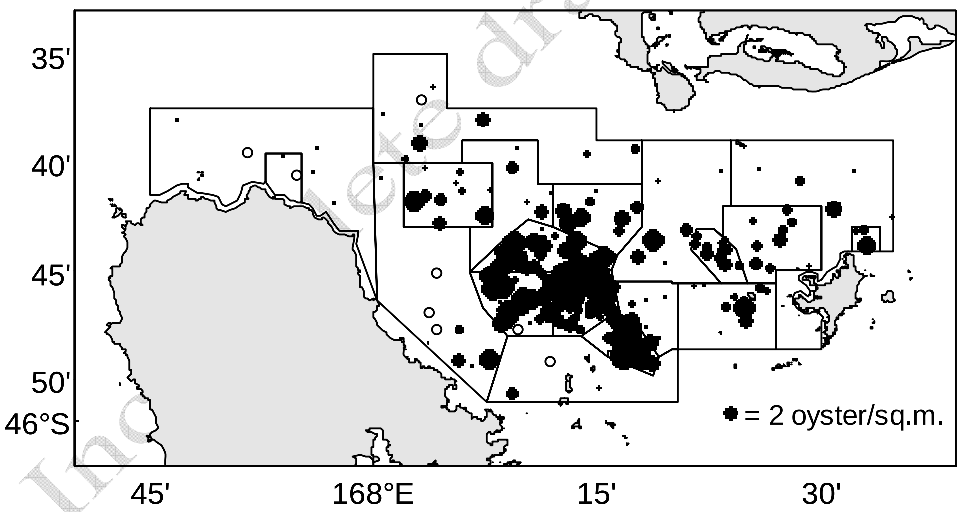


**Figure 15: Relative density of live recruit oysters in the October 2001 survey. Stations with no oysters are denoted by an open circle.**

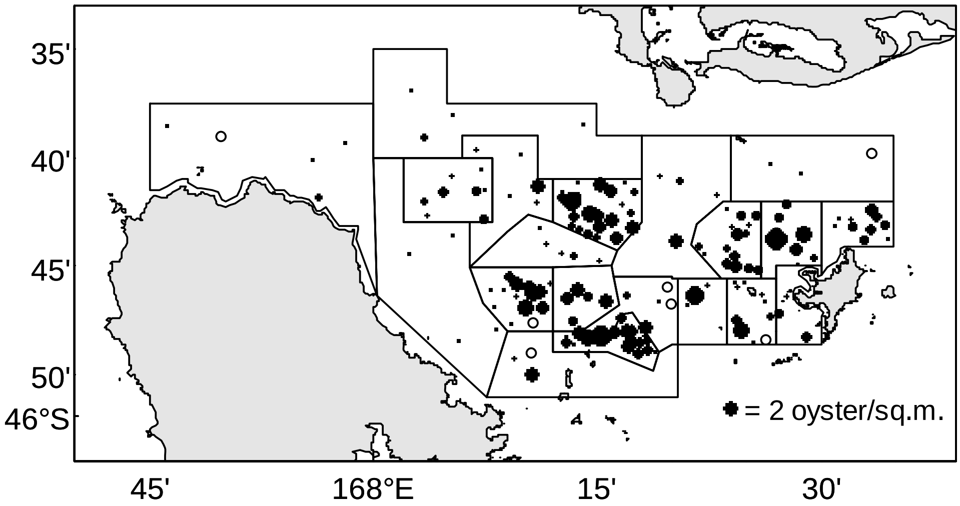


**Figure 16: Relative density of live recruit oysters in the October 2002 survey. Stations with no oysters are denoted by an open circle.**

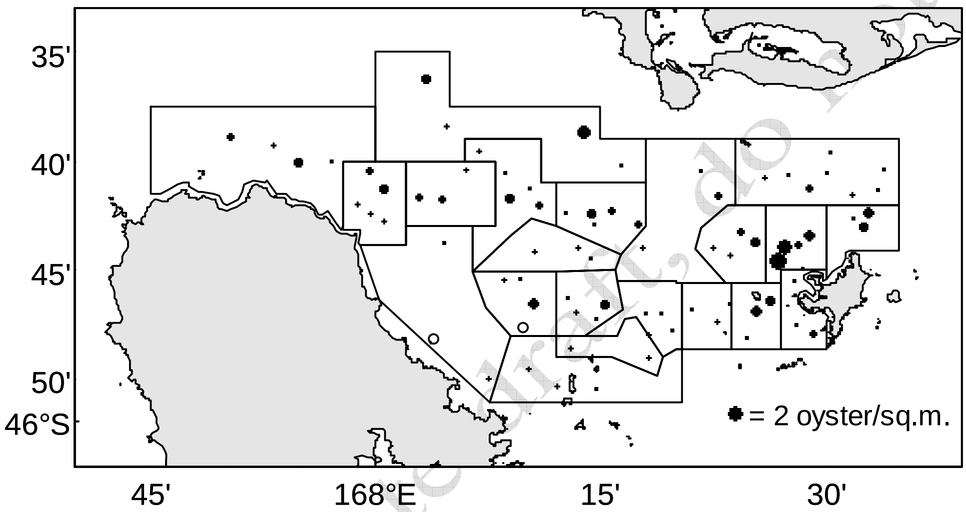


**Figure 17: Relative density of live recruit oysters in the January 2005 survey. Stations with no oysters are denoted by an open circle.**

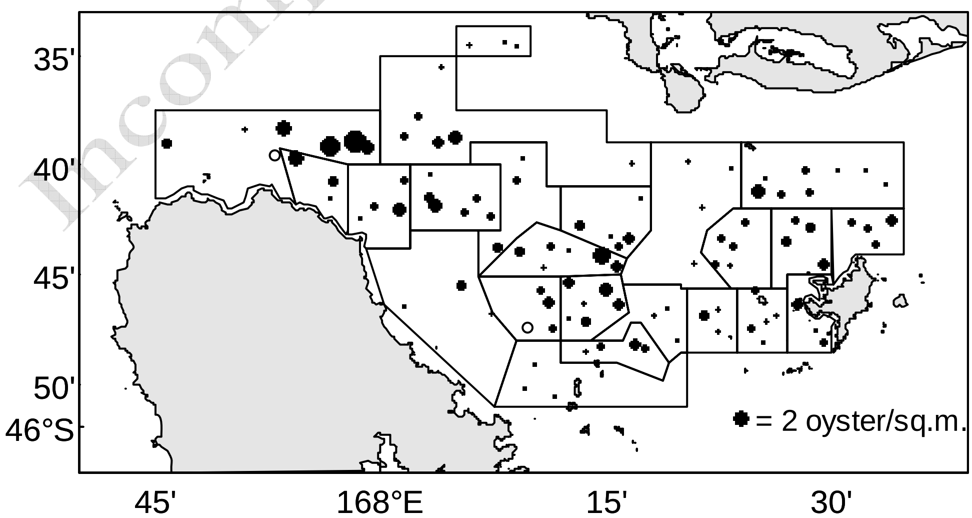


**Figure 18: Relative density of live recruit oysters in the February 2007 survey. Stations with no oysters are denoted by an open circle.**

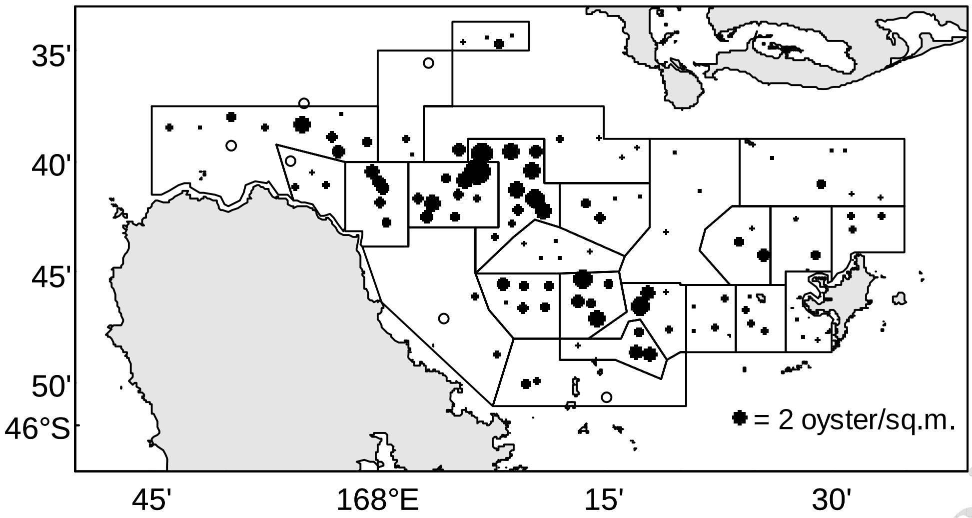


**Figure 19: Relative density of live recruit oysters in the February 2009 survey. Stations with no oysters are denoted by an open circle.**

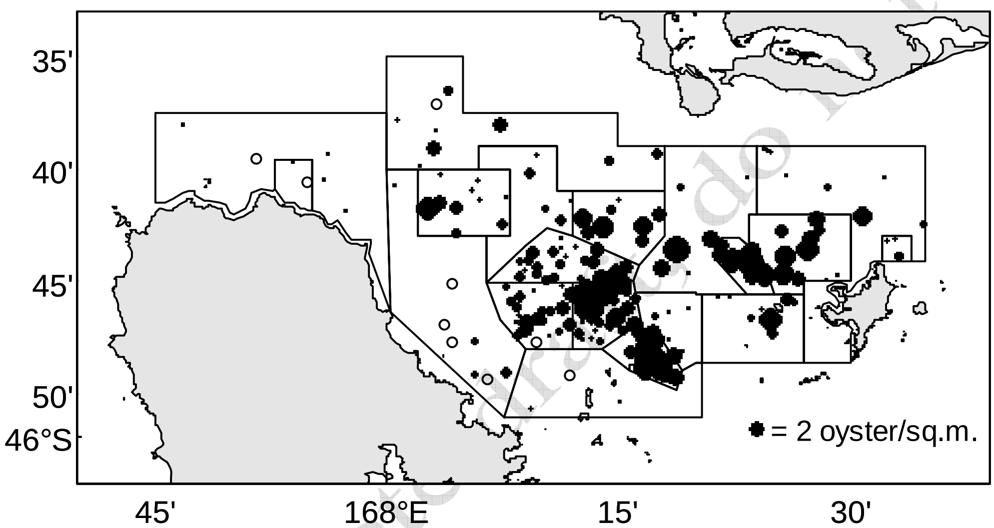


**Figure 20: Relative density of live pre-recruit oysters in the October 2001 survey. Stations with no oysters are denoted by an open circle.**

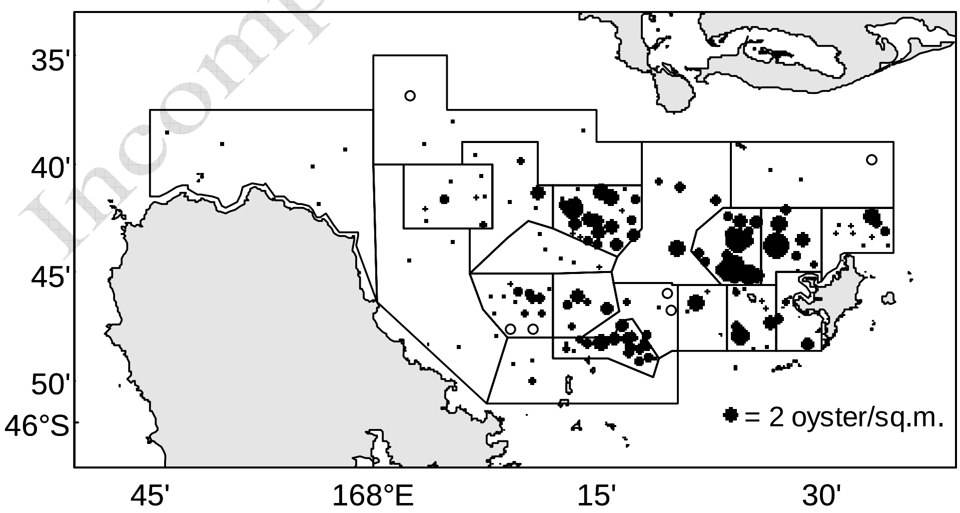


**Figure 21: Relative density of live pre-recruit oysters in the October 2002 survey. Stations with no oysters are denoted by an open circle.**

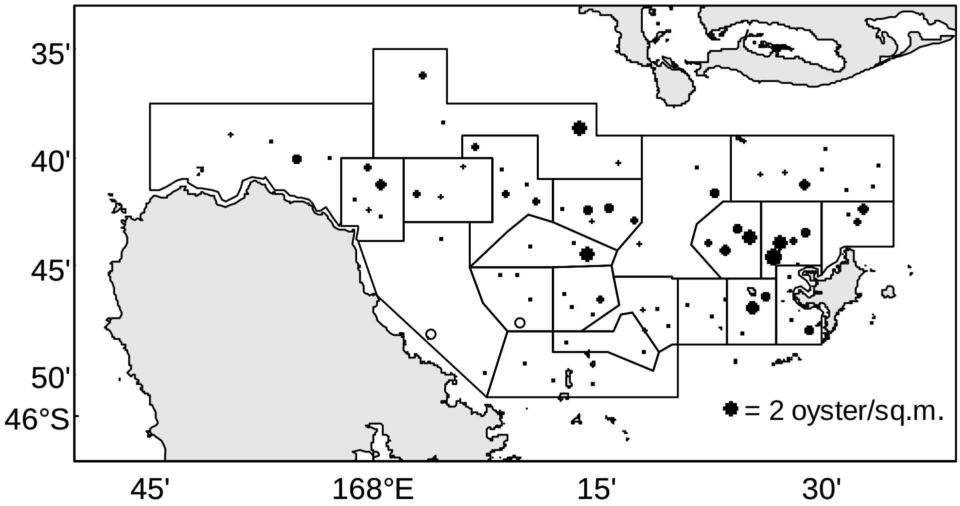


**Figure 22: Relative density of live pre-recruit oysters in the January 2005 survey. Stations with no oysters are denoted by an open circle.**

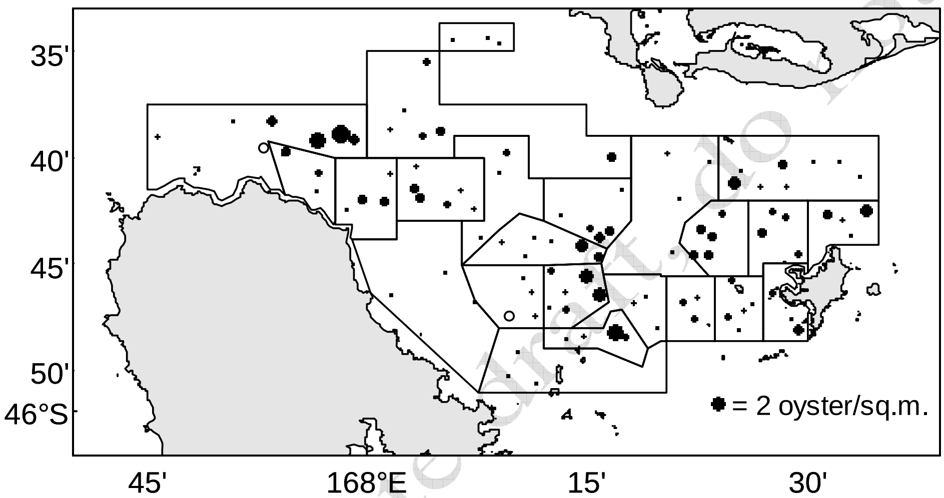


**Figure 23: Relative density of live pre-recruit oysters in the February 2007 survey. Stations with no oysters are denoted by an open circle.**

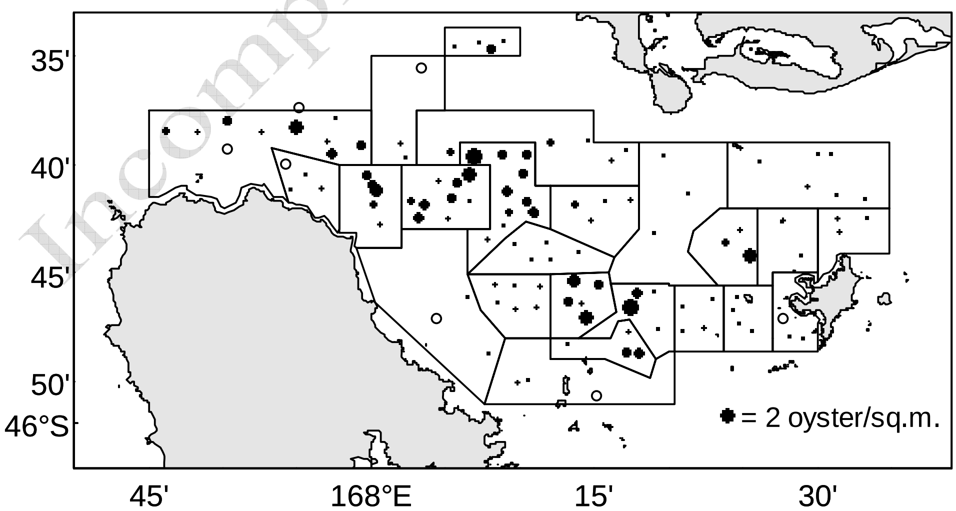


**Figure 24: Relative density of live pre-recruit oysters in the February 2009 survey. Stations with no oysters are denoted by an open circle.**

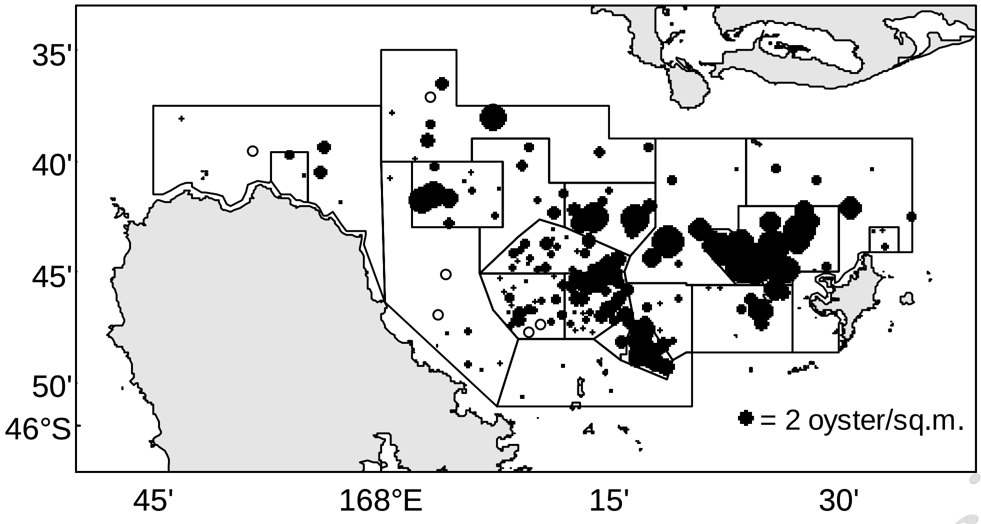


**Figure 25: Relative density of live small oysters in the October 2001 survey. Stations with no oysters are denoted by an open circle.**

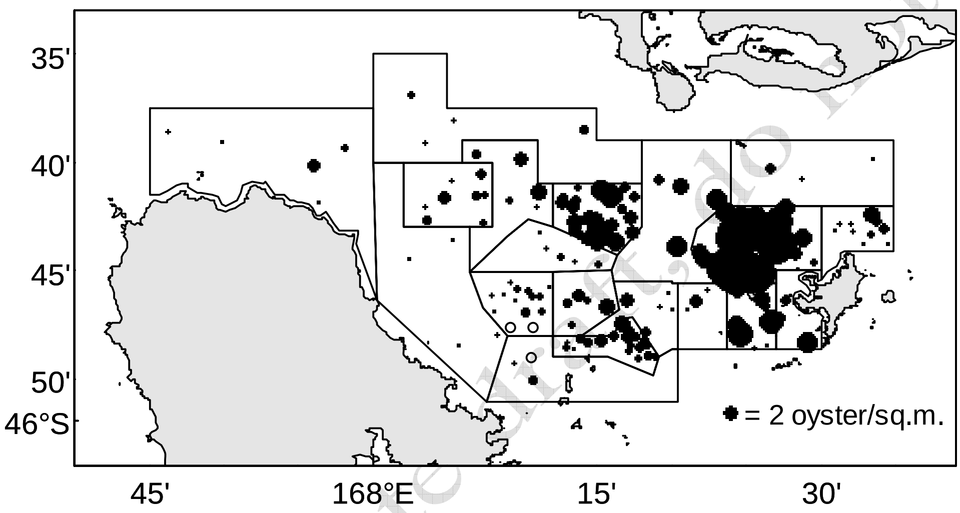


**Figure 26: Relative density of live small oysters in the October 2002 survey. Stations with no oysters are denoted by an open circle.**

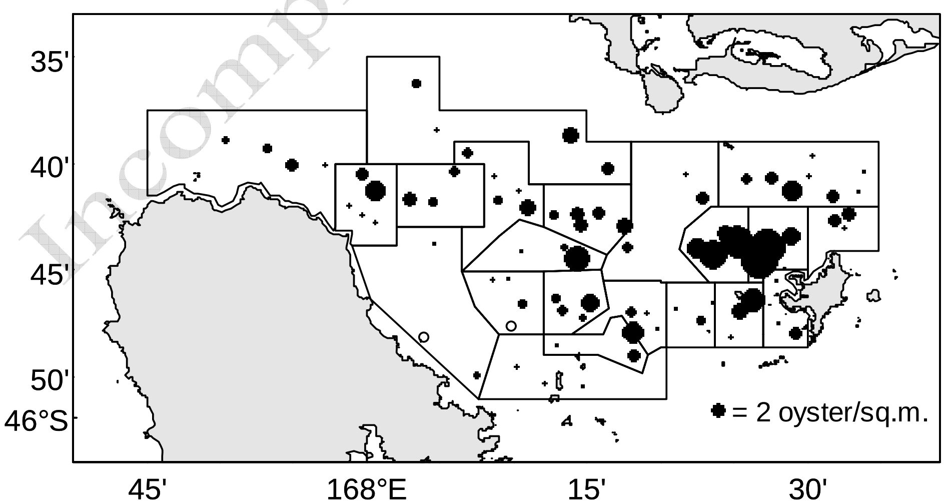


**Figure 27: Relative density of live small oysters in the January 2005 survey. Stations with no oysters are denoted by an open circle.**

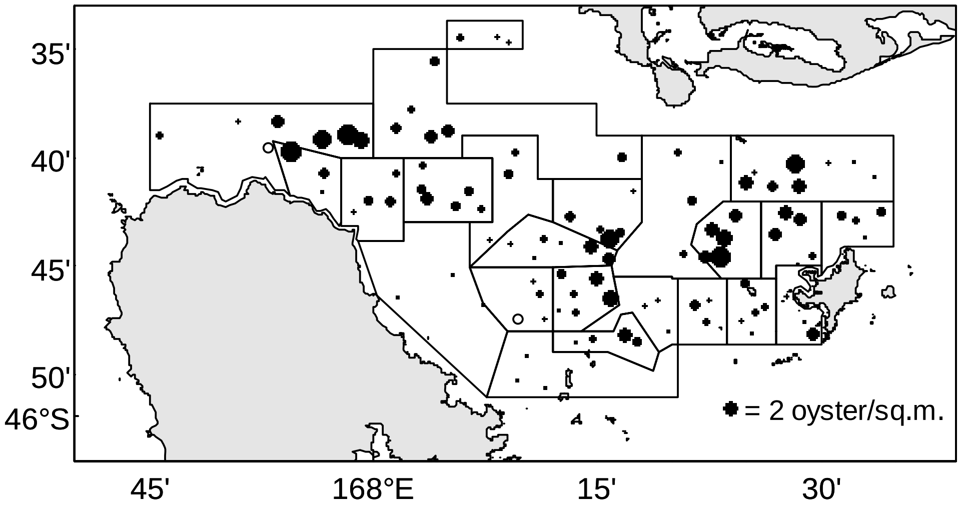


**Figure 28: Relative density of live small oysters in the February 2007 survey. Stations with no oysters are denoted by an open circle.**

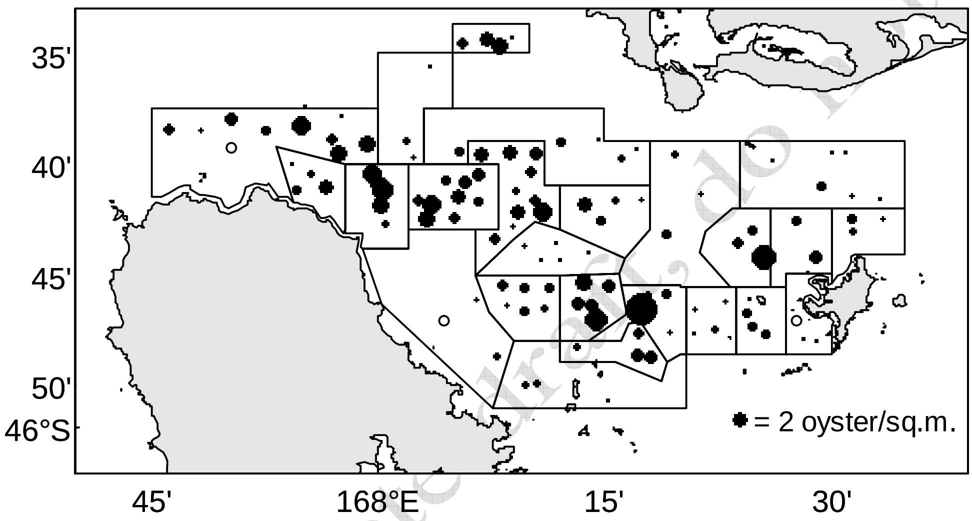


**Figure 29: Relative density of live small oysters in the February 2009 survey. Stations with no oysters are denoted by an open circle.**



## 3.4 Estimated prevalence and intensity of bonamia infection

Heart imprint slides from 106 stations were examined 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.

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, February 2007, and February 2009 surveys is shown in Figure 30. Overall, prevalence has been declining since 2007, and is similar to the lowest levels recorded in January to March sampling since 2001. The speed with which low level, undetectable infections intensify to detectable infections and progress within an annual cycle, and further to intensify to fatal infections, is poorly understood.

In February 2009, 106 stations of the 130 were sampled for bonamia infection (first-phase and target stations only). Of these, 104 stations had sufficient recruit and pre-recruit oysters to reliably determine bonamia infection, but only 94 stations had full samples of 25 recruited oysters for comparison to previous surveys. The prevalence of infection was mostly low. Heart imprints could not detect bonamia at 34% of stations examined (Figure 30, Table 3A), similar to 2008 (33%), but less than in 2007 (43%). Prevalence of bonamia infection ranged from 4% to 64%; 40% of stations had a prevalence of infection less than 10% (1–2 infected oysters), similar to 2008 (37%); and 26% had a prevalence of infection greater than 10%, ranging from 12 to 64%. Most of these stations ranged from 12 to 30% prevalence (3–6 infected oysters per sample), and 5 stations (4%) had a prevalence over 30%, 8–16 infected oysters. Less than 1% of stations had a prevalence of 50% or more, compared to 10% of stations in January 2004 and 24% in February 2003.

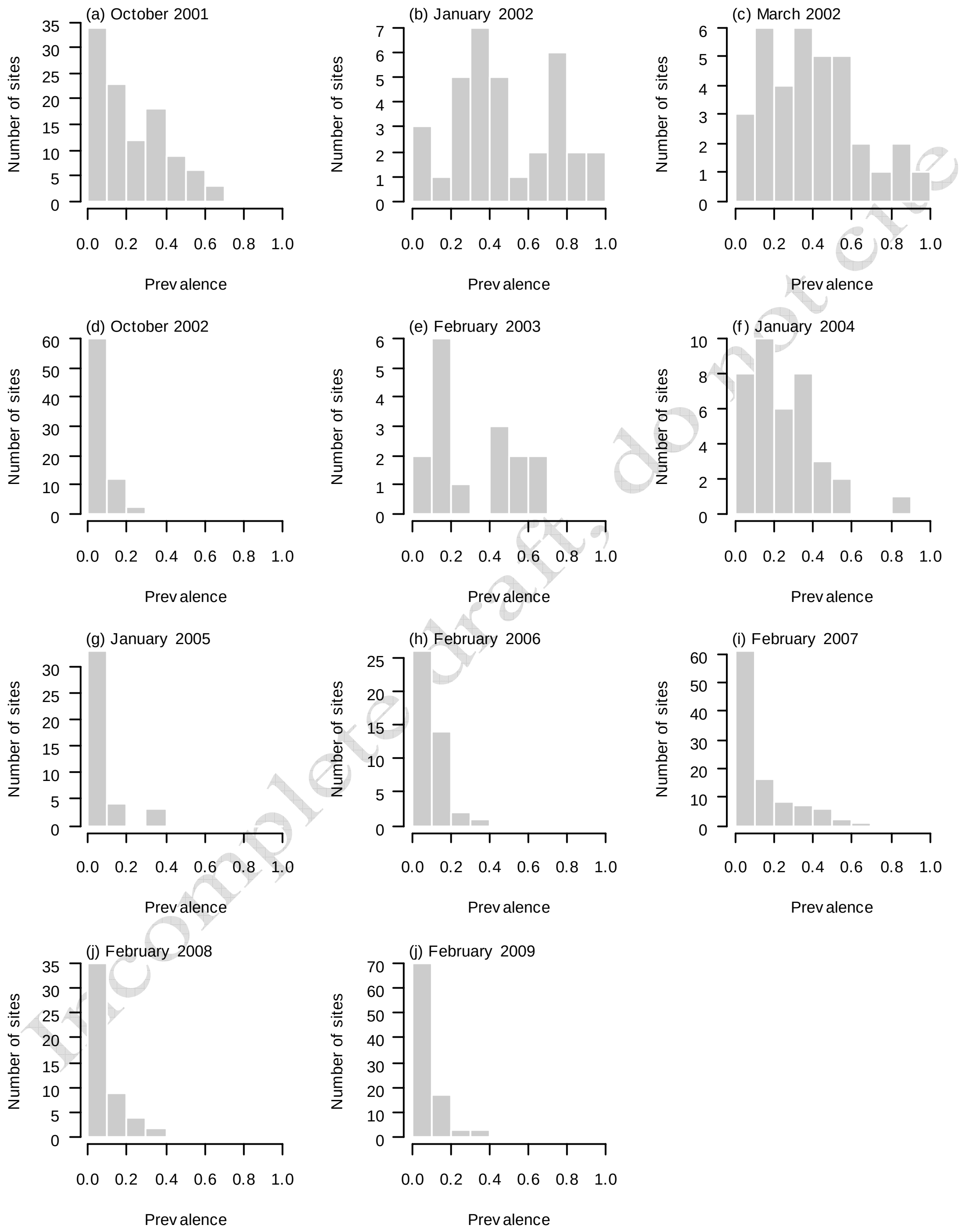




**Figure 30: Prevalence of bonamia infection at sites sampled in this and previous surveys.**

Intensity of infections 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 31. Of the 2463 oysters sampled, 197 (8.0%) had detectable infections (categories 1–5), and 5.8% 3+ infections (compared with 7.9% in 2007). The intensity of infection in February 2009 varied considerably within individual sample stations (Figure 32). The percentage of all infected stations with a mean intensity of category 3+ infections was 78% (compared with 47% in 2007 and 68% in 2008, Figure 31). Category 3+ infected oysters were projected to reduce the recruited population size by 6.25%, from 724.8 million oysters to 679.2 million oysters (Appendix 4 Table 4A). These data suggest prevalence is similar to that in 2008, but intensity of infection from bonamia has increased from 2007.

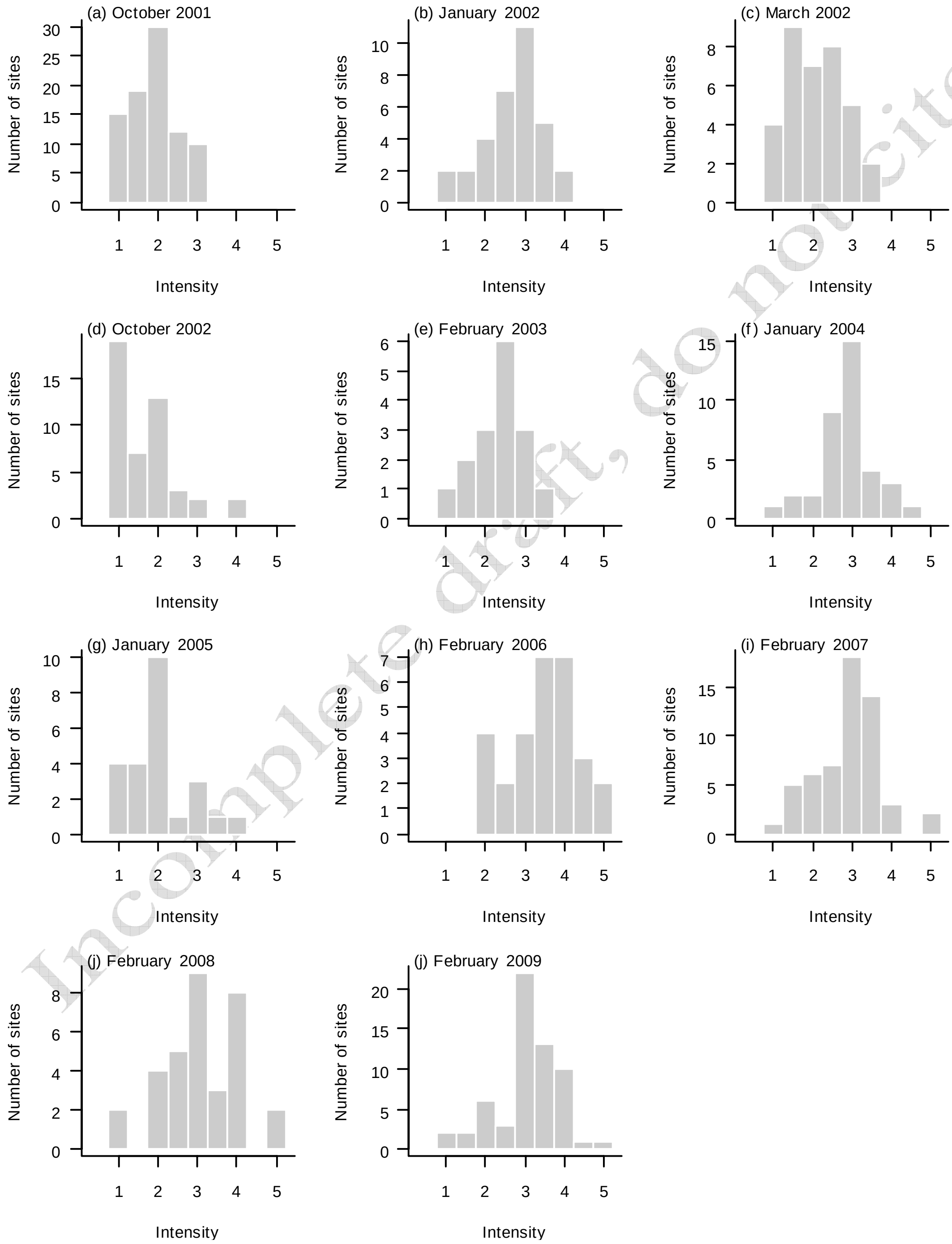


**Figure 31: Mean intensity of bonamia infection at sites sampled in this and previous surveys.**

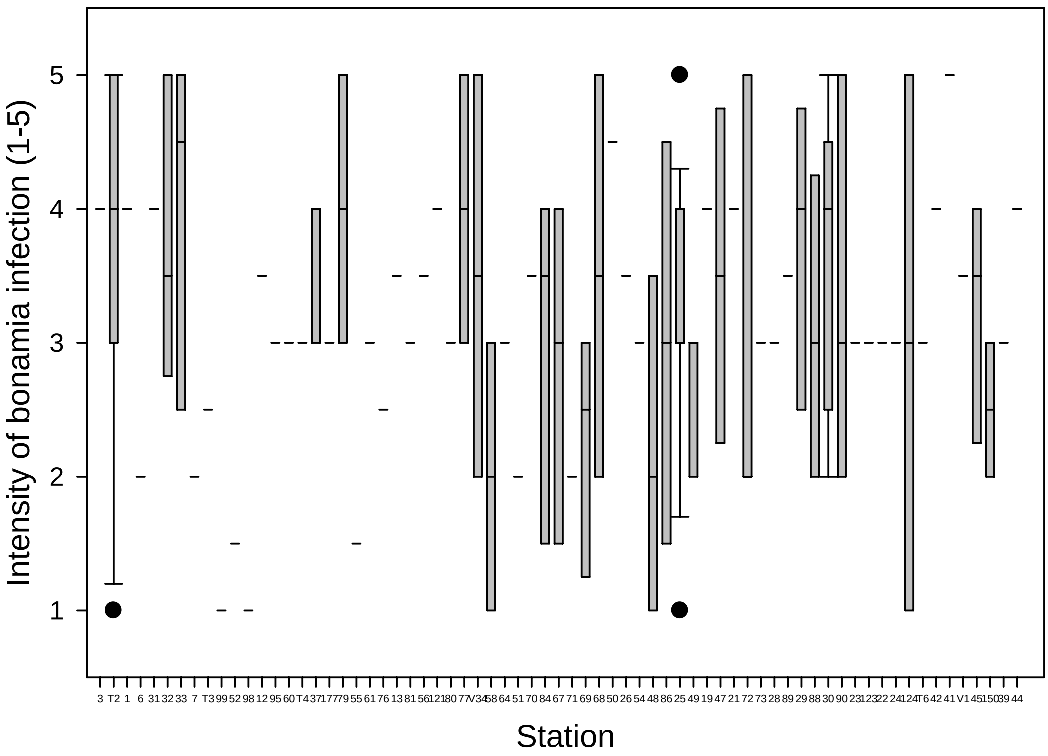


**Figure 32: Box plots of the variation in the intensity of bonamia infection within stations sampled in February 2009. Stations are arranged west to east on the x axis.**

The distribution of prevalence from October 2001 to February 2009 is shown in Figures 33–43. By October 2001, high prevalence of infection was found south and east (Figure 33) 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 34 & 35), prevalence was low throughout the fishery in October 2002 (Figure 36), 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 areas where oyster density was still relatively high and prevalence of infection widespread and relatively high (Figures 37 & 38). 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 higher oyster densities (Figure 39). A limited survey in February 2006 (Figure 40) and a more extensive survey in 2007 (Figure 41) 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. In February 2008, infection was still widespread and prevalence low in western, central, and southern fishery areas, but eastern areas continued to have relatively high prevalence of infection despite their reduced oyster densities. The February 2009 survey found continuing widespread infection with prevalence increasing in western, central, and southern fishery areas, but similar to that in eastern areas in 2008.

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 and higher infections, it is difficult to determine the distribution of infection over the whole fishery area and how it may have changed over time.

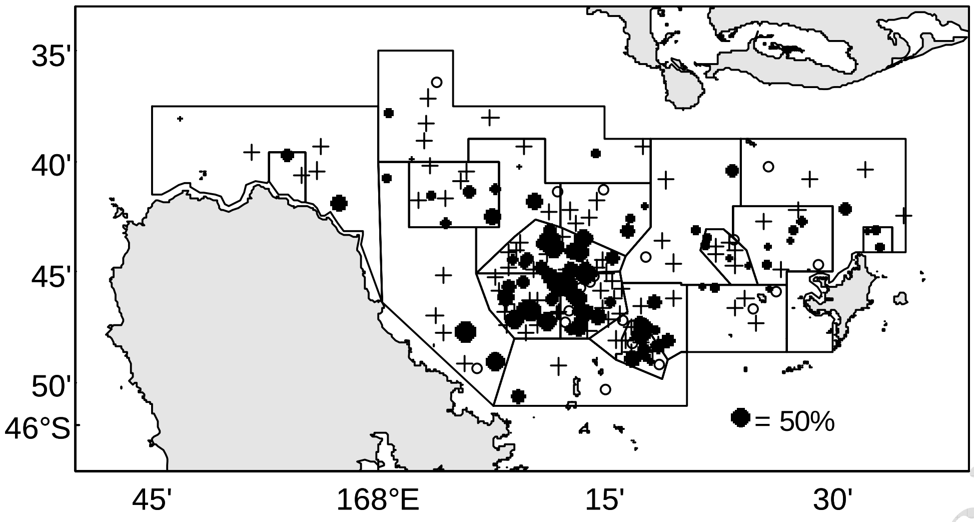


**Figure 33: Relative prevalence of infection of bonamia in recruit-sized oysters in the October 2001 survey. Stations with zero prevalence are denoted by an open circle, and stations that were not sampled for bonamia are denoted by a cross.**

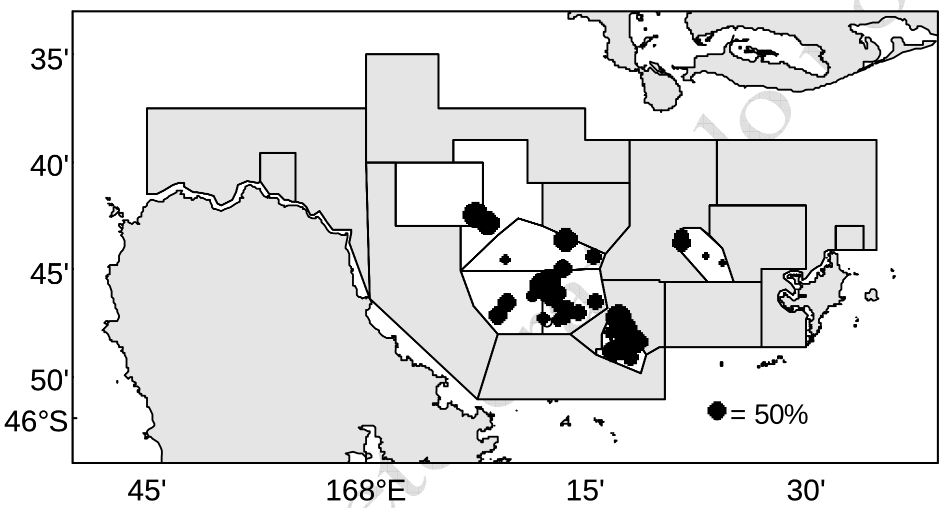


**Figure 34: Relative prevalence of infection of bonamia in recruit-sized oysters in the January 2002 survey. Stations with zero prevalence are denoted by an open circle.**

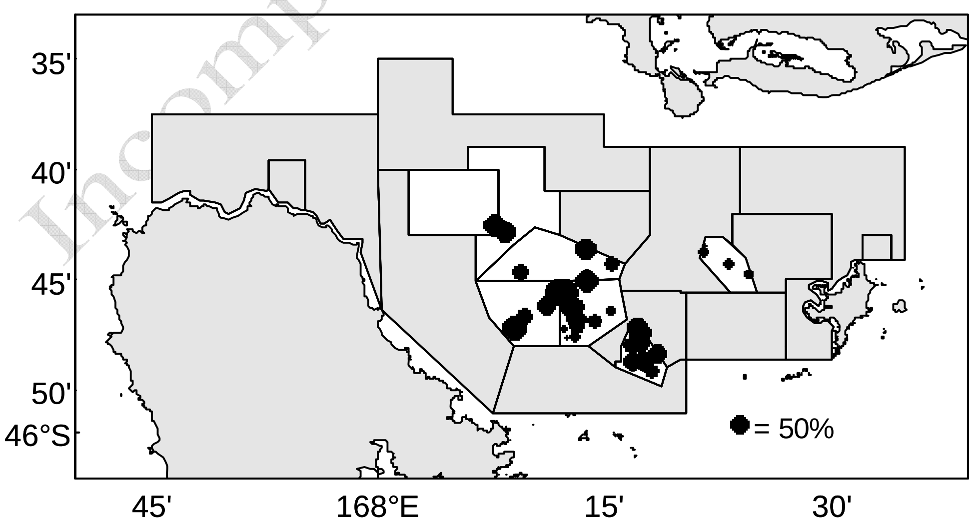


**Figure 35: Relative prevalence of infection of bonamia in recruit-sized oysters in the March 2002 survey.**

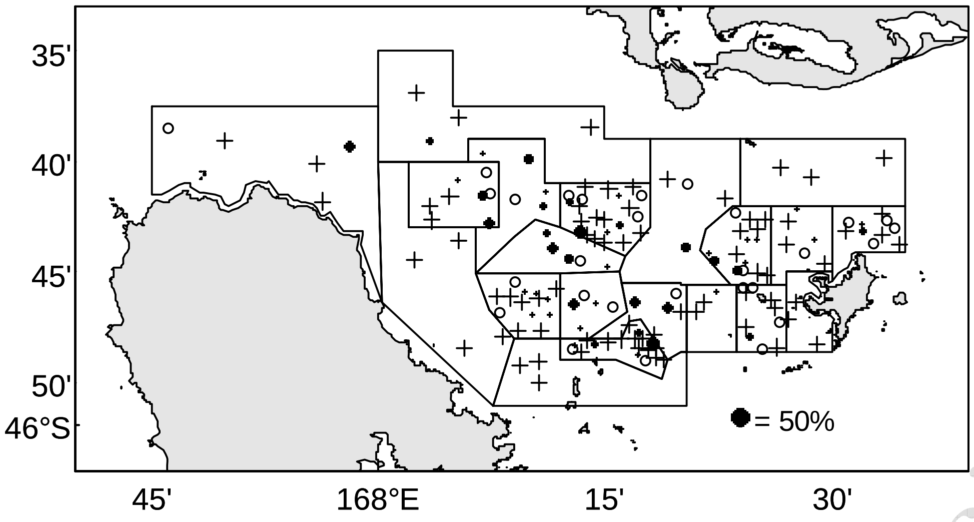


**Figure 36: Relative prevalence of infection of bonamia in recruit-sized oysters in the October 2002 survey. Stations with zero prevalence are denoted by an open circle, and stations that were not sampled for bonamia are denoted by a cross.**

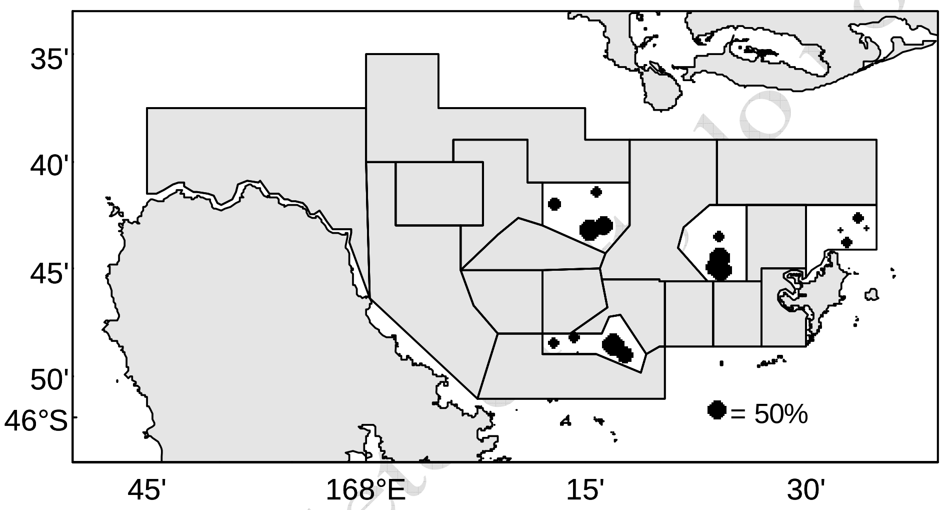


**Figure 37: Relative prevalence of infection of bonamia in recruit-sized oysters in the February 2003 survey.**

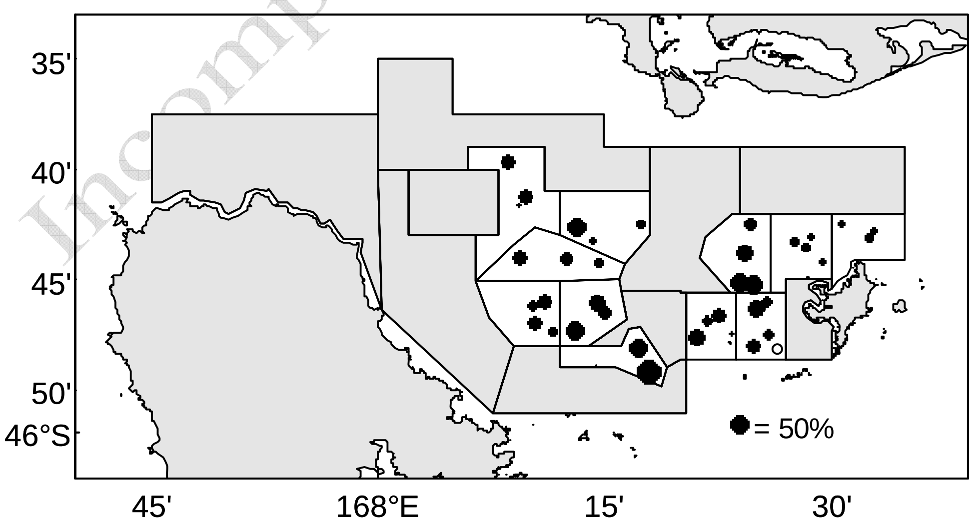


**Figure 38: Relative prevalence of infection of bonamia in recruit-sized oysters in the January 2004 survey.**

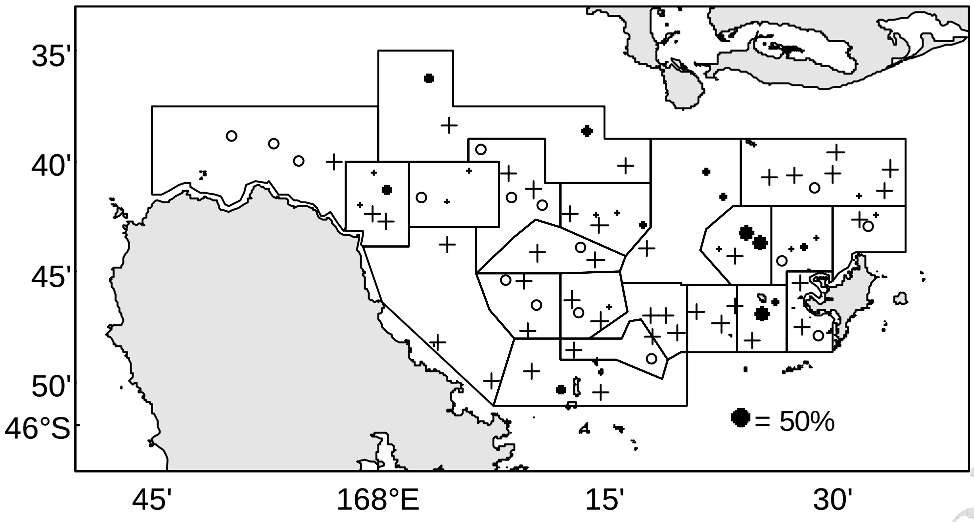


**Figure 39: Relative prevalence of infection of bonamia in recruit-sized oysters in the January 2005 survey. Stations with zero prevalence are denoted by an open circle, and stations that were not sampled for bonamia are denoted by a cross.**

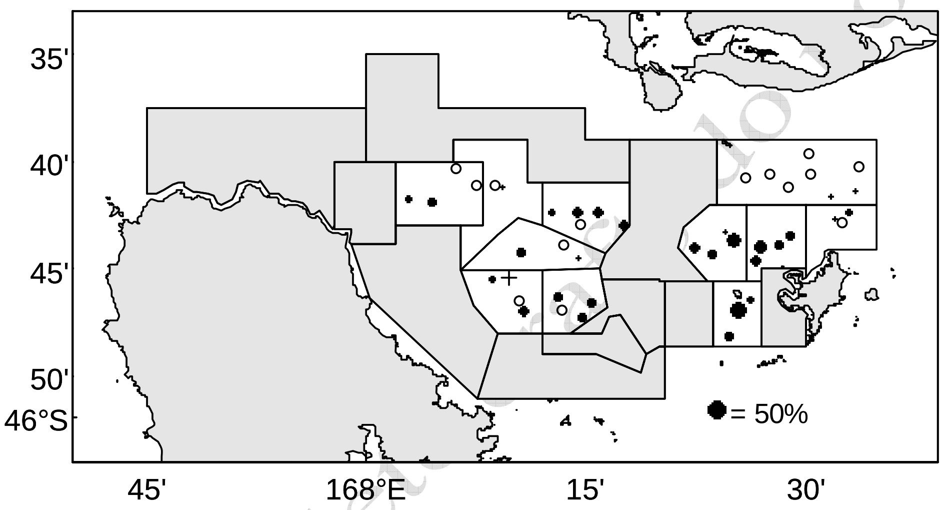


**Figure 40: Relative prevalence of infection of bonamia in recruit-sized oysters in the February 2006 survey. Stations with zero prevalence are denoted by an open circle, and stations that were not sampled for bonamia are denoted by a cross.**

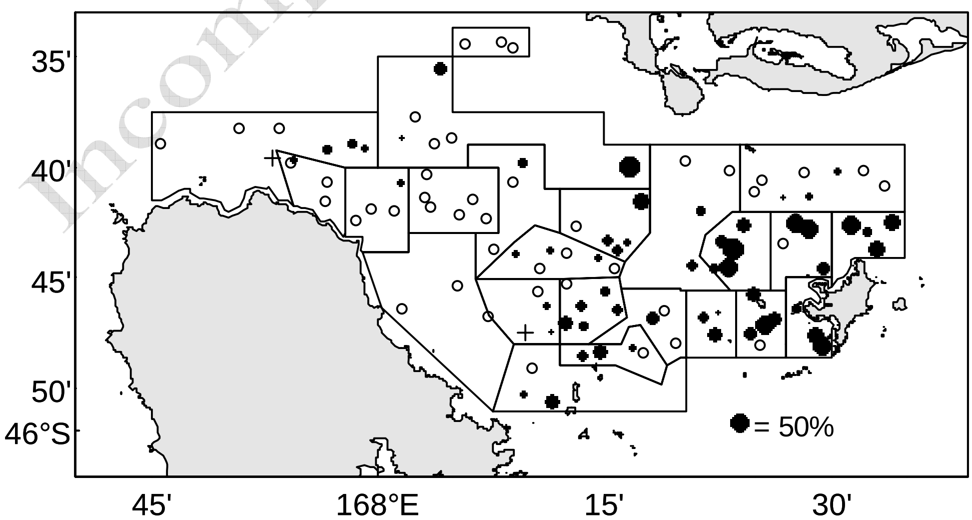


**Figure 41: Relative prevalence of infection of bonamia in recruit-sized oysters in the February 2007 survey. Stations with zero prevalence are denoted by an open circle, and stations that were not sampled for bonamia are denoted by a cross.**

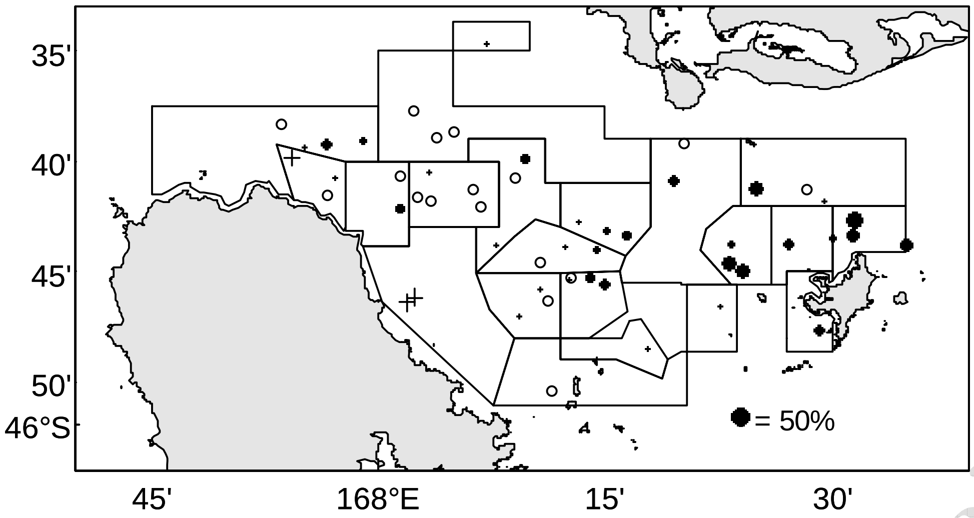


**Figure 42: Relative prevalence of infection of bonamia in recruit-sized oysters in the February 2008 survey. Stations with zero prevalence are denoted by an open circle, and stations that were not sampled for bonamia are denoted by a cross.**

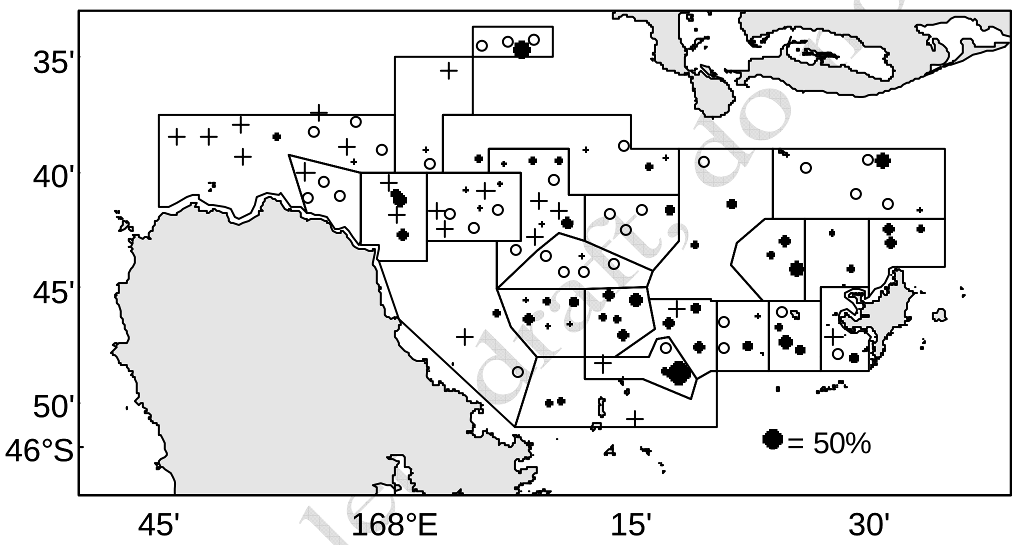


**Figure 43: Relative prevalence of infection of bonamia in recruit-sized oysters in the February 2009 survey. Stations with zero prevalence are denoted by an open circle, and stations that were not sampled for bonamia are denoted by a cross.**

The distribution of intensity of infection from October 2001 to February 2007 is shown in Figures 44–54. Intensity of infection was mostly low in October 2001 (Figure 44) at a time of year when infections can be difficult to detect; it was higher in January 2002 (Figure 45) and March 2002 (Figure 46). In October 2002, intensity of infection was mainly low after oysters with category 3 and higher infection in January and March 2002 had probably died, but there were some relatively high intensity patches still present (Figure 47). The number of high intensity patches increased over 2003 and 2005 (Figures 48–50), and infected oysters had mainly high intensity of infection in 2006 and 2007 (Figures 51 & 52). The intensity of infection was widespread in 2008 (Figure 53) and had increased further in 2009 (Figure 54). A summary of prevalence and intensity of infection in February 2009 is shown in Figure 55. These data suggest increasing intensity of infection within sites rather than a spread of infection through the fishery. Further, the persistence of generally low prevalence high intensity infection in most fishery areas suggest temporal cycles of infection and mortality at small spatial scales.

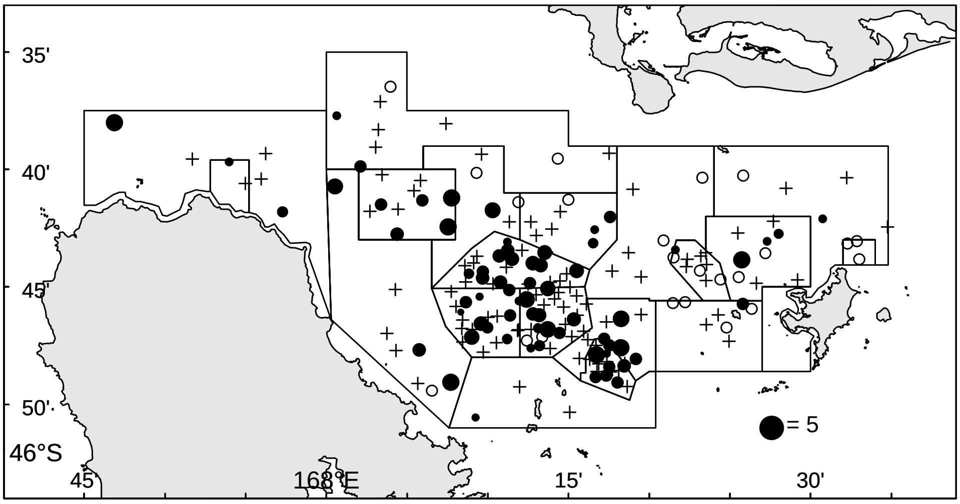


**Figure 44: Intensity of infection of bonamia in recruit-sized oysters in the October 2001 survey. Stations with zero prevalence are denoted by an open circle, and stations that were not sampled for bonamia are denoted by a cross.**

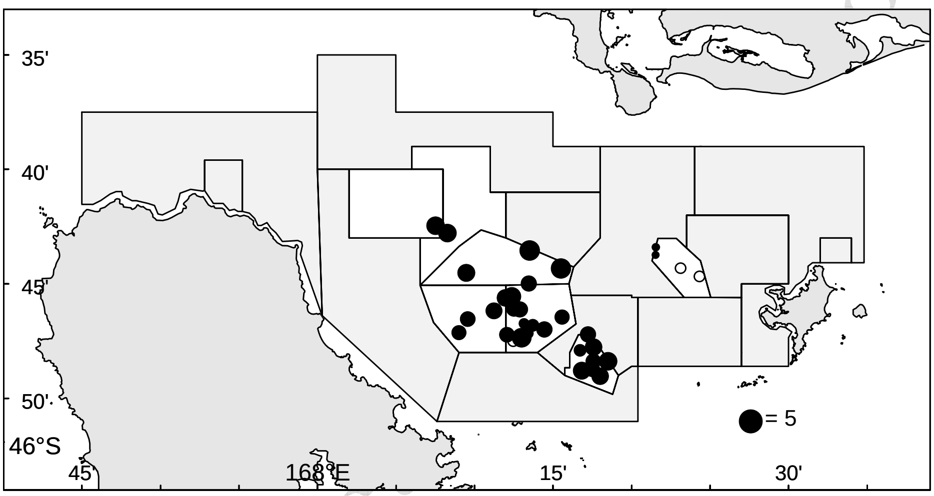


**Figure 45: Intensity of infection of bonamia in recruit-sized oysters in the January 2002 survey. Stations with zero prevalence are denoted by an open circle.**

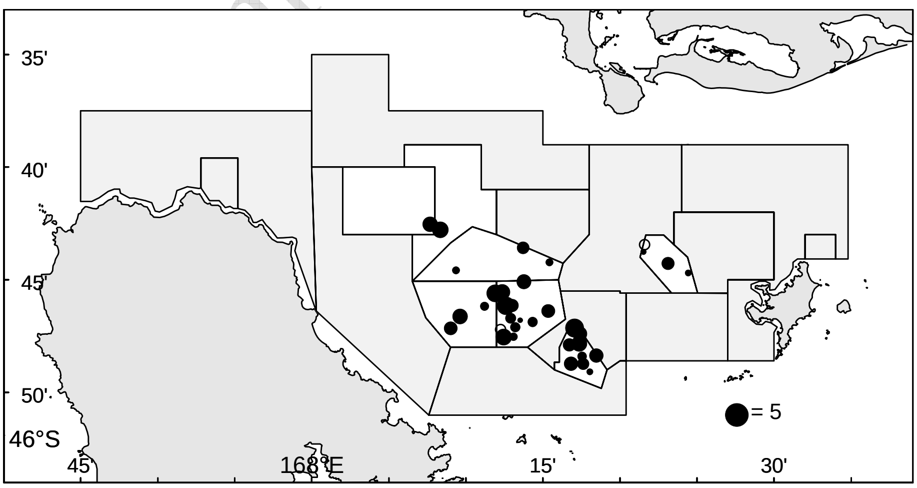


**Figure 46: Intensity of infection of bonamia in recruit-sized oysters in the March 2002 survey. Stations with zero prevalence are denoted by an open circle.**

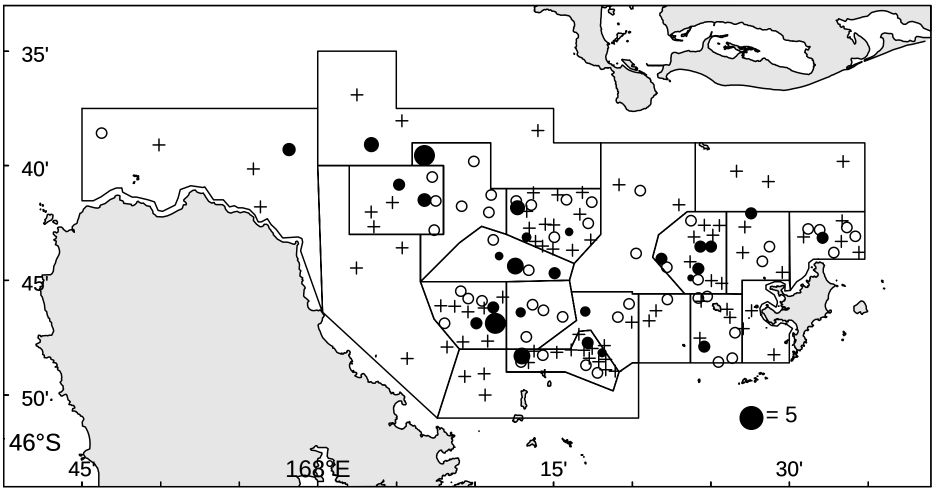


**Figure 47: Intensity of infection of bonamia in recruit-sized oysters in the October 2002 survey. Stations with zero prevalence are denoted by an open circle, and stations that were not sampled for bonamia are denoted by a cross.**

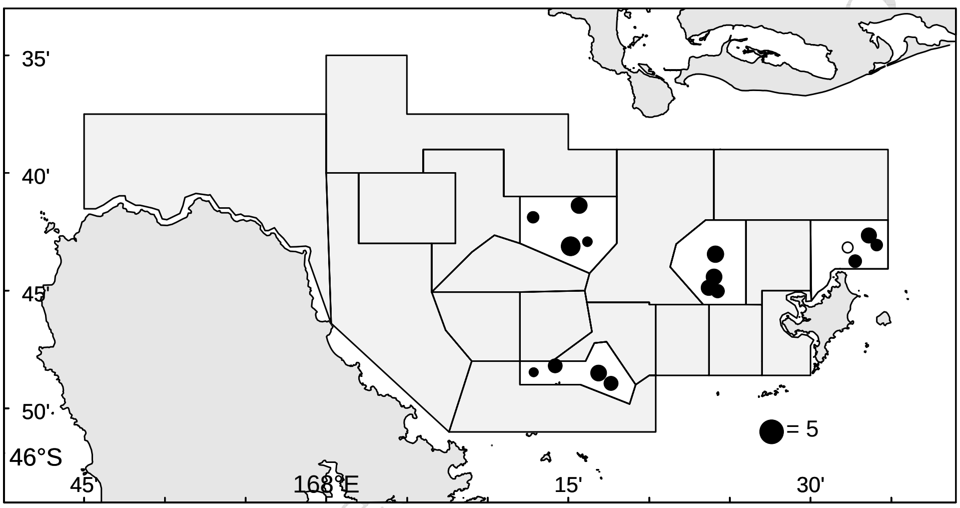


**Figure 48: Intensity of infection of bonamia in recruit-sized oysters in the February 2003 survey. Stations with zero prevalence are denoted by an open circle.**

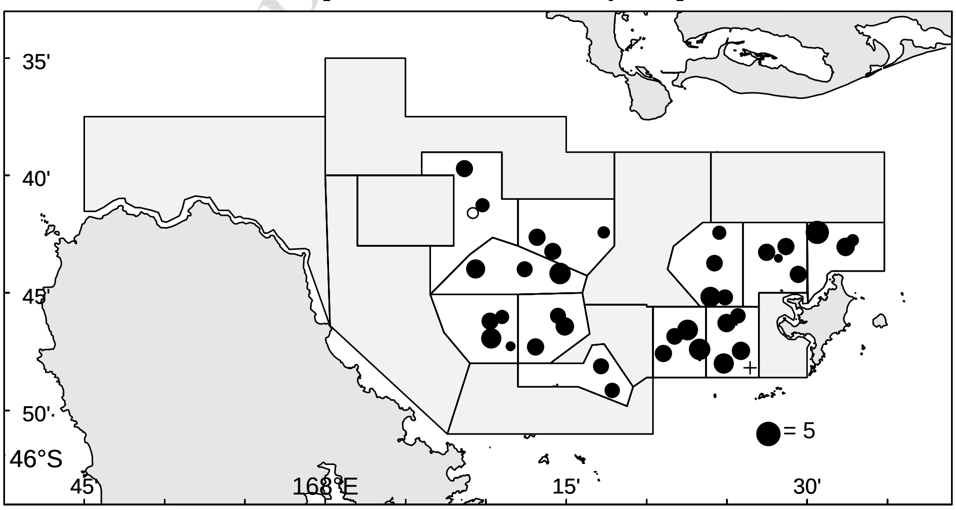


**Figure 49: Intensity of infection of bonamia in recruit-sized oysters in the January 2004 survey. Stations with zero prevalence are denoted by an open circle, and stations that were not sampled for bonamia are denoted by a cross.**

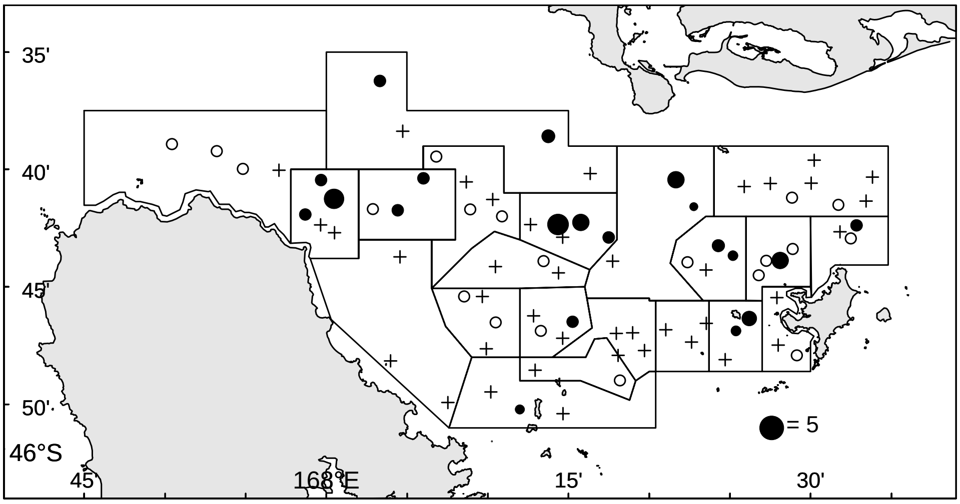


**Figure 50: Intensity of infection of bonamia in recruit-sized oysters in the January 2005 survey. Stations with zero prevalence are denoted by an open circle, and stations that were not sampled for bonamia are denoted by a cross.**

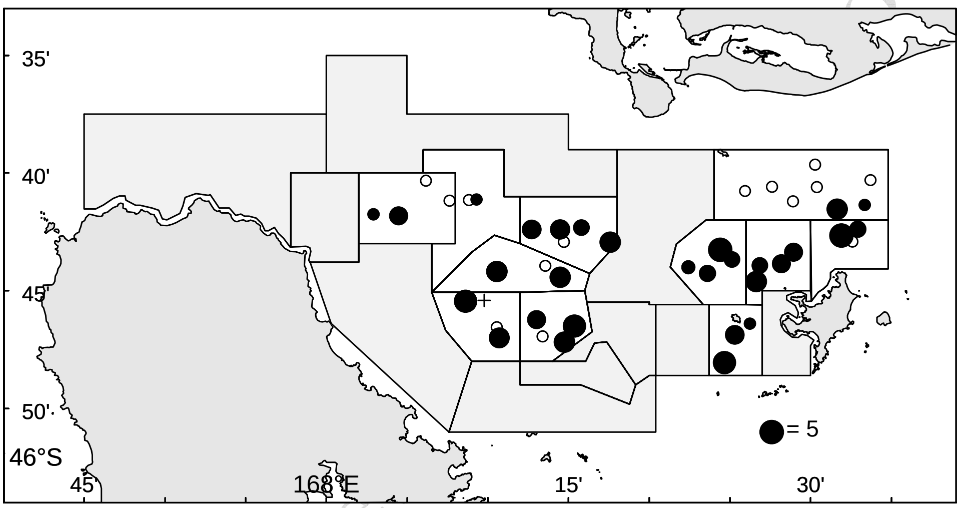


**Figure 51: Intensity of infection of bonamia in recruit-sized oysters in the February 2006 survey. Stations with zero prevalence are denoted by an open circle, and stations that were not sampled for bonamia are denoted by a cross.**

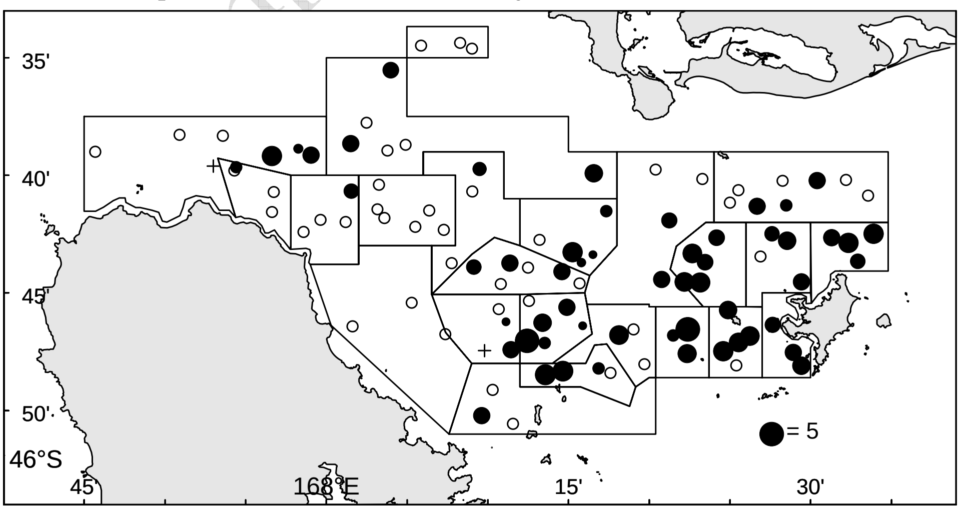


**Figure 52: Intensity of infection of bonamia in recruit-sized oysters in the February 2007 survey. Stations with zero prevalence are denoted by an open circle, and stations that were not sampled for bonamia are denoted by a cross.**

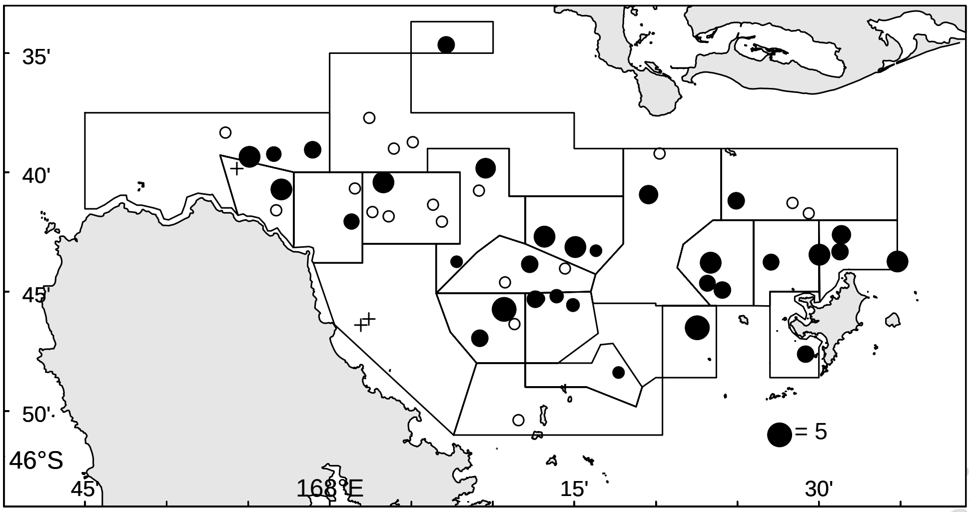


**Figure 53: Intensity of infection of bonamia in recruit-sized oysters in the February 2008 survey. Stations with zero prevalence are denoted by an open circle, and stations that were not sampled for bonamia are denoted by a cross.**

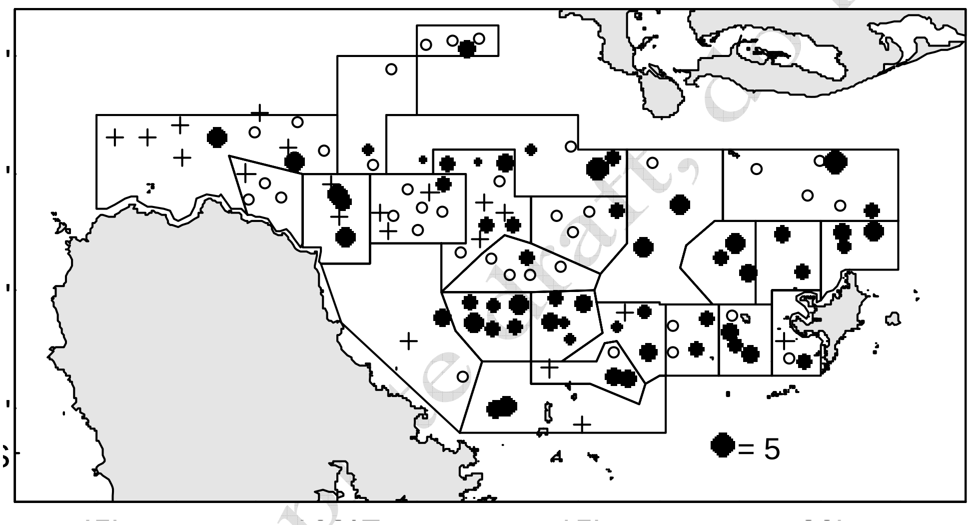


**Figure 54: Intensity of infection of bonamia in recruit-sized oysters in the February 2009 survey. Stations with zero prevalence are denoted by an open circle, and stations that were not sampled for bonamia are denoted by a cross.**

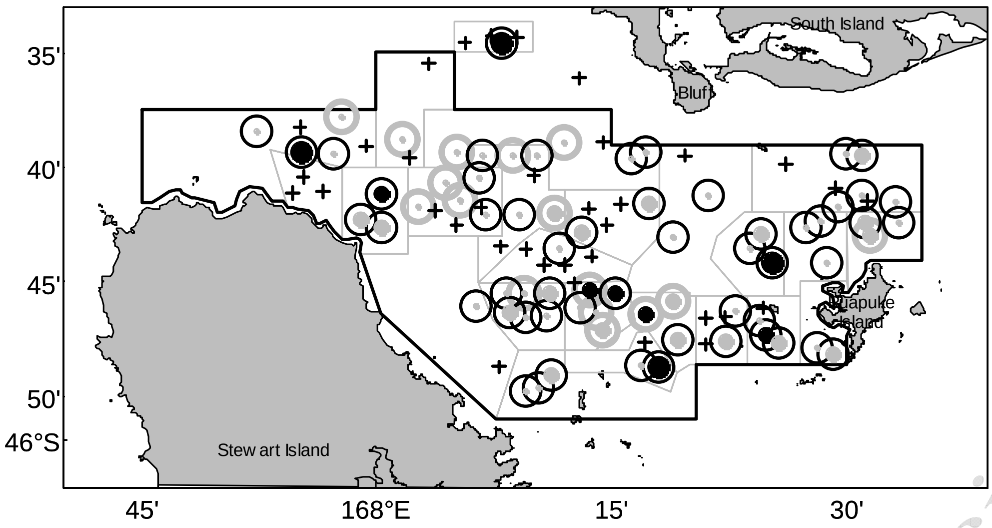


**Figure 55: Status of bonamia in February 2009. Stations with no bonamia are shown as black crosses, prevalence (the proportion of oysters infected in the sample) shown as small, grey, filled circles from less than 10%; and large, grey, filled circles for 11–20%; small, black, filled circles 21–30%; and large, black, filled circles more than 30%. Mean intensity of infection for categories 1–2 shown as grey open circles, and likely fatal infections from categories 3–5 in black.**

## 3.5 Survey estimates of population size

Survey estimates of population size for recruit, pre-recruit, and small oysters from the February 2009 survey by strata are shown in Tables 4–6. Table 7 compares survey estimates for recruit, pre-recruit, and small oysters from population surveys 1999–2009 within the 1999 survey area only (excludes stratum B1a).

In February 2009, there were two distinct commercial fishery areas with relatively high densities of recruited oysters; a southern area comprising strata CB8, C2, and E4 with oyster densities of 1.4–2.1 oysters/m$^2$, and a western area (strata B1, C7, E2, and B3) with 1.3–2.0 oysters/m$^2$. The western area strata (B3, B1, and E2) have the highest population sizes, 88.8, 86.0, and 82.0 million oysters respectively. Eastern fishery areas have relatively low oyster density (0.1–0.2 oysters/m$^2$) and population sizes (Table 4).

Pre-recruit oyster densities were generally low with the highest recorded in strata CB8 and E4 at 1.2 and 1.0 oysters/m$^2$ respectively. The population estimates for pre-recruits are also relatively low with 58.2 million for stratum B1 and about 32–34 million oysters for strata B3, CB8, and E2. Small oyster densities and population sizes followed similar patterns to pre-recruit oysters with densities ranging from 1.4 to 2.5 oysters/m$^2$ and 65 to 68 million oysters. Mean densities for recruit, pre-recruit, and small oysters were 0.7, 0.3, and 0.9 oysters/m$^2$ respectively, similar to those in February 2007 (0.6, 0.5, and 0.8 oysters/m$^2$ respectively for the same size groups).

The estimated mean population size of recruit-sized oysters in the 1999 survey area increased from 408 million oysters in January 2005 to 622 million in February 2007, and 720 million in February 2009. Mean oyster density over the whole fishery also increased from 0.39 oysters/m$^2$ to 0.68 /m$^2$ over the same period. Although pre-recruit oysters increased from 414 million oysters in 2005 to 463 million in 2007, the population declined to 354 million oysters in 2009. Pre-recruit oyster densities were similar, 0.39 oysters/m$^2$ in 2005 and 0.33 oysters/m$^2$ in 2009. Small oysters decreased from 1344 million in 2005 oysters to 842 million in 2007 and increased to 889 million in 2009. Mean small oyster density is lower in 2009, 0.85 oysters/m$^2$ compared to 1.28 oysters/m$^2$ in 2007. The low numbers of pre-recruit and small oysters may represent temporal lags from low recruit oyster numbers around 2005, and suggest a stock recruit relationship between recruited oyster numbers and the settlement and survival of small oysters.

Populations of recruited oysters have increased from 2005, but pre-recruit and small oysters have declined. Although the increase in the recruited oyster population from the low point in 2005 is similar to the level of rebuilding between 1993 and 1997, the future levels of rebuilding may be slower than in 1997 to 2001. The numbers of pre-recruits and small oysters are lower, and bonamia mortality is present in the fishery at low levels (there was no heightened mortality apparent between 1997 and 2001).

**Table 4: Absolute population survey estimates for recruited oysters: 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 (Area), by stratum for the February 2009 Foveaux Strait oyster survey.**

| Stratum | No. stations | Mean density | Density s.d. | c.v. | Mean population | Lower 95% CI | Upper 95% CI | Area (km$^2$) |
|---|---|---|---|---|---|---|---|---|
| B1 | 11 | 0.75 | 0.23 | 0.30 | 85.95 | 32.09 | 156.97 | 114.39 |
| B1A | 4 | 0.29 | 0.20 | 0.69 | 4.70 | 0.00 | 12.00 | 16.02 |
| B2A | 3 | 0.21 | 0.16 | 0.76 | 9.90 | 0.00 | 26.76 | 47.69 |
| B2B | 5 | 0.59 | 0.25 | 0.42 | 49.25 | 8.25 | 101.13 | 83.34 |
| B3 | 10 | 1.99 | 0.34 | 0.17 | 88.79 | 50.94 | 142.22 | 44.68 |
| B4 | 3 | 0.34 | 0.17 | 0.51 | 33.72 | 0.00 | 74.59 | 98.70 |
| B5 | 3 | 0.43 | 0.22 | 0.52 | 27.54 | 0.00 | 61.90 | 63.64 |
| B6B | 3 | 0.09 | 0.07 | 0.77 | 1.72 | 0.00 | 4.69 | 19.82 |
| B7 | 3 | 0.15 | 0.05 | 0.33 | 12.49 | 4.16 | 23.49 | 86.11 |
| B9 | 5 | 0.17 | 0.06 | 0.36 | 6.00 | 1.64 | 11.57 | 34.46 |
| C1A | 6 | 0.79 | 0.18 | 0.23 | 24.59 | 11.99 | 41.88 | 31.25 |
| C2 | 3 | 1.37 | 0.57 | 0.41 | 30.13 | 5.50 | 61.46 | 21.94 |
| C3 | 4 | 0.85 | 0.21 | 0.25 | 27.66 | 12.73 | 48.05 | 32.71 |
| C4 | 3 | 0.45 | 0.03 | 0.08 | 11.76 | 7.81 | 17.60 | 26.29 |
| C5 | 5 | 0.81 | 0.39 | 0.48 | 30.34 | 1.88 | 66.39 | 37.68 |
| C6 | 4 | 0.37 | 0.06 | 0.17 | 8.74 | 5.05 | 13.98 | 23.52 |
| C7 | 5 | 1.32 | 0.20 | 0.15 | 47.71 | 28.49 | 75.14 | 36.08 |
| CB6A | 6 | 0.23 | 0.11 | 0.49 | 17.45 | 1.09 | 38.40 | 77.12 |
| CB8 | 4 | 2.07 | 0.53 | 0.26 | 55.65 | 25.69 | 97.79 | 26.84 |
| CE5A | 5 | 0.36 | 0.15 | 0.42 | 8.58 | 1.42 | 17.66 | 23.52 |
| CE6 | 3 | 0.43 | 0.23 | 0.52 | 12.98 | 0.00 | 29.16 | 29.99 |
| CE7A | 4 | 0.29 | 0.11 | 0.37 | 6.81 | 1.86 | 13.33 | 23.60 |
| E2 | 9 | 1.91 | 0.59 | 0.31 | 82.02 | 29.67 | 150.76 | 42.83 |
| E4 | 4 | 1.44 | 0.64 | 0.45 | 40.31 | 4.29 | 84.64 | 28.04 |
| All | 115 | 0.68 | 0.06 | 0.08 | 724.77 | 475.62 | 1081.23 | 1070.27 |

* 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 pre-recruit oysters: 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 (Area), by stratum for the February 2009 Foveaux Strait oyster survey.**

| Stratum | No. stations | Mean density | Density s.d. | c.v. | Mean population | Lower 95% CI | Upper 95% CI | Area (km$^2$) |
|---|---|---|---|---|---|---|---|---|
| B1 | 11 | 0.51 | 0.16 | 0.31 | 58.23 | 21.00 | 106.24 | 114.39 |
| B1A | 4 | 0.26 | 0.18 | 0.69 | 4.16 | 0.00 | 10.78 | 16.02 |
| B2A | 3 | 0.10 | 0.07 | 0.67 | 4.74 | 0.00 | 11.81 | 47.69 |
| B2B | 5 | 0.25 | 0.08 | 0.32 | 21.21 | 7.43 | 39.87 | 83.34 |
| B3 | 10 | 0.76 | 0.18 | 0.24 | 33.80 | 16.11 | 58.59 | 44.68 |
| B4 | 3 | 0.08 | 0.04 | 0.52 | 7.92 | 0.00 | 17.78 | 98.70 |
| B5 | 3 | 0.14 | 0.07 | 0.51 | 8.68 | 0.00 | 19.45 | 63.64 |
| B6B | 3 | 0.05 | 0.03 | 0.65 | 0.96 | 0.00 | 2.39 | 19.82 |
| B7 | 3 | 0.11 | 0.02 | 0.18 | 9.33 | 5.19 | 15.03 | 86.11 |
| B9 | 5 | 0.05 | 0.02 | 0.34 | 1.61 | 0.51 | 3.04 | 34.46 |
| C1A | 6 | 0.22 | 0.02 | 0.09 | 6.79 | 4.43 | 10.22 | 31.25 |
| C2 | 3 | 0.58 | 0.27 | 0.46 | 12.80 | 1.42 | 26.84 | 21.94 |
| C3 | 4 | 0.74 | 0.46 | 0.62 | 24.36 | 0.00 | 59.35 | 32.71 |
| C4 | 3 | 0.20 | 0.05 | 0.24 | 5.20 | 2.46 | 8.91 | 26.29 |
| C5 | 5 | 0.48 | 0.19 | 0.41 | 18.05 | 3.52 | 36.33 | 37.68 |
| C6 | 4 | 0.11 | 0.03 | 0.24 | 2.70 | 1.27 | 4.67 | 23.52 |
| C7 | 5 | 0.77 | 0.19 | 0.25 | 27.85 | 12.98 | 47.96 | 36.08 |
| CB6A | 6 | 0.09 | 0.04 | 0.46 | 6.94 | 0.78 | 14.50 | 77.12 |
| CB8 | 4 | 1.22 | 0.28 | 0.23 | 32.76 | 15.96 | 55.78 | 26.84 |
| CE5A | 5 | 0.13 | 0.06 | 0.48 | 3.09 | 0.16 | 6.58 | 23.52 |
| CE6 | 3 | 0.14 | 0.04 | 0.32 | 4.17 | 1.49 | 7.84 | 29.99 |
| CE7A | 4 | 0.13 | 0.07 | 0.54 | 3.09 | 0.00 | 7.10 | 23.60 |
| E2 | 9 | 0.74 | 0.16 | 0.22 | 31.57 | 16.06 | 52.94 | 42.83 |
| E4 | 4 | 1.00 | 0.55 | 0.56 | 27.91 | 0.00 | 64.19 | 28.04 |
| All | 115 | 0.33 | 0.03 | 0.10 | 357.92 | 232.29 | 537.39 | 1070.27 |

* 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 small oysters: 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 (Area), by stratum for the February 2009 Foveaux Strait oyster survey.**

| Stratum | No. stations | Mean density | Density s.d. | c.v. | Mean population | Lower 95% CI | Upper 95% CI | Area (km$^2$) |
|---|---|---|---|---|---|---|---|---|
| B1 | 11 | 1.14 | 0.33 | 0.29 | 130.28 | 50.85 | 235.44 | 114.39 |
| B1A | 4 | 1.36 | 0.53 | 0.39 | 21.72 | 5.13 | 42.91 | 16.02 |
| B2A | 3 | 0.27 | 0.11 | 0.43 | 12.71 | 1.88 | 25.97 | 47.69 |
| B2B | 5 | 0.50 | 0.16 | 0.32 | 41.42 | 14.20 | 77.54 | 83.34 |
| B3 | 10 | 1.22 | 0.18 | 0.15 | 54.73 | 32.71 | 85.92 | 44.68 |
| B4 | 3 | 0.31 | 0.17 | 0.56 | 30.35 | 0.00 | 70.20 | 98.70 |
| B5 | 3 | 0.34 | 0.17 | 0.49 | 21.90 | 0.71 | 48.02 | 63.64 |
| B6B | 3 | 0.07 | 0.04 | 0.55 | 1.44 | 0.00 | 3.29 | 19.82 |
| B7 | 3 | 0.48 | 0.09 | 0.18 | 41.44 | 23.11 | 67.03 | 86.11 |
| B9 | 5 | 0.11 | 0.03 | 0.25 | 3.95 | 1.86 | 6.83 | 34.46 |
| C1A | 6 | 0.70 | 0.10 | 0.15 | 21.98 | 13.05 | 34.75 | 31.25 |
| C2 | 3 | 1.22 | 0.41 | 0.33 | 26.76 | 8.80 | 50.66 | 21.94 |
| C3 | 4 | 1.98 | 1.00 | 0.50 | 64.70 | 0.29 | 144.91 | 32.71 |
| C4 | 3 | 0.49 | 0.09 | 0.18 | 12.99 | 7.34 | 21.09 | 26.29 |
| C5 | 5 | 1.25 | 0.47 | 0.37 | 47.13 | 12.05 | 93.22 | 37.68 |
| C6 | 4 | 0.60 | 0.15 | 0.25 | 14.01 | 6.48 | 24.43 | 23.52 |
| C7 | 5 | 2.38 | 0.55 | 0.23 | 85.72 | 41.24 | 145.50 | 36.08 |
| CB6A | 6 | 0.21 | 0.10 | 0.49 | 15.92 | 0.72 | 35.24 | 77.12 |
| CB8 | 4 | 2.43 | 0.64 | 0.26 | 65.22 | 29.34 | 115.11 | 26.84 |
| CE5A | 5 | 0.48 | 0.22 | 0.45 | 11.35 | 1.36 | 23.86 | 23.52 |
| CE6 | 3 | 0.89 | 0.28 | 0.32 | 26.60 | 9.03 | 49.81 | 29.99 |
| CE7A | 4 | 0.85 | 0.42 | 0.49 | 20.10 | 1.03 | 43.88 | 23.60 |
| E2 | 9 | 1.60 | 0.25 | 0.15 | 68.72 | 40.80 | 108.14 | 42.83 |
| E4 | 4 | 2.47 | 1.93 | 0.78 | 69.36 | 0.00 | 190.69 | 28.04 |
| All | 115 | 0.85 | 0.08 | 0.10 | 907.84 | 588.67 | 1366.73 | 1070.27 |

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

**Table 7: Absolute population survey estimates for recruited, pre-recruit, and small oysters 1999–2009; mean population size (millions of oysters) with upper and lower 95% confidence intervals in parentheses. Estimates exclude stratum B1A.**

| Survey | | Recruits | | Pre-recruits | | Small |
|---|---|---|---|---|---|---|
| 1999 (October) | 1 461 | (872–2334) | 899 | (570–1387) | 1 373 | (874–2115) |
| 2001 (October) | 995 | (632–1511 | 871 | (548–1330 | 1 410 | (884–2156) |
| 2002 (October) | 502 | (310–785) | 520 | (333–795) | 1 243 | (806–1884) |
| 2005 (January) | 408 | (253–628) | 414 | (247–652) | 1 344 | (845–2056 |
| 2007 (February) | 622 | (398–947) | 463 | (293–708) | 842 | (546–1273) |
| 2009 (February) | 720 | (470–1085) | 354 | (228–538) | 889 | (574–1351) |

## 3.6 Survey estimates of the commercial population size

Survey estimates for recruit-sized oysters in designated commercial fishery areas from population surveys in 1999–2009 are compared in Table 8. Oyster densities in designated commercial fishery areas in 2009 ranged from 0.2 to 1.0 oyster/m$^2$ compared to 0.4 to 0.7 oyster/m$^2$ in 2007. The mean density over all designated commercial fishery areas in February 2009 was 1.0 oyster/m$^2$, higher than the 0.53 oyster/m$^2$ in 2007, which was similar to most exploratory and background areas at that time.

Estimates of population size of recruited oysters in designated commercial areas have increased from 164 million oysters in January 2005 to 361 million in February 2009, while the sizes of commercial areas have remained the same (366–372 km$^2$).

**Table 8: Population estimates for recruited oysters in designated commercial areas, 1999–2009; 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. stations | Mean density | s.d. | c.v. | Mean population | | Area km$^2$ |
|---|---|---|---|---|---|---|---|
| 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 |
| 2009 | 57 | 0.97 | 0.11 | 0.12 | 361 | (227–549) | 372 |

In 1995 and 1997, the commercial population used to estimate yield represented the population above a baseline 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 9) to allow some comparison with previous years (Table 10).

**Table 9: Percentage of the oyster population in areas above a density of 400 oysters per survey tow (equivalent to about 6–8 sacks per hour in commercial dredging) in February 2009.**

| Stratum | No. stations | Mean density | s.d. | Density c.v. | Mean population | Lower 95% CI | Upper 95% CI | Area (km2) |
|---|---|---|---|---|---|---|---|---|
| B1 | 11 | 0.22 | 0.22 | 1.00 | 25.1 | 0.0 | 80.6 | 114.4 |
| B3 | 10 | 1.61 | 0.47 | 0.29 | 72.0 | 29.8 | 128.8 | 44.7 |
| C2 | 3 | 0.70 | 0.70 | 1.00 | 15.4 | 0.0 | 49.2 | 21.9 |
| C5 | 5 | 0.43 | 0.43 | 1.00 | 16.3 | 0.0 | 52.4 | 37.7 |
| CB8 | 4 | 1.46 | 0.85 | 0.58 | 39.2 | 0.0 | 92.4 | 26.8 |
| E2 | 9 | 1.26 | 0.72 | 0.57 | 53.8 | 0.0 | 125.4 | 42.8 |
| E4 | 4 | 1.26 | 0.74 | 0.59 | 35.3 | 0.0 | 84.5 | 28.0 |
| All | 115 | 0.24 | 0.06 | 0.23 | 257.2 | 129.1 | 441.4 | 1070.3 |

Less than one-third of strata had a mean oyster density above 400 oysters per standard survey tow, and the mean density was low at 0.24 oyster/m$^2$ (see Table 9). The highest densities and the highest oyster population sizes were found in the central fishery area, in strata B3, CB8, E2, and E4. The highest commercial population sizes were in strata B3 and E2 despite their relatively small areas (see Table 9).

**Table 10: Estimates of commercial population size from the proportion of oysters above 400 oysters per standard survey tow over the entire fishery area 2001–09; 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 (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 | | Area $km^2$ |
|---|---|---|---|---|---|---|---|
| 2001 | 192 | 0.59 | 0.1 | 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 |
| 2009 | 115 | 0.24 | 0.06 | 0.23 | 257 | (129–441) | 1070 |

Estimates of the oyster population size above a threshold of 400 oysters per standard survey tow (using catch at each site less 400 oysters; the number of oysters available to the fishery before density is reduced below the historical threshold level) was 257 million oysters in 2009, compared to 204 million in 2007, and 33 million in 2005. In 1997, four years after the low population levels of 1993, the commercial population was 109 million oysters, less than half the size of 2009. These data suggest oyster density is increasing in commercial fishery areas, but the size and number of commercial areas may be relatively small compared to the pre-epizootic fishery (before 1986).

## 3.7 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 of small oysters had not changed from about 1300 million oysters in 1999, but the 2007 survey found a decrease in the population of small oysters to 842 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 be part of the normal variation in recruitment in the fishery. In February 2009, the numbers of small oysters had increased slightly to 908 million, but numbers of pre-recruit oysters had (expectedly) declined from 463 million to 358 million over the same time.

Between 2001 and 2005, high densities of small oysters were recorded from eastern fishery areas, but from 2007 densities of small oysters have continued to decline. Given the low densities of recruit and pre-recruit oysters and that settlement and survival of oyster spat occurs almost entirely on live oysters and oyster shell, the eastern fishery area may experience lower recruitment in the short to medium term, and these areas may not contribute significantly to commercial catches in the near future.

# 4. DISCUSSION

## 4.1 The 2009 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 and projecting mortality. The February 2009 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 relatively high proportions of new clocks sampled and the presence of some gapers suggested significant recent and ongoing mortality from bonamia 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 lead to underestimation of 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 dredges to be landed more than 70% full, and the 80% threshold may need to be revised. Video of dredges fishing on the seabed show dredge saturation can occur within 3 minutes, just over half the time required to complete a standard survey tow. Dredge contents compacted into the dredge on hauling remove signs of dredge saturation (author's observations).

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 8%, 10%, and 10% for recruit, pre-recruit, and small oysters respectively, similar to those in 2007 (10%, 11%, and 9% ) and lower than pre-2007 surveys.

## 4.2 Estimates of population size

The 2009 survey was not able to detect statistically significant changes in oyster population size of recruited, pre-recruit, or small oysters from those estimated from the January 2005 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 725 (476–1081) million oysters in February 2009 (Figure 56). Overall, oyster densities are still low in the fishery compared to pre-disease levels, but both mean recruit size oyster density over the whole fishery (0.7/$m^2$) in 2009 has increased from that in 2005 (0.4 oysters/$m^2$), and densities in commercial strata are increasing. Increased oyster densities have translated to increased catch rates in the fishery, from a fleet average of 1.8 sacks per hour in 2005 to 3.3 sacks per hour in 2008.

The recruit-sized oyster population has increased more slowly than predicted by the stock assessment model update in 2007 (Table 11). The difference between predicted and estimated population sizes may be due to either underestimates of bonamia mortality and, or differences in the way the model estimates recruited population size (using a dredge selectivity ogive for recruit sized oysters instead of absolute counts) that may produce slightly higher estimates.

The current rate of rebuilding of the oyster population may be slower than the 1993–99 rebuild (Figure 56). The two patterns of rebuilding are similar; the low population size (408 million oysters) in 2005 was similar to the 1992 population (397 million oysters), and after 4 years both rebuilds have increased by about 300 million oysters (increasing by 263 million in 1997 and 318 million in 2009). The key difference between 1997 and 2009 is (the assumption of) no bonamia mortality in the 1993–99 rebuild and higher numbers of pre-recruits (772 million in 1997 compared with 358 million in 2009). Half the pre-recruits are expected to enter the fishery in the following season; however, bonamia mortality affects pre-recruits to the same degree as recruits and continuing mortality of pre-recruits could further slow rebuilding of commercial oyster densities.

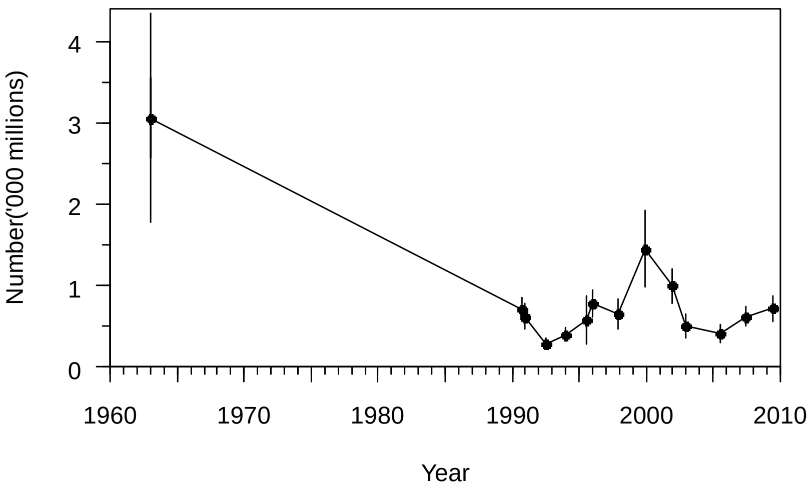


**Figure 56: Estimates of recruit-sized oyster population in Foveaux Strait, 1963–2007.**

**Table 11: Projections from the OYU 5 stock assessment model of the population sizes of recruit-sized oysters in 2009 (millions of oysters) based on the 2007 population size of 622 million oysters, a future harvest level of 7.5 million oysters, no bonamia mortality, and bonamia mortality (Bon %M) of 10% and 20%.**

| Bon %M | 2007 | increase | 2009 |
|---|---|---|---|
| 0 | 622 | 1.37 | 852 |
| 10 | 622 | 1.31 | 815 |
| 20 | 622 | 1.07 | 666 |

Populations of recruited and small oysters are increasing, and pre-recruit oysters have probably declined from 2005. These patterns are similar to those observed in the previous rebuilding phase of the oyster fishery in 1992–99 (Figure 57). The decline in pre-recruit oysters could reflect a time lag between low recruit densities (2002–05) and low numbers of small oysters in 2007. Further, changes in the distributions of oyster densities from eastern to western fishery areas where fewer spat and wings normally occur on oysters could also contribute to the decline in pre-recruit oysters.

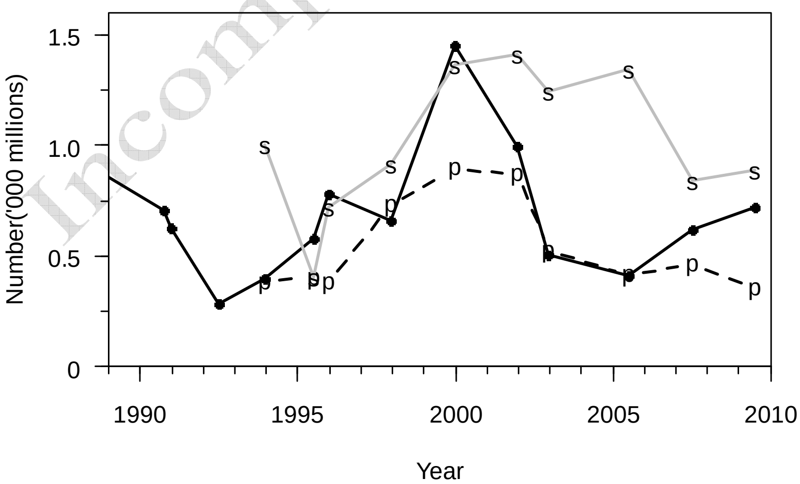


**Figure 57: Estimates of mean population size for recruited, pre-recruit, and small oysters 1990–2007.**

Both methods of estimating commercial population size show an increase in both the population size and oyster densities. 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 (Cranfield et al. 1996). Although this threshold has no biological basis, it has been used as an indicator of commercial densities. These estimates have increased from January 2005 (see Table 10). Oyster densities and population sizes in designated commercial fishery areas are also increasing (see Table 8). Many exploratory and background areas (B1, B2b, C7, E4, and B4) had similar oyster densities and population sizes to designated commercial areas, suggesting fishers' logbook data may not have identified all potential commercial fishery areas. Further, biennial changes in which survey strata are designated as commercial increases the uncertainty in determining trends in commercial population size; however, increasing commercial population sizes are supported by increasing catch rates in the fishery.

## 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 morality.

## 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 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 1300 million to 842 million oysters, and this has translated to a reduction in pre-recruit oysters in 2009. If the oyster fishery is going to rebuild in a similar pattern to that observed in 1993–99, an increase in the numbers of small oyster should be evident by 2011.

## 4.5 Status of infection

An extensive survey in 2007 found widespread infection that has persisted through to February 2009. Fishery areas east of a line between Bluff Hill and Saddle Point continue to be the worst affected, despite the low oyster densities there. Overall, prevalence continued to slowly decrease from January 2007, but there is localised, high prevalence of infection in all commercial areas throughout the fishery area. The intensity of infection has varied considerably within individual sample stations, but the mean intensity of infection has increased. Most of the infected stations (78%) in February 2009 had a mean intensity of infection higher than category 3, compared to 68% in 2008. Mean mortality from higher than category 3 infections over the summer of 2009 was 6.25%, reducing the oyster population from 725 million oysters to 679 million. Continuing oyster mortality from bonamia and the decline in numbers of pre-recruit and small oysters is expected to slow the rate of rebuilding in the oyster population.

These data suggest increasing intensity of infection within sites rather than a spread of infection through the fishery.

## 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 (622 million oysters). Disease mortality for 2007 and 2008 was estimated at 6.9% and 3.3%, and the population size of recruited oysters projected to increase to 815–852 million oysters in 2009 under a harvest limit of 15 million oysters.

All fishery indicators show an improvement in the status of the fishery to date. Population sizes of recruited oysters (absolute, commercial, and above 400 oysters per survey tow) have increased as have oyster densities, especially in commercial fishery areas. Oyster densities in commercial strata are only 40% of 1999–2001 levels. This improved status is reflected in catch rates; the fleet season average of 1.9 sacks per hour in 2005 has increased to 3.1 sacks per hour in 2008, and about 4 sacks per hour in the first half of the 2009 season. The proportion of large oysters in the commercial catch has also increased; 53.6% of the catch was 64 mm or over in 2007 compared with 61.6% of the catch in 2008. This increase in the proportion of large oysters landed may in part be due to incentives given to land large oysters that have a higher market value. Increases in the recruited oyster population are lower than predicted by the 2007 stock assessment for the estimated levels of bonamia mortality.

The rate of rebuilding in the oyster population has been similar to that in 1992–99, but could slow substantially due to low numbers of pre-recruits and small oysters available to recruit to the fishery. The intensity of bonamia infection has increased in 2009, and the mean mortality from bonamia infection has also increased from 3.3% in 2008 to 6.5% in 2009, but is below the level thought to have an effect on future stock increases. Continuing oyster mortality from bonamia and fewer pre-recruit and small oysters introduce greater uncertainty around how this will affect the oyster population rebuild compared with 1992–1999 when there was an assumption of no heightened mortality from bonamia (there was no bonamia sampling over that period and no data to suggest heightened mortality).

Surveys of the Foveaux Strait oyster population estimate the size of the stock (numbers of oysters over the entire fishery area) and the population size of predetermined areas (strata) in three oyster size groups. These data allow predictions of future stock size. In simple terms, these estimates are the products of average oyster densities from sampling and the sizes of survey areas. While this approach will provide reliable data on the numbers of oysters in Foveaux Strait, these data do not provide the detailed data on the small spatial-scale distribution of oysters that delineate areas of high oyster density (commercial fishery patches) on which the fishery relies to maintain economic catch rates. Further, these high density areas are important for maintaining oyster production; when oyster densities have been reduced by bonamia mortality, the numbers of small oysters have also declined. For stock assessment, rebuilding is currently defined as increasing numbers of oysters over the fishery area. From a fishery perspective, rebuilding is defined as increasing the numbers and sizes of commercial areas with high oyster density. Both these indicators show rebuilding of the oyster populations.

The fishery currently comprises a number of relatively high oyster density areas, and large areas of low oyster density; 50% of the population is in 30% of the fishery area. A large portion of the fishery area has relatively low oyster densities. The stock assessment model predicts that a harvest of 15 million oysters is not likely to have an effect on the rate of increase in the total number of oysters in Foveaux Strait. Any increase or decrease is driven by levels of bonamia mortality. The model does not consider the fishing effort required to harvest this catch and the effects on the limited numbers of high oyster density areas.

Eastern fishery areas have low population levels and bonamia mortality is continuing to reduce oyster densities there. There is no evidence of any rebuilding in eastern fishery areas and they will not provide an alternative commercial fishery area (if required) as in 2002–06.

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## 6. REFERENCES

Annala, J.H.; Sullivan, K.J.; O'Brien, C.J.; Smith, N.W.M.; Varian, S.J.A. (2002). Report from the Fishery Assessment Plenary, May 2002: stock assessments and yield estimates. 639 p. (Unpublished report held by the Ministry of Fisheries, Wellington.)

Cranfield, H.J.; Doonan, I.J.; Michael, K.P. (1991). Assessment of the effects of mortality due to bonamia on the oyster population of Foveaux Strait in 1990 and the outlook for management in 1991. New Zealand Fisheries Assessment Research Document 91/18. 24 p. (Unpublished report held in NIWA library, Wellington.)

Cranfield, H.J.; Michael, K.P.; Doonan, I.J. (1996). Foveaux Strait oyster (*Tiostrea chilensis*) assessment, 1995. (Unpublished report held by the Ministry of Fisheries, Wellington.) 25 p.

Cranfield, H.J.; Michael, K.P.; Doonan, I.J. (1998). Dredge survey of Foveaux Strait oysters, 1997. *NIWA Technical Report 45*. 18 p.

Cranfield, H.J.; Michael, K.P.; Doonan, I.J. (1999). Foveaux Strait oyster (*Tiostrea chilensis*) assessment, 1997. New Zealand Fisheries Assessment Research Document 99/11. 31 p. (Unpublished report held in NIWA library, Wellington.)

Diggles, B.K. (2004). Survey of dredge oysters (*Ostrea chilensis*) from Foveaux Strait from bonamiosis, oyster condition, and other concurrent infections DF04-11 (Unpublished report held by NIWA, Greta Point, Wellington). 15 p.

Diggles, B.K.; Cochennec-Laureau, N.; Hine, P.M. (2003). Comparison of diagnostic techniques for *Bonamia exitiosus* from flat oysters *Ostrea chilensis* in New Zealand. *Aquaculture 220 (1–4*): 145–156.

Diggles, B.K.; Hine, P.M. (2002). *Bonamia exitiosus* epidemiology in Foveaux Strait oysters. Final Research Report to the Ministry of Fisheries Project No OYS1999/01A/other services. (Unpublished report held by the Ministry of Fisheries, Wellington.) 52 p.

Doonan, I.J.; Cranfield, H.J.; Michael, K.P. (1994). Catastrophic reduction of the oyster, *Tiostrea chilensis* (Bivalvia: Ostreidae), in Foveaux Strait, New Zealand, due to infestation by the protistan *Bonamia* sp. *New Zealand Journal of Marine and Freshwater Research 28 (4)*: 335–344.

Dunn, A. (2002). Summary of the Foveaux Strait oyster fishery catch effort logbooks for the 2002 fishing season. NIWA Client Report WLG2002-76. 23 p.

Dunn, A. (2007). Stock assessment of Foveaux Strait dredge oysters (*Ostrea chilensis*) for the 2006-07 fishing year (Unpublished Final Research Report held by the Ministry of Fisheries, Wellington). 63 p.

Dunn, A. (2005). Stock assessment of Foveaux Strait dredge oysters (*Ostrea chilensis*) for the 2003-04 fishing year. *New Zealand Fisheries Assessment Report 2005/25*. 63 p.

Dunn, A.; Michael, K.P. (2001). Summary of the Foveaux Strait oyster fishery catch effort logbooks for the 2001 fishing season. NIWA Client Report to the Bluff Oyster Management Company 2001/64. 18 p.

Dunn, A.; Michael, K.P.; Diggles, B.K. (2002). Updated estimates of the commercial population size, yields, and estimates of intensity and prevalence of infection by *Bonamia exitiosus* in Foveaux Strait oysters for selected sites in Foveaux Strait in March 2002. Final Research Report for Ministry of Fisheries, Research Project MOF2001/03L June 2002: 20 p. (Unpublished report held by the Ministry of Fisheries, Wellington).

Dunn, A.; Michael, K.P.; Forman, J.; Diggles, B.K. (2003). Estimates of intensity and prevalence of infection by *Bonamia exitiosus* in oysters for selected sites in Foveaux Strait in February 2003. NIWA Client Report to the Bluff Oyster Management Company: WLG2003-10. 30 p.

Dunn, A.; Michael, K.P.; Hine, P.M.; Andrew, N.L.; Diggles, B.K.; Cranfield, H.J. (2000). Analysis of a survey of the prevalence and intensity of *Bonamia* sp. in Foveaux Strait oysters. *New Zealand Fisheries Assessment Report* 2000/32: 28 p.

Hine, P.M. (1991). The annual pattern of infection by *Bonamia* sp. in the New Zealand flat oyster *Tiostrea chilensis*. *Diseases of Aquatic Organisms 93*: 241–251.

Jolly, G.M.; Hampton, I. (1990). A stratified random transect design for acoustic surveys of fish stocks. *Canadian Journal of Fisheries and Aquatic Sciences 47(7)*: 1282–1291.

Michael, K.P.; Dunn, A.; Andrew, N.L.; Breen, P.A. (2001). Foveaux Strait dredge oyster (*Tiostrea chilensis*) stock assessment, 1999. *New Zealand Fisheries Assessment Report 2001/38*. 42 p.

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

Michael, K.P.; Dunn, A.; Diggles, B.K.; Parsons, M. (2004b). Foveaux Strait dredge oyster (*Ostrea chilensis*) stock assessment: population and bonamia surveys October 2001, January and March 2002, and yields for the 2002 oyster season. *New Zealand Fisheries Assessment Report 2004/13*. 18 p.

Michael, K.P., Dunn, A., Forman, J. (2005). A survey of *Bonamia exitiosa* infection in Foveaux Strait dredge oysters (*Ostrea chilensis*), oyster density and recruitment, January 2004 Research Progress Report to the Ministry of Fisheries. 30 p. (Unpublished report held by the Ministry of Fisheries, Wellington.)

Michael, K.P.; Dunn, A.; Forman, J. (2006). A survey of Bonamia exitiosa infection, and oyster density and recruitment in Foveaux Strait dredge oyster (*Ostrea chilensis*), January 2005. *New Zealand Fisheries Assessment Report 2006/40*: 31 p.

Michael, K.P.; Dunn, A.; Forman, J. (2008a). A survey of *Bonamia exitiosa* infection, and oyster density and recruitment in Foveaux Strait dredge oysters (*Ostrea chilensis*), February 2006. *New Zealand Fisheries Assessment Report 2006/47*: 35 p.

Michael, K.P.; Dunn, A.; Forman, J.; Arlidge, A. (2008b). 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. *New Zealand Fisheries Assessment Report 2008/61*: 50 p.

Michael, K.P.; Dunn, A.; Forman, F. (2008c). A survey of *Bonamia exitiosa* infection, and oyster density and recruitment in Foveaux Strait dredge oyster (*Ostrea chilensis*), February 2006. *New Zealand Fisheries Assessment Report, 2008/42.* 35 p.

Sullivan, K.J.; Mace, P.M.; Smith, N.W.M.; Griffiths, M.H.; Todd, P.R.; Livingston, M.E.; Harley, S.J.; Key, J.M.; Connell, A.M. (2005). Report from the Fishery Assessment Plenary, May 2005: stock assessments and yield estimates. 792 p. (Unpublished report held in NIWA library, Wellington.)

## APPENDIX 1: STATION DATA RECORD FORM

### FOVEAUX STRAIT OYSTER SURVEY, STATION DATA RECORD

Vessel name

Recorder ..................................................

Date: Day | Month | Year | Time NZST | Station no. | Stratum

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

Finish position: Latitude S | Longitude E

Number of Oysters ≥58 mm: Live | Gapers | New clocks* | Old clocks**

Number of Oysters 50-57 mm: Live | Gapers | New clocks* | Old clocks** | Number of live oysters 10-50 mm

% fullness of dredge including sediment | Live Bryozoa | Bycatch photo numbers –

Wind force, beaufort | Did the dredge fish well? Y=1 or N=2 | *Bonamia* sample? | Comments?

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 |
|---|---|---|---|---|---|---|---|---|
| 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |

Comments:

1 Nautical mile = 1.853 km

* New clocks are hinged shells of recently dead oysters, 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 2: BONAMIA DATA RECORD.

### FOVEAUX STRAIT OYSTER BONAMIA DATA RECORD

Page ___ of ___

Recorder

.............................................................

Comments

| Station no. | Date: Day | Month | Year | Time NZST |
|---|---|---|---|---|
| | | | | |

| Oyster no | Length (mm) | Height (mm) | Size category [4] | Heat imprint score | Histology sample |
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1) Start a new form for each new station
2) Measure oysters to the nearest mm down
3) Check oysters for size; recruit (R), pre-recruit (P), and small recruit (O) size with 'oyster rings'.

## 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. NA denotes no oysters sampled for bonamia infection.**

| Stratum | Station | r | n | Prevalence | | Density | Intensity |
|---|---|---|---|---|---|---|---|
| B1 | 1 | 1 | 25 | 0.04 | (0.00-0.20) | 1.55 | 4.00 |
| B1 | 2 | 0 | 25 | 0 | (0.00-0.14) | 2.42 | 0.00 |
| B1 | 3 | 2 | 25 | 0.08 | (0.01-0.26) | 0.55 | 4.00 |
| B1 | 4 | NA | NA | NA | (-) | 0.00 | NA |
| B1 | 6 | 0 | 15 | 0 | (0.00-0.22) | 0.08 | 0.00 |
| B1 | 101 | 0 | 24 | 0 | (0.00-0.14) | 0.79 | 0.00 |
| B1 | 102 | NA | NA | NA | (-) | 0.13 | NA |
| B1 | 104 | NA | NA | NA | (-) | 0.60 | NA |
| B1 | 106 | NA | NA | NA | (-) | 0.91 | NA |
| B1 | 107 | NA | NA | NA | (-) | 1.25 | NA |
| B1 | 109 | NA | NA | NA | (-) | 0.00 | NA |
| B1A | 34 | 0 | 7 | 0 | (0.00-0.41) | 0.02 | 0.00 |
| B1A | 35 | 0 | 2 | 0 | (0.00-0.84) | 0.01 | 0.00 |
| B1A | 36 | 0 | 25 | 0 | (0.00-0.14) | 0.26 | 0.00 |
| B1A | 37 | 8 | 22 | 0.36 | (0.17-0.59) | 0.87 | 3.63 |
| B2A | 7 | 1 | 25 | 0.04 | (0.00-0.20) | 0.52 | 2.00 |
| B2A | 8 | 0 | 25 | 0 | (0.00-0.14) | 0.11 | 0.00 |
| B2A | 9 | NA | NA | NA | (-) | 0.00 | 0.00 |
| B2B | 50 | 2 | 25 | 0.08 | (0.01-0.26) | 0.32 | 4.50 |
| B2B | 51 | 1 | 25 | 0.04 | (0.00-0.20) | 0.50 | 2.00 |
| B2B | 52 | 2 | 25 | 0.08 | (0.01-0.26) | 1.57 | 1.50 |
| B2B | 53 | 0 | 25 | 0 | (0.00-0.14) | 0.27 | 0.00 |
| B2B | 54 | 1 | 25 | 0.04 | (0.00-0.20) | 0.30 | 3.00 |
| B3 | 55 | 2 | 25 | 0.08 | (0.01-0.26) | 2.22 | 1.50 |
| B3 | 56 | 2 | 25 | 0.08 | (0.01-0.26) | 1.66 | 3.50 |
| B3 | 57 | 0 | 25 | 0 | (0.00-0.14) | 2.26 | 0.00 |
| B3 | 58 | 3 | 25 | 0.12 | (0.03-0.31) | NA | 2.00 |
| B3 | 59 | 0 | 25 | 0 | (0.00-0.14) | 0.55 | 0.00 |
| B3 | 60 | 1 | 23 | 0.04 | (0.00-0.22) | 3.75 | 3.00 |
| B3 | 61 | 1 | 25 | 0.04 | (0.00-0.20) | 1.06 | 3.00 |
| B3 | 160 | NA | NA | NA | (-) | 3.30 | NA |
| B3 | 161 | NA | NA | NA | (-) | 2.37 | NA |
| B3 | 162 | NA | NA | NA | (-) | 0.50 | NA |
| B4 | 10 | 0 | 25 | 0 | (0.00-0.14) | 0.45 | 0.00 |
| B4 | 12 | 2 | 25 | 0.08 | (0.01-0.26) | 0.57 | 3.50 |
| B4 | 110 | NA | NA | NA | (-) | 0.00 | NA |
| B5 | 13 | 2 | 25 | 0.08 | (0.01-0.26) | 0.75 | 3.50 |
| B5 | 15 | NA | NA | NA | (-) | 0.00 | NA |
| B5 | 121 | 2 | 24 | 0.08 | (0.01-0.27) | 0.55 | 4.00 |
| B6B | 18 | NA | NA | NA | (-) | 0.01 | NA |
| B6B | 123 | 0 | 7 | 0 | (0.00-0.41) | 0.03 | 0.00 |
| B6B | 124 | 2 | 20 | 0.1 | (0.01-0.32) | 0.22 | 3.00 |

**Table 3: Continued**

| Stratum | Station | r | n | Prevalence | | Density | Intensity |
|---|---|---|---|---|---|---|---|
| B7 | 19 | 2 | 25 | 0.08 | (0.01-0.26) | 0.24 | 4.00 |
| B7 | 20 | 0 | 19 | 0 | (0.00-0.18) | 0.11 | 0.00 |
| B7 | 21 | 2 | 15 | 0.13 | (0.02-0.40) | 0.08 | 4.00 |
| B9 | 62 | 0 | 25 | 0 | (0.00-0.14) | 0.36 | 0.00 |
| B9 | 63 | 0 | 15 | 0 | (0.00-0.22) | 0.08 | 0.00 |
| B9 | 64 | 1 | 17 | 0.06 | (0.00-0.29) | 0.08 | 3.00 |
| B9 | 65 | 0 | 25 | 0 | (0.00-0.14) | 0.06 | 0.00 |
| B9 | 66 | 0 | 25 | 0 | (0.00-0.14) | 0.29 | 0.00 |
| C1A | 76 | 2 | 25 | 0.08 | (0.01-0.26) | 0.66 | 2.50 |
| C1A | 77 | 3 | 25 | 0.12 | (0.03-0.31) | 0.62 | 4.00 |
| C1A | 79 | 3 | 18 | 0.17 | (0.04-0.41) | 0.15 | 4.00 |
| C1A | 80 | 1 | 25 | 0.04 | (0.00-0.20) | 0.77 | 3.00 |
| C1A | 81 | 1 | 25 | 0.04 | (0.00-0.20) | 1.04 | 3.00 |
| C1A | 177 | 1 | 25 | 0.04 | (0.00-0.20) | 1.48 | 3.00 |
| C2 | 25 | 16 | 25 | 0.64 | (0.43-0.82) | 2.11 | 3.19 |
| C2 | 26 | 2 | 25 | 0.08 | (0.01-0.26) | 1.76 | 3.50 |
| C2 | 132 | NA | NA | NA | (-) | 0.25 | NA |
| C3 | 27 | 0 | 25 | 0 | (0.00-0.14) | 0.83 | 0.00 |
| C3 | 28 | 2 | 25 | 0.08 | (0.01-0.26) | 0.84 | 3.00 |
| C3 | 29 | 4 | 21 | 0.19 | (0.05-0.42) | 0.34 | 3.75 |
| C3 | 30 | 9 | 27 | 0.33 | (0.17-0.54) | 1.37 | 3.56 |
| C4 | 44 | 2 | 25 | 0.08 | (0.01-0.26) | 0.45 | 4.00 |
| C4 | 45 | 4 | 25 | 0.16 | (0.05-0.36) | 0.50 | 3.25 |
| C4 | 150 | 4 | 25 | 0.16 | (0.05-0.36) | 0.38 | 2.50 |
| C5 | 82 | 0 | 25 | 0 | (0.00-0.14) | 0.95 | 0.00 |
| C5 | 83 | 0 | 25 | 0 | (0.00-0.14) | 0.79 | 0.00 |
| C5 | 84 | 4 | 25 | 0.16 | (0.05-0.36) | NA | 3.00 |
| C5 | 85 | 0 | 6 | 0 | (0.00-0.46) | 0.03 | 0.00 |
| C5 | 86 | 1 | 10 | 0.1 | (0.00-0.45) | 0.09 | 3.00 |
| C6 | 87 | 0 | 25 | 0 | (0.00-0.14) | 0.19 | 0.00 |
| C6 | 88 | 6 | 25 | 0.24 | (0.09-0.45) | 0.41 | 3.17 |
| C6 | 89 | 2 | 25 | 0.08 | (0.01-0.26) | 0.46 | 3.50 |
| C6 | 90 | 3 | 22 | 0.14 | (0.03-0.35) | 0.43 | 3.33 |
| C7 | 31 | 3 | 25 | 0.12 | (0.03-0.31) | NA | 4.00 |
| C7 | 32 | 6 | 25 | 0.24 | (0.09-0.45) | 1.46 | 3.67 |
| C7 | 33 | 4 | 25 | 0.16 | (0.05-0.36) | 0.74 | 4.00 |
| C7 | 138 | NA | NA | NA | (-) | 1.74 | NA |
| C7 | 139 | NA | NA | NA | (-) | 0.99 | NA |
| CB6A | 38 | 0 | 25 | 0 | (0.00-0.14) | 0.74 | 0.00 |
| CB6A | 39 | 1 | 25 | 0.04 | (0.00-0.20) | 0.24 | 3.00 |
| CB6A | 40 | 0 | 12 | 0 | (0.00-0.26) | 0.05 | 0.00 |
| CB6A | 41 | 1 | 3 | 0.33 | (0.01-0.91) | 0.02 | 5.00 |
| CB6A | 42 | 0 | 13 | 0 | (0.00-0.25) | 0.07 | 0.00 |
| CB6A | 43 | 0 | 25 | 0 | (0.00-0.14) | 0.25 | 0.00 |
| CB8 | 67 | 5 | 25 | 0.2 | (0.07-0.41) | 3.15 | 2.80 |
| CB8 | 68 | 6 | 25 | 0.24 | (0.09-0.45) | 0.77 | 3.50 |
| CB8 | 69 | 4 | 25 | 0.16 | (0.05-0.36) | 2.69 | 2.25 |
| CB8 | 70 | 2 | 25 | 0.08 | (0.01-0.26) | 1.68 | 3.50 |

**Table 3: Continued**

| Stratum | Station | r | n | Prevalence | | Density | Intensity |
|---|---|---|---|---|---|---|---|
| CE5A | 71 | 2 | 25 | 0.08 | (0.01-0.26) | 0.88 | 2.00 |
| CE5A | 72 | 3 | 26 | 0.12 | (0.02-0.30) | 0.42 | 3.00 |
| CE5A | 73 | 1 | 25 | 0.04 | (0.00-0.20) | 0.42 | 3.00 |
| CE5A | 74 | 0 | 14 | 0 | (0.00-0.23) | 0.07 | 0.00 |
| CE5A | 75 | 0 | 6 | 0 | (0.00-0.46) | 0.03 | 0.00 |
| CE6 | 22 | 1 | 22 | 0.05 | (0.00-0.23) | 0.35 | 3.00 |
| CE6 | 23 | 1 | 19 | 0.05 | (0.00-0.26) | 0.09 | 3.00 |
| CE6 | 24 | 2 | 25 | 0.08 | (0.01-0.26) | 0.86 | 3.00 |
| CE7A | 92 | 0 | 25 | 0 | (0.00-0.14) | 0.26 | 0.00 |
| CE7A | 93 | 0 | 25 | 0 | (0.00-0.14) | 0.42 | 0.00 |
| CE7A | 94 | 0 | 25 | 0 | (0.00-0.14) | 0.48 | 0.00 |
| CE7A | 193 | NA | NA | NA | (-) | 0.00 | NA |
| E2 | 95 | 1 | 25 | 0.04 | (0.00-0.20) | 6.21 | 3.00 |
| E2 | 96 | 0 | 25 | 0 | (0.00-0.14) | 0.82 | 0.00 |
| E2 | 97 | 0 | 25 | 0 | (0.00-0.14) | 2.45 | 0.00 |
| E2 | 98 | 1 | 25 | 0.04 | (0.00-0.20) | 1.27 | 1.00 |
| E2 | 99 | 1 | 25 | 0.04 | (0.00-0.20) | 0.76 | 1.00 |
| E2 | 100 | 0 | 25 | 0 | (0.00-0.14) | 0.38 | 0.00 |
| E2 | 194 | NA | NA | NA | (-) | 1.12 | NA |
| E2 | 195 | NA | NA | NA | (-) | 2.64 | NA |
| E2 | 196 | NA | NA | NA | (-) | 1.58 | NA |
| E4 | 47 | 4 | 25 | 0.16 | (0.05-0.36) | 0.38 | 3.50 |
| E4 | 48 | 5 | 25 | 0.2 | (0.07-0.41) | 2.90 | 2.20 |
| E4 | 49 | 3 | 25 | 0.12 | (0.03-0.31) | 0.33 | 2.67 |
| E4 | 154 | NA | NA | NA | (-) | 2.14 | NA |

## APPENDIX 4

**Table 4A: Projected population size by stratum corrected for oysters with category 3 and higher infections expected to die before the beginning of the oyster season. For each stratum, the total number of stations (No. stations), where r is the number of oysters infected with bonamia and n the number of oysters in the samples, Removed is the number of small oysters removed, Factor is the scaling applied to stratum densities based on oysters with category 3 and higher infections, Mean density is the density of recruit-sized oysters, Density s.d. is the standard deviation and c.v. coefficient of variation. Mean popn 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$^2$.**

| Stratum | No. stations | r | n | Removed | Factor | Mean density | Density s.d. | c.v. | Mean popn (millions) | Lower 95% CI | Upper 95% CI | Area (km$^2$) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| B1 | 11 | 3 | 114 | 0 | 0.98 | 0.74 | 0.22 | 0.30 | 84.26 | 31.46 | 153.89 | 114.39 |
| B1A | 4 | 8 | 56 | 0 | 0.79 | 0.23 | 0.16 | 0.69 | 3.71 | 0.00 | 9.49 | 16.02 |
| B2A | 3 | 1 | 50 | 0 | 1.00 | 0.21 | 0.16 | 0.76 | 9.90 | 0.00 | 26.76 | 47.69 |
| B2B | 5 | 6 | 125 | 0 | 0.99 | 0.58 | 0.24 | 0.42 | 48.60 | 8.14 | 99.79 | 83.34 |
| B3 | 10 | 9 | 173 | 0 | 0.97 | 1.93 | 0.33 | 0.17 | 86.44 | 49.59 | 138.46 | 44.68 |
| B4 | 3 | 2 | 50 | 0 | 0.96 | 0.33 | 0.17 | 0.51 | 32.21 | 0.00 | 71.25 | 98.70 |
| B5 | 3 | 4 | 49 | 0 | 0.96 | 0.42 | 0.22 | 0.52 | 26.56 | 0.00 | 59.71 | 63.64 |
| B6B | 3 | 2 | 27 | 0 | 0.92 | 0.08 | 0.06 | 0.77 | 1.58 | 0.00 | 4.31 | 19.82 |
| B7 | 3 | 4 | 59 | 0 | 0.91 | 0.13 | 0.04 | 0.33 | 11.39 | 3.80 | 21.42 | 86.11 |
| B9 | 5 | 1 | 107 | 0 | 0.99 | 0.17 | 0.06 | 0.36 | 5.97 | 1.63 | 11.51 | 34.46 |
| C1A | 6 | 11 | 143 | 0 | 0.95 | 0.74 | 0.17 | 0.23 | 23.27 | 11.35 | 39.63 | 31.25 |
| C2 | 3 | 18 | 50 | 0 | 0.68 | 0.93 | 0.39 | 0.41 | 20.49 | 3.74 | 41.80 | 21.94 |
| C3 | 4 | 15 | 98 | 0 | 0.87 | 0.74 | 0.18 | 0.25 | 24.04 | 11.07 | 41.76 | 32.71 |
| C4 | 3 | 10 | 75 | 0 | 0.90 | 0.40 | 0.03 | 0.08 | 10.58 | 7.03 | 15.83 | 26.29 |
| C5 | 5 | 5 | 91 | 0 | 0.93 | 0.75 | 0.36 | 0.48 | 28.30 | 1.75 | 61.93 | 37.68 |
| C6 | 4 | 11 | 97 | 0 | 0.92 | 0.34 | 0.06 | 0.17 | 8.05 | 4.65 | 12.87 | 23.52 |
| C7 | 5 | 13 | 75 | 0 | 0.85 | 1.12 | 0.17 | 0.15 | 40.56 | 24.21 | 63.87 | 36.08 |
| CB6A | 6 | 2 | 103 | 0 | 0.99 | 0.22 | 0.11 | 0.49 | 17.22 | 1.08 | 37.88 | 77.12 |
| CB8 | 4 | 17 | 100 | 0 | 0.90 | 1.86 | 0.48 | 0.26 | 49.87 | 23.02 | 87.64 | 26.84 |
| CE5A | 5 | 6 | 96 | 0 | 0.98 | 0.36 | 0.15 | 0.42 | 8.38 | 1.39 | 17.24 | 23.52 |
| CE6 | 3 | 4 | 66 | 0 | 0.96 | 0.42 | 0.22 | 0.52 | 12.46 | 0.00 | 27.99 | 29.99 |
| CE7A | 4 | 0 | 75 | 0 | 1.00 | 0.29 | 0.11 | 0.37 | 6.81 | 1.86 | 13.33 | 23.60 |
| E2 | 9 | 3 | 150 | 0 | 0.98 | 1.87 | 0.58 | 0.31 | 80.30 | 29.05 | 147.61 | 42.83 |
| E4 | 4 | 12 | 75 | 0 | 0.95 | 1.36 | 0.61 | 0.45 | 38.21 | 4.07 | 80.24 | 28.04 |
| All | 115 | 167 | 2104 | 0 | | 0.63 | 0.05 | 0.09 | 679.15 | 445.30 | 1013.60 | 1070.27 |