Ministry for Primary Industries
Manatū Ahu Matua

The status of infection by bonamia (*Bonamia exitiosa*) in Foveaux Strait oysters (*Ostrea chilensis*) in February 2011, estimates of pre-survey and projections of post-survey disease mortality, and implications for the projections of future stock status made in the 2009 stock assessment for OYU 5.

New Zealand Fisheries Assessment Report 2012/37

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ISSN 1179-5352 (online)
ISBN 978-0-478-40070-0 (online)

August 2012

New Zealand Government

Growing and Protecting New Zealand

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EXECUTIVE SUMMARY

Michael, K.P.; Forman, J.; Hulston D.; Fu, D. (2012). The status of infection by bonamia (*Bonamia exitiosa*) in Foveaux Strait oysters (*Ostrea chilensis*) in February 2011, estimates of pre-survey and projections of post-survey disease mortality, and implications for the projections of future stock status made in the 2009 stock assessment for OYU 5.

***New Zealand Fisheries Assessment Report 2012*/37. 55 p.**

The February 2011 bonamia (*Bonamia exitiosa*) survey was undertaken to monitor the status of infection and oyster mortality in the Foveaux Strait oyster population between stock assessments as a means of verifying projections of future recruit-sized stock abundance. This survey was a joint programme between the Bluff Oyster Management Company and NIWA, and continues a series of surveys of bonamia infection in the oyster population and changes in the distribution and densities of recruit, pre-recruit, and small oysters. Projections of disease mortality were made from oysters with category 3+ infections and used to estimate the effects of disease mortality on the future stock status of the Foveaux Strait oyster population.

While a new vessel and crew were used for the 2011 survey, the sampling used the same survey dredge as for previous surveys. This change was not expected to affect the comparability of survey data across years, as the survey catchability was not likely to have changed. Sampling and operational procedures were the same as those of previous surveys. The survey sampled 54 stations (42 randomly selected stations from the 2009 survey and 12 previously sampled 'target' stations) for oyster density and bonamia infection using standard Foveaux Strait oyster survey methods. Bonamia samples were taken from a random sample of 25 oysters at each station.

Bonamia infection in oysters was widespread across Foveaux Strait in February 2011 and variable between sites; stations with no detectable infection were interspersed amongst stations with high prevalence of infection. However, the pattern of the distribution of infection (both prevalence and intensity) was similar to that observed in February 2010, and showed an increased prevalence and intensity at some central fishery areas since February 2009. Most (90%) of the oysters examined for bonamia had no detectable infection, few (3%) had category 1 and 2 infections, and the remainder (7%) had category 3 or higher infections.

The mean prevalence of infection across all stations in 2011 was slightly lower than the prevalence in 2010 and 2009 (10% versus 12%). And, although there was a larger percentage of uninfected stations in 2011 than in 2010 or 2009, the percentage with high prevalence (at least 20% prevalence) was higher in 2011 (15%) and 2010 (16%) than in 2009 (8%). The mean intensity of infection in 2011 remained unchanged from 2010 and 2009 at category 3, although there were also more stations with category 4 and 5 infections in 2011.

Estimates of the number of recruit-sized oysters infected with bonamia from the strata sampled in 2009, 2010, and 2011 showed that the prevalence of infection in the population increased from 8.3% (95% CI 4.9–13.5%) in 2009 to 13.3% (95% CI 6.1–2.9%) in 2010, and decreased to 11.3% (95% CI 5.3–19.6%) in 2011. Estimates of category 3+ infections showed a similar trend, 5.4%, 9.0%, and 6.7% in 2009, 2010, and 2011 respectively.

Estimates of the change in abundance between February 2009 and February 2011 were made for strata sampled in both surveys. Overall, the densities of recruit-sized oysters increased by 40% between 2009 and 2011, but were higher in 2010. In strata that had high bonamia mortality in 2010, oyster densities were the same or had declined in 2011. The mean density of recruit-sized oysters increased from 0.9 oysters/m^2 in 2009 to 1.3 oysters/m^2 in 2011; and the population size over the ten common strata increased from 443 (95% CI 286–665) million oysters in 2009 to 596 million oysters (95% CI 378–902) in 2011. The abundance of oysters in commercial densities increased from 190 (95% CI 84–333) million oysters in 2009 to 352 million oysters (95% CI 186–580) in 2011.

Estimates of the mortality from bonamia showed a decrease from 8.5% in 2007 to 7.5% in 2010, and increased to about 10% in 2011. This corresponds to an expected loss of about 62 million oysters. Of these, 22 million oysters (95% CI 13–35 million) were assumed to have died before the survey (i.e., were estimated from the numbers of new clocks and gapers observed in the survey) and about 40 million oysters (95% CI 26–61 million) were expected to die post-survey from category 3+ infections. At this level of bonamia mortality, the oyster population is expected to continue to rebuild.

In strata that were surveyed in both 2009 and 2010, the estimate of the population size of pre-recruits was slightly higher in 2011 than in 2009 and the population size of small oysters similar. However, these levels were below the levels observed over the last decade, with the pre-recruit population at about 30% and the small oyster population at 40% of that in observed in 2000. This suggests that recent recruitment may have been lower than might be expected and hence that the rebuilding of the population may be slower than otherwise expected in the short term.

1. INTRODUCTION

The Foveaux Strait oyster fishery is a high value, iconic fishery that has been fished for about 140 years. Oysters (*Ostrea chilensis*) are an important customary (taonga), recreational, and commercial species, and important to the socioeconomics of Bluff and Invercargill. Mortality from the haplosporidian parasite *Bonamia exitiosa* (bonamia) is the principal driver of oyster population abundance during epizootics. Before the recent bonamia epizootics began in 1985 (Doonan et al. 1994), the long-term, average landings from the fishery were about 80 million oysters. The first of two bonamia epizootics, between 1985 and 1992 probably reduced the oyster population to 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 the catch limit has remained unchanged since. The recreational and customary take is about 1 million oysters annually in addition to the Total Allowable Commercial Catch (TACC). Between 2003 and 2008, the Bluff Oyster Management Company (BOMC) shelved half of the TACC, harvesting about 7.5 million oysters annually (Ministry of Fisheries 2008). The 2009 OYU 5 survey showed an increase in the total population size from 622 million oysters in 2007 to 720 million oysters and an increase in the commercial population size from 196 million oysters to 361 million oysters over the same period (Michael et al. 2009b). This improvement prompted BOMC to unshelve 10% of the shelved quota for the 2009 oyster season and a further 10% for the 2010 season.

Between 2000 and 2005, widespread mortality from bonamia had reduced the numbers of oysters to the historically low levels of the early 1990s. Following the onset of the epizootic in 2000, a series of mostly annual surveys were implemented to determine the distribution, prevalence and intensity of infection by bonamia. These data have allowed the pattern of disease in the population to be tracked through the fishery by monitoring the spatial and temporal changes in the prevalence and intensity of infection, resulting oyster mortality, and subsequent changes in oyster densities.

Biennial stock assessments have estimated the status of the stock and have made projections of future stock status based on expected levels of recruitment, harvest, and bonamia mortality. The stock assessments have used abundance information from ‘stock assessment surveys’, i.e., random stratified surveys of Foveaux Strait oysters are used to provide population abundance information in the assessment. In years between stock assessments, smaller focused surveys of bonamia prevalence and intensity (bonamia surveys) are used to monitor the status of bonamia infection, and then to estimate the mortality from bonamia in the short term. In general, mortality rates from bonamia of less than 10% have resulted in an increase in population abundance, while levels of about 20% result in a population decrease. The fishery has shown an ability to rebuild rapidly in the absence of disease (assuming average recruitment).

The status of bonamia in the fishery is determined from new clock and gaper densities, the distribution of prevalence and intensity of infection, and oyster densities in three size groups. New clocks are the shells of oysters that have died since the beginning of summer (November–December), but before the survey; and these provide estimates of recent oyster mortality caused by bonamia. Gapers are moribund oysters unable to close their valves and persist in the fishery for only a short time (about 24 hours). Gapers are indicative of oyster mortality at the time of sampling. The prevalence of infection provides estimates of the proportion of the oyster population with detectable infections; and the intensity of infection estimates the proportions of infected oysters with non-fatal and fatal infections (see Section 2.7.1). Estimates of oyster densities also allow the status of commercial fishery areas to be determined in the context of disease mortality on localised populations and recruitment.

Surveys between 2000 and 2005 of the status of bonamia infection, mortality, and the oyster population found that bonamia had drastically 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). Then a survey in January 2005 found that the prevalence (the number of infected oysters per sample) and intensity of infection (mean level of infection in infected oysters — based on a categorical scale, see Table 2) was much lower than that observed in January 2004 (Michael et al. 2005). Few new clocks or gaping oysters were found in January 2005, indicating low mortality in the period immediately prior to the survey. And, based on the small numbers of oysters with category 3 and higher (3+) infections found, little disease mortality was expected to occur over that summer.

In February 2006, bonamia infection was found to be more widespread, and while the prevalence of infection was similar to previous years, the intensity of infection was higher. The status of infection in February 2007 was similar to that in February 2006. But, while overall prevalence was found to be lower, most of the infected oysters had intense infections that were likely to be fatal. However, almost all of the sample sites with infections were in eastern fishery areas (east of a line between Bluff Hill and Saddle Point) where oyster densities were low.

In February 2008, low prevalence of infection was found in the central fishery areas, but eastern areas continued to have relatively high prevalence despite lower reduced oyster densities. In February 2009, prevalence was generally low, but the infection was widespread and variable; stations with no infection were interspersed with stations with low and high infection intensity. The distribution of infection was similar to that found in 2010, but prevalence was higher and infected stations generally had higher intensities of infection than in 2009, especially in central fishery areas.

The mean mortality from category 3+ infections over the summer of 2009 was estimated at 6.25%, reducing the oyster population from 725 million oysters to 679 million (Michael et al. 2009b). The total mortality from bonamia during the 2010 summer was estimated to be about 59 million oysters (7.3% of the recruit sized population), of which about 6 million occurred before the survey (as estimated from new clocks and gapers) and 53 million oysters post-survey (as estimated from category 3+ infection rates).

In areas sampled by the survey, densities of oysters increased from 1.2 oysters/m^2 in 2009, to 2.7 oysters/m^2 in 2010. Pre-recruit and small oysters increased by similar levels (Michael et al. 2011). Observed increases in the densities and abundance of recruited, pre-recruit, and small oysters in 2010 suggest that densities and population sizes have continued to increase.

Central, western, and southern fishery areas in Foveaux Strait where oyster density has been increasing in recent years are potentially at greatest risk of mortality from bonamia due to their high density. These areas are also of greatest importance to commercial fishers. Monitoring these areas for bonamia infection was the primary objective of the February 2011 survey.

This report documents a collaborative survey between NIWA and BOMC of the status of bonamia infection in oysters and changes in oyster densities, and in part fulfils Milestone 7 of the Ministry of Fisheries project OYS2009/01B, objective 1: To carry out a survey in February 2011 to determine the distribution, prevalence and intensity of infection by *Bonamia exitiosa*.

2. METHODS

2.1 Sampling design

The February 2011 survey continued a time series of surveys using the 2005 Foveaux Strait oyster survey area (1054 km^2) and core stratification (Figure 1). Stratum B1a (an additional stratum with an area of 16 km^2 that was introduced by oyster skippers for the survey in 2007, but was outside the original survey boundary) was not sampled. The 2011 survey retained the remaining 2009 survey boundary and strata to continue a time series of oyster density data and data on the disease status of commercial fishery areas. Some of these strata were also sampled in a 43 station survey undertaken in February 2010.

In 2011, sampling was mainly focused in strata from the 2009 stock assessment survey that had either the highest densities of oysters in 2009 and 2010 (Figure 1) or were commercial fishery areas that were important to fishers (Figure 2). Some additional sampling was carried out in the low oyster density areas, the eastern fishery, and from previously defined target stations. Fifteen of the 24 survey strata from 2009 were sampled in 2011; ten strata (B1, B3, B7, B9, C1a, C3, C4, C7, CB8, and E2) represented core commercial fishery areas and were allocated most of the sampling effort (Table 1). Six of these strata (B1, B3, C1a, C3, C7, and E2) were also sampled with three or more randomly selected tows in 2010. The remaining stations were allocated to areas with high and low levels of bonamia infection in 2010 (Figures 3 and 4), and areas with high and low fishing effort over the 2009 oyster season from fishers' logbook data (Figure 2).

The survey was a stratified random survey, and had 42 randomly selected stations that had been sampled in 2009 and an additional 12 target stations. The target stations were chosen to investigate potential changes in bonamia infection at a set of consistent locations over time, and have been sampled since 2007. The location of stations is given in Figure 5. The strata, strata areas, and the number of stations sampled are given in Table 1.

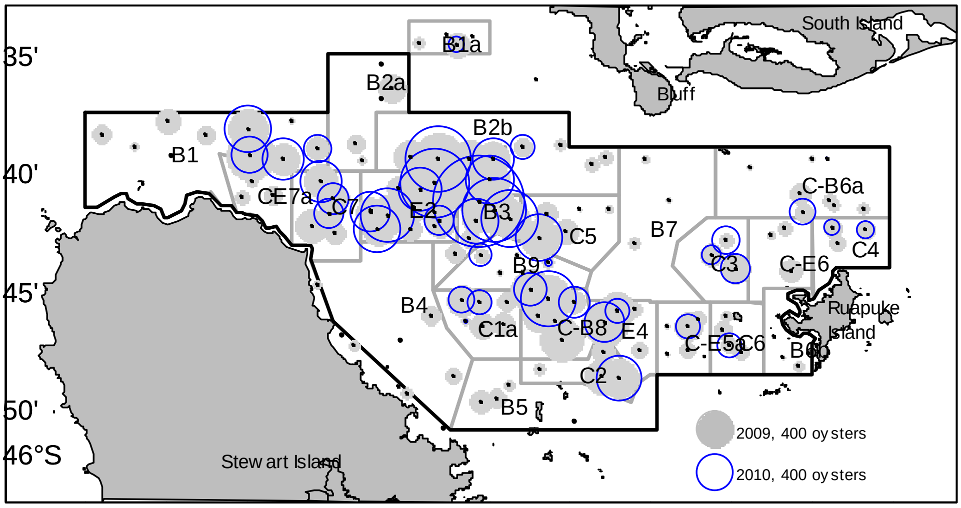

Figure 1: Numbers of recruit-sized oysters per standard survey tow in February 2009 (scaled grey circles, oyster catches up to 1200 per tow) and in February 2010 (open blue circles, oyster catches up to 2500 per tow). The 2005 survey area boundary is shown as black lines, strata by grey lines, and stratum designations are shown in black text. Strata designated commercial by oyster skippers in 2010 have a "C" prefix; exploratory strata "E" prefix, and background strata "B".

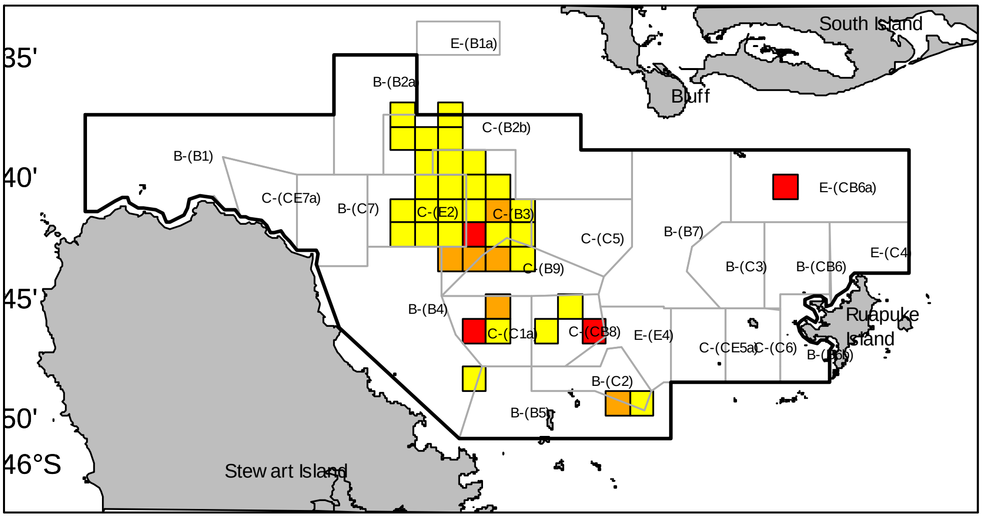

Figure 2: The distribution of mean annual catch rate in sacks per hour (S/H) in 2010 as a proxy for oyster density, 6-6.9 S/H (red), 5-5.9 S/H (orange), and 4-4.9 S/H (yellow).The black outer line is the 2005 survey boundary and the February 2009 strata are shown as grey lines. Strata designated commercial by oyster boat skippers have a "C" prefix. Exploratory strata have an "E" prefix, and background strata "B". B1A is a new stratum added in 2007 survey.

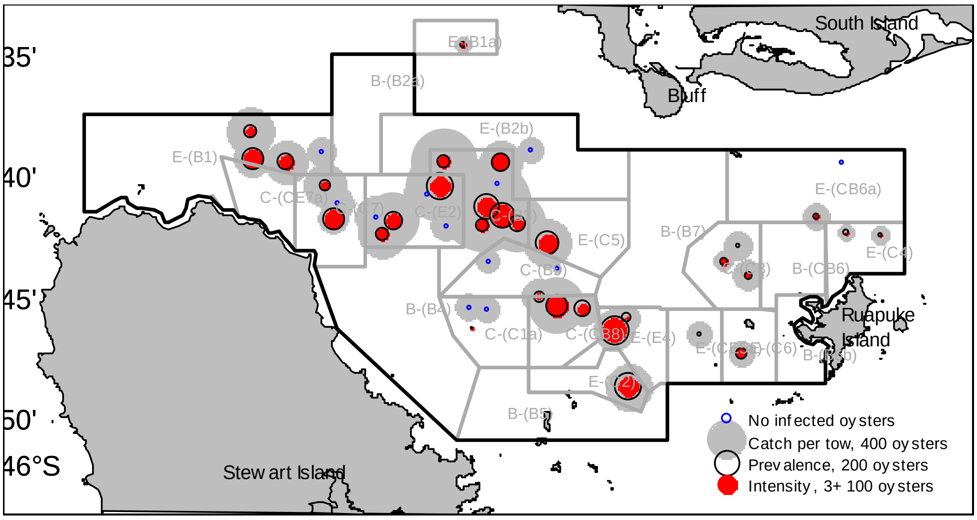

Figure 3: The distribution of oysters and bonamia infection in February 2010. Numbers of oysters (filled grey circles), numbers of oysters with bonamia infection (intensity categories 1–5 combined, open black circles); and fatal infections (intensity categories 3–5 combined, filled red circles). Stations with no bonamia (open blue circles). The 2005 stock assessment survey area (black outer line) and the February 2009 survey strata (grey lines); the 2009 survey stratum designations are shown in brackets. Strata designated commercial by oyster skippers in 2010 have a "C" prefix; exploratory strata "E" prefix, and background strata "B".

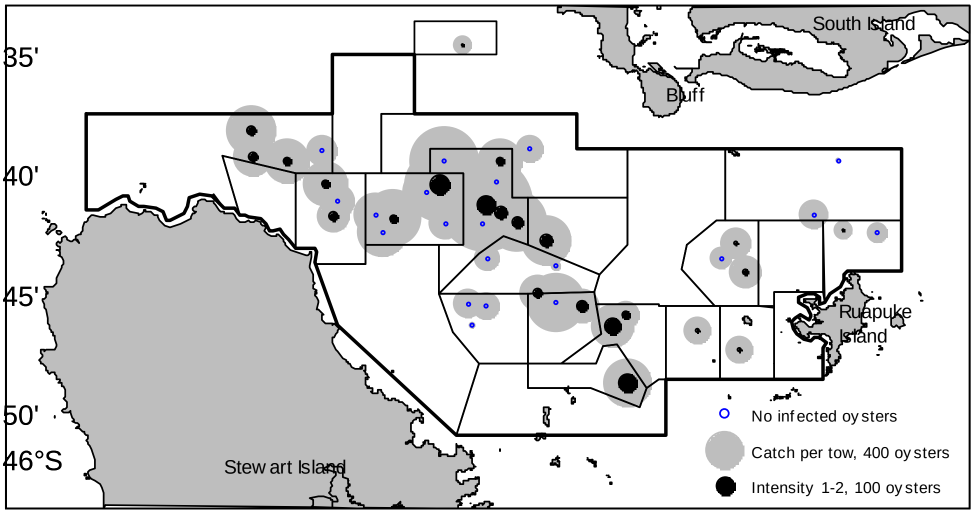

Figure 4: The distribution of recruited oysters (filled grey circles showing numbers per standard tow) and oysters with non fatal infections (filled black circles, the scaled numbers of oysters with intensity of infection category 1 and 2) in February 2010. Sites with no bonamia infection are shown by open blue circles. The heavy black outer line is the 2005 survey boundary and strata shown in thin black lines. Strata designated commercial by oyster boat skippers have a "C" prefix. Exploratory strata have an "E" prefix, and background strata "B". B1A is a new stratum added in 2007 survey.

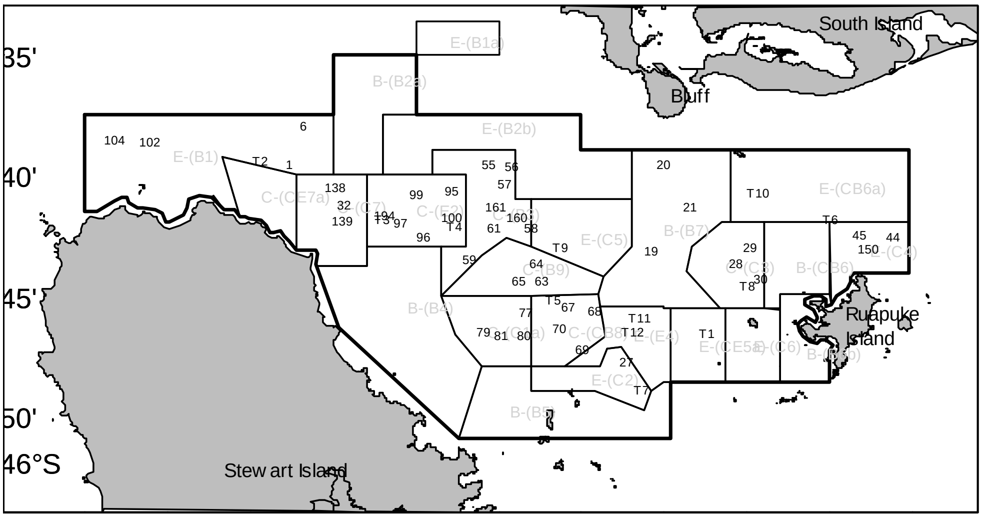

Figure 5: The 2010 survey strata shown as black lines, stratum labels (grey text), and 2011 survey stations numbers in black text (2009 survey numbering was retained). The black outer line is the 2005 survey boundary. Strata designated commercial by oyster boat skippers have a "C" prefix. Exploratory strata have an "E" prefix, and background strata "B". B1A is a new stratum added in 2007 survey.

Table 1: The numbers of stations (No. stns from 2009, 2010, and 2011) and numbers of targeted stations (No. target Stns.) sampled in each stratum in February 2011, and the percentage of 2009 stations sampled. The mean oyster density and mean population (popn.) size in 2009. The current designation of strata in 2011, strata designated commercial prefixed "C", exploratory strata prefixed "E", and background strata prefixed "B".

Stratum	No. stns 2009	No. stns 2010	No. stns 2011	Percent of 2009	No. target Stns. 2011	Mean density 2009	Mean popn. 2009
B1	11	3	4	36	1	0.75	86.0
B1A	4	1	0	0	0	0.29	4.7
B2B	5	1	0	0	0	0.59	49.3
B3	10	7	8	80	0	1.99	88.8
B7	3	0	3	100	0	0.26	18.7
B9	5	2	3	60	0	0.17	6.0
C1A	6	3	4	67	0	0.79	24.6
C2	3	1	0	0	1	1.37	30.1
C3	4	3	3	75	1	0.85	27.7
C4	3	2	3	100	0	0.45	11.8
C5	5	1	0	0	1	0.81	30.3
C6	4	1	0	0	0	0.37	8.7
C7	5	3	3	60	0	1.32	47.7
CB6A	5	1	0	0	2	0.23	17.5
CB8	4	2	4	100	1	2.07	55.7
E2	9	4	6	67	2	1.91	82.0
E4	4	2	0	0	2	1.44	40.3
CE5A	5	0	0	0	1	0.40	8.6

2.2 Operational procedure

Sampling followed similar procedures to 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), February 2007 (Michael et al. 2008b), February 2008 (Michael et al. 2009a), February 2009 (Michael et al. 2009b), and February 2010 (Michael et al. 2011). FV *Golden Quest*, a commercial oyster vessel skippered by Stephen Hawke, was used for the survey. Survey stations were sampled with the Foveaux Strait oyster survey dredge, a standard commercial dredge (3.35 m wide, 430 kg).

While the vessel and crew were different from previous surveys, the vessel characteristics between the vessels were similar (e.g., length, power, etc.); the same survey dredge was used; and the fishing characteristics of the vessel were likely to be very similar to that of vessels used in previous surveys. As with previous surveys, the vessel were instructed in the standard sampling protocols, and NIWA staff were on the vessel during the survey to ensure consistency of procedures.

2.3 Navigation

The survey used standalone high-resolution GPS position fixing (Garmin GPS 17-HVS, position fixing within 3 m, 90% of the time) with positions downloaded to a laptop computer running SEAPLOT navigation software. Start and finish tow positions were recorded both manually and electronically as waypoints (gear up and down).

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. Oyster surveys use straight-line tows to enable the area sampled by the dredge to be easily calculated. This differs to the elliptical tows used by commercial oyster fishers, who fish down tide, then fish back to the start position to enable them to stay on oyster patches. Straight-line 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 distance towed was monitored against a 0.2 nautical mile range ring on SEAPLOT. 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 as waypoints in SEAPLOT, and later saved to file to provide a backup.

Tows that could not be dredged because of foul ground were replaced with the next randomly allocated sites in the same stratum. Tows were repeated with the same site number when the dredge became tangled or 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 including the presence/absence of bycatch species 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.

The catch of oysters and bycatch from each survey tow was photographed with a digital camera 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.

In the October surveys, new clocks are defined 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 February surveys, new clocks are defined as those that had clean inner valves that had retained their lustre, but may have had some minor speckling of fouling organisms (Figure 6). The difference is because fouling organisms are likely to settle only over the summer period. New clocks are assumed to be the shells of those oysters that died since the settlement of fouling organisms in the previous summer, within the previous year. For this analysis, we assumed that new clocks were only those oysters that have died since summer mortality from bonamia began, and oysters that died before this were categorised as old clocks.

The shells of oysters that are fouled or in which the inner valves have lost their lustre are termed old clocks (Figures 7 and 8). 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 about a three-year period, old clocks represent oysters that died between one and three years previously (Cranfield et al. 1991). We note that 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 that both valves remain attached beyond three years. Gravel habitats are usually shallower with stronger tidal currents and higher swell energy and the valves of old clocks there may be disconnected much more quickly than three years, or the clocks (new and old) may be transported out of the fishery area by the strong tides. We ignore these potential differences in classification in the analysis.

The catch was sorted into two size groups: recruit (unable to pass through a 58 mm internal diameter ring, and hence of legal size), 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). Standard 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 heart imprints and histology to estimate levels of bonamia infection. From this sample, 25 were processed for bonamia infection; the additional five were to provide backup samples in case samples were not able to be used following transit or to replace slides of heart imprints). When there were insufficient recruit-sized 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 station number, date, and time on waterproof labels and the sacks tied securely. The oysters for bonamia samples were kept cool and wet in oyster sacks, transferred to poly bins, and flown to NIWA, Wellington, for processing. Additional samples of oysters were also collected for Victoria and Otago University studies, and additional tissue samples were also taken — these were archived for future histology and molecular genetics studies.

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. The presence/absence of bycatch species was also recorded directly from the dredge contents.

Figure 6: New clock (with hinge intact), glossy inner valve with no fouling except a few white coralline specks.

Figure 7: Recent old clock (with hinge intact), glossy inner valve with light fouling.

Figure 8: 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 the same day on arrival. 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. The 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 with bonamia infections. Each oyster was assigned a size category using oyster size rings, measured for length and height (Figure 9), and the measurement truncated to the lower whole millimetre using callipers. If samples contained insufficient recruit-sized oysters, pre-recruits were used in preference to small oysters. Gaping oysters with valves of the shell apart, but closed when tapped, were marked with an asterisk alongside the corresponding oyster number. Oysters were recorded as either incubating white (early-stage) larvae, grey (late-stage) larvae; or with no larva present.

Heart imprints were made by removing the heart (dark organ adjacent to adductor muscle, see Figure 10) 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 eight to ten imprints were made on labelled slides. Slides were placed in slide racks to air dry for at least five 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 10) 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 histology 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

The prevalence and intensity of bonamia were determined from heart imprints taken from all 54 sites. Oyster heart imprints were examined under a microscope using a times 50 objective lens under oil and scored for intensity of infection using the criteria listed in Table 2. Three good heart imprints containing oyster haemocytes were located and examined on each slide, and the number of bonamia cells counted for each. If no bonamia cells were found, further imprints were examined to confirm the absence of bonamia. Heart imprints were examined by two readers. A review of scoring protocols was undertaken before screening samples, initial samples were scored together, and thereafter three common stations were read by both readers.

Visual examination of heart imprints has been found to be at least as sensitive in detecting bonamia infection as histology (Diggles et al. 2003). But whereas histology is time consuming and hence expensive, heart imprints can be screened rapidly and are comparatively inexpensive. Molecular techniques such as in-situ hybridisation have been found to be much more sensitive in detecting low levels of infections, and have similar rates of detection at high levels of infection. Correlation studies using in-situ hybridisation have shown the prevalence of bonamia estimated from the visual examination of heart imprints can underestimate the true infection rate by about 30% (Diggles et al. 2003). However, in-situ hybridisation is a very time consuming and expensive method, even when compared with histology.

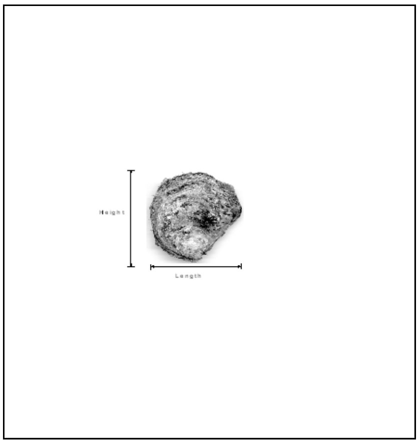

Figure 9: An oyster showing length (anterior-posterior axis) and height (dorsal-ventral axis) dimensions.

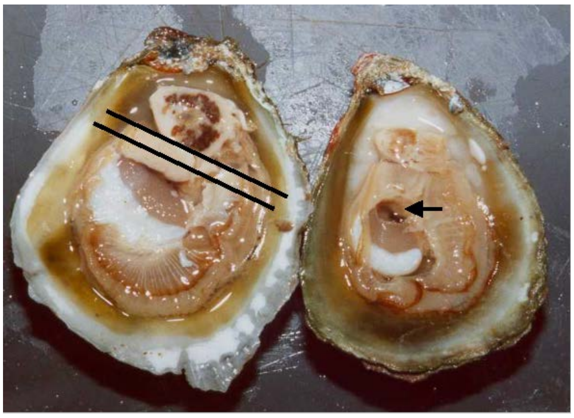

Figure 10: Lines on left oyster show location of 5 mm thick standard section taken for histology. The arrow on the oyster on the right shows the heart, a black organ adjacent to the adductor muscle.

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

Stage	Criteria
0	No bonamia observed
1	One bonamia cell observed after examining an imprint
2	More than 1, but fewer than 10, bonamia cells 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

We assume that category 0 oysters are not infected. Previous studies (Diggles et al. 2003) suggested that stage 1 and 2 level bonamia infections are relatively light and do not appear to adversely affect the host. Stage 3 infections are much more elevated and systemic, and are associated with minor tissue damage throughout the host. It is likely that stage 3 infections will almost always progress to stage 4 (Diggles et al. 2003). 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.

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 because oysters are increasingly less vulnerable to infections and mortality as size decreases. Exact 95% confidence intervals are given for prevalence and for the proportion of new clocks, determined from the *F*-distribution, i.e., for a proportion π, where $\pi = r/n$ (where r is the number of oysters infected with bonamia and n the number of oysters in the sample), the 95% confidence interval is determined by:

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

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

2.7.2 Estimates of oyster density and population size

While the February 2011 survey did not cover all strata used for the stock assessment surveys, estimates of oyster densities can be made in strata that were sampled and can be compared with previous surveys. Although we note that these estimates of population abundance are based on a subset of strata and have relatively small numbers of samples.

The 2011 survey sampled a randomly selected subset of stations from the stations sampled in the 2009 for stock assessment. The oyster population sizes for recruit, pre-recruit, and small oysters were only estimated for 2011 strata where three or more stations were sampled. Estimates of commercial population size used to estimate yield were estimated as the percentage of the recruited population above a density of 400 oysters per tow. Commercial population size was estimated from ten common strata (B1, B3, B7, B9, C1a, C3, C4, C7, CB8, and E2) in 2011. These estimates allow comparisons of the pattern of distribution of high oyster density patches in commercially viable densities.

Estimates of absolute abundance and variance were calculated using standard stratified random sampling theory (Jolly & Hampton 1990). We assumed a mean dredge efficiency, estimated from the 1990 data, of 0.17 (95% confidence intervals 0.13–0.22), and hence calculated the absolute population size of recruit, pre-recruit, and small oysters using the combined population sizes in each stratum as,

$$\bar{x} = \sum W_i \bar{x}_i$$

where $\bar{x}$ is the estimated population size (numbers of oysters) for each size group, W_i is the area (m^2), and $\bar{x}_i$ is the mean oyster density corrected for dredge efficiency in stratum *i*.

Variance estimates were calculated by bootstrapping the error of the estimated dredge efficiency using the method of Cranfield et al. (1999). Note that only the sampling 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 was investigated from changes in the estimates of pre-recruit and small oysters, and from changes in patterns of distribution of small oyster densities between the February 2009 and February 2011 surveys.

Small oysters settle and remain attached to settlement surfaces up to a size of about 40 mm in length. Most small oysters are found attached to live oysters, possibly because survival of juveniles is better on large, live oysters. Relatively few small oysters are found on other settlement surfaces. The numbers of small oysters per recruit-sized oyster were estimated in order to investigate trends in recruitment between 2009 and 2011.

2.7.4 Population estimates of bonamia infection

For each station, the total number of oysters in each bonamia infection category (1–5) was calculated based on the estimated proportion of oysters in each infection category in the sample, and scaled to the total catch. The population prevalence was calculated as the ratio of the estimated number of oysters with bonamia (category 1–5 combined) in the population to the total number of oysters (recruit-sized), and the overall intensity was calculated as the average bonamia level in the population. Stratum mean prevalence was estimated from the three or more random stations in each stratum. Variance for prevalence and intensity was estimated using standard methods as for population estimates.

2.7.5 Estimates of mortality

The total summer mortality was assumed to be the sum of pre-survey mortality estimated from new clocks and gapers, and the post-survey mortality estimated from the proportion of the population with category 3+ infections.

Pre-survey mortality for the oyster population was estimated as the total, scaled numbers of recruit-sized new clocks and gapers. Mortality at individual stations sampled in 2009, 2010, and 2011 is shown as numbers of recruit-sized new clocks and gapers scaled to the size of the catch. Differences between years used paired t-test on all data for paired stations from common strata between years 2009 and 2011, and another smaller subset for 2010 and 2011.

The post-survey mortality in each stratum was estimated as the mean proportion of category 3+ infected oysters in each stratum multiplied by the estimate of the population abundance. The total post-survey mortality is then the sum of the stratum estimates.

3. RESULTS

3.1 Survey operational detail

The oyster vessel *Golden Quest* skippered by Stephen Hawke, the crew, and two NIWA staff sampled 54 stations; 42 randomly selected stations from the 2009 survey strata and an additional 12 target stations.

Sampling began on the 7th of February 2011 and was completed on the 14th of February, with sampling occurring on 5 days over this period. Three full and two half days were lost due to rough weather and sea conditions that were unsuitable for dredge sampling. Survey strata and sample locations are shown in Figure 5, survey tows completed in Figure 11, and the numbers of stations sampled in each stratum are the same as for those shown in Table 1.

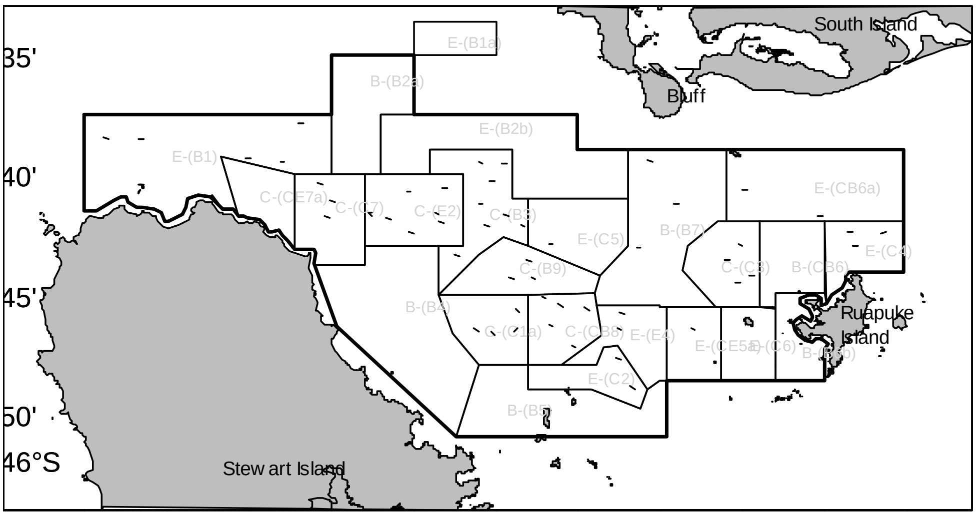

Figure 11: The survey tows sampled in February 2011 to determine the status of bonamia infection and oyster density.

3.1.1 Survey comparability

Dredge tow lengths were almost all about 0.2 nautical miles (370 m) in length (Figure 12). All oyster and clock densities were standardised to the 0.2 nautical mile standard tow length for analysis. Most of the survey stations were sampled in light wind conditions and the remainder in moderate to rough sea conditions (Figure 13). The median wind force was 2 on the Beaufort scale (3–6 knots), with 5 and 95 percentiles of Beaufort scale 1 (1–2 knots) and 5 (16–20 knots) respectively, and maximum wind during sampling about 20 knots. These wind and resulting sea conditions were similar to sampling conditions on previous surveys and mostly below the level likely to affect dredge efficiency.

Oyster dredges are considered saturated and cease fishing before the end of tow when they are more than 80% full on landing. Dredge saturation may lead to an underestimate of oyster density. One dredge was landed 80% full. Dredge fullness ranged from 2% to 80% with a median fullness of 40%, suggesting dredge saturation is not likely to have had a large effect on sampling effectiveness and the survey (Figure 14). 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 and anecdotal evidence from video data recorded from dredge trials suggest that dredge saturation is likely to occur below 80% dredge fullness.

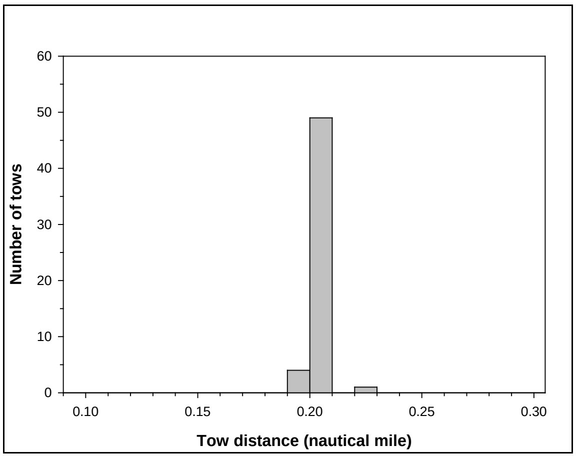

Figure 12: Distribution of tow lengths from the February 2011 survey. The standard tow length was 0.2 nautical mile (370 m).

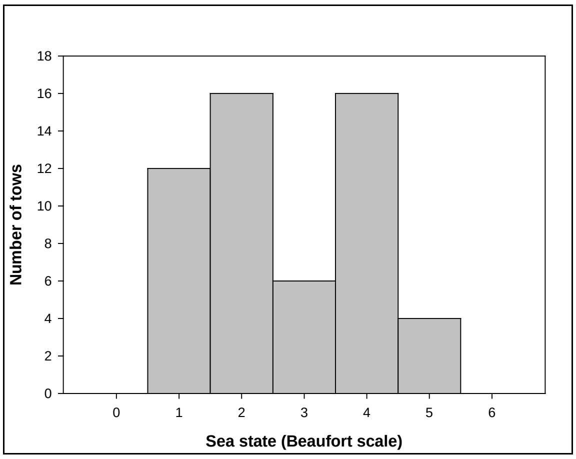

Figure 13: Distribution of sea state (Beaufort scale) recorded during survey tows in February 2011. Beaufort scale: 0, < 1 knot; 1, 1−2 knots; 2, 3−6 knots; 3, 7−10 knots; 4, 11−15 knots; 5, 16−20 knots; and 6, 21−26 knots.

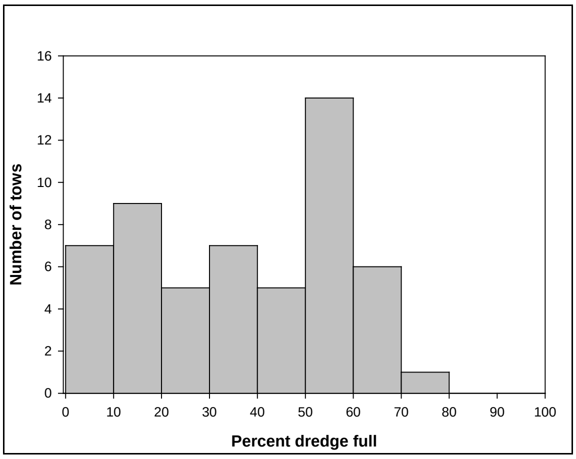

Figure 14: Distribution of dredge fullness recorded for survey tows in February 2011. One of the tows was landed with a dredge fullness of greater than 70%, suggesting that it may have saturated before the end of the tow leading to an underestimate of oyster density. It is likely from video data that dredge saturation may occur below 70% full.

3.2 Observations from sampling

There were indications of continuing bonamia mortality from the presence of new clocks (the shells of oysters that had recently died) and gapers (moribund oysters). The number of gapers was low. These observations suggest detectable levels of bonamia mortality present before the February 2011 survey.

Growth and recruitment to the commercial oyster populations appears to have slowed between 2010 and 2011. Increases in oyster density at many sites in 2010 may have been due to small, fast growing oysters attaining legal size, but they were thin and did not yet provide a marketable product in 2010. The February 2011 survey suggests there has been little increase in recruited oyster density or recruitment to commercial populations over the summer of 2010 and 2011, probably due to a combination of heightened mortality and lower growth through to commercial sized oysters (recruitment). Dredge catches in the western, central, and southern fishery areas had high recruited oyster densities relative to those in 2009. Recruited oyster densities in eastern areas are increasing slowly, but are still generally low, and bonamia infection is still present in some eastern fishery areas.

3.3 Mortality in oysters before the February 2011 survey

New clock and gaper numbers sampled at the 54 stations in 2011 were higher than in February 2009, and higher again than in February 2010 when pre-survey oyster mortality was relatively low. However, the percentages of recruit-sized new clocks and gapers from recruit-sized oysters, new clocks, and gapers combined at paired stations were not significantly different between 2009 and 2011. The percentage of survey stations with no detectable mortality (no clocks or gapers) was lower in 2011 and the median percentage mortality higher than 2009 and 2010 suggesting more widespread infection, and heightened pre-survey mortality between 2010 and 2011 (Table 3). Low mortality (less than 5%) was lower in 2011 than in 2010, and similar to 2009; moderate mortality (5%–10%) was much higher in 2011 than in 2010 or 2009; and heightened mortality (more than 10%) higher than in 2010, but lower than in 2009.

Table 3: Changes in the percentages of survey stations with no detectable mortality (no clocks & gapers), low (less than 5%), moderate (5%–10%), and heightened mortality (more than 10%) at stations sampled in 2009, 2010, and 2011.

Year	2009	2010	2011
Number of stations	48	43	54
Median mortality	1.4	0.8	3.0
Lower 95% CI	0.0	0.0	0.7
Upper 95% CI	10.9	3.7	11.0
Range of mortality	0.0–25.7	0.0–73.0	0.0–33.3
Percent with no mortality	18.8	16.3	3.7
Percent with <5% mortality	62.5	81.4	66.7
Percent with 5–10% mortality	10.4	2.3	24.0
Percent with >10% mortality	8.3	0.0	5.6

The distribution of oyster mortality before the February surveys in 2009, 2010, and 2011, as indicated by the numbers of recruit-sized new clocks and gapers, was similar (Figures 15–17), except for some localised high mortality in 2009. The levels of mortality were lower in 2009 and much lower in 2010 than in 2011. Mortality was highest in eastern areas in 2009, but similar in other areas to 2010 and 2011.

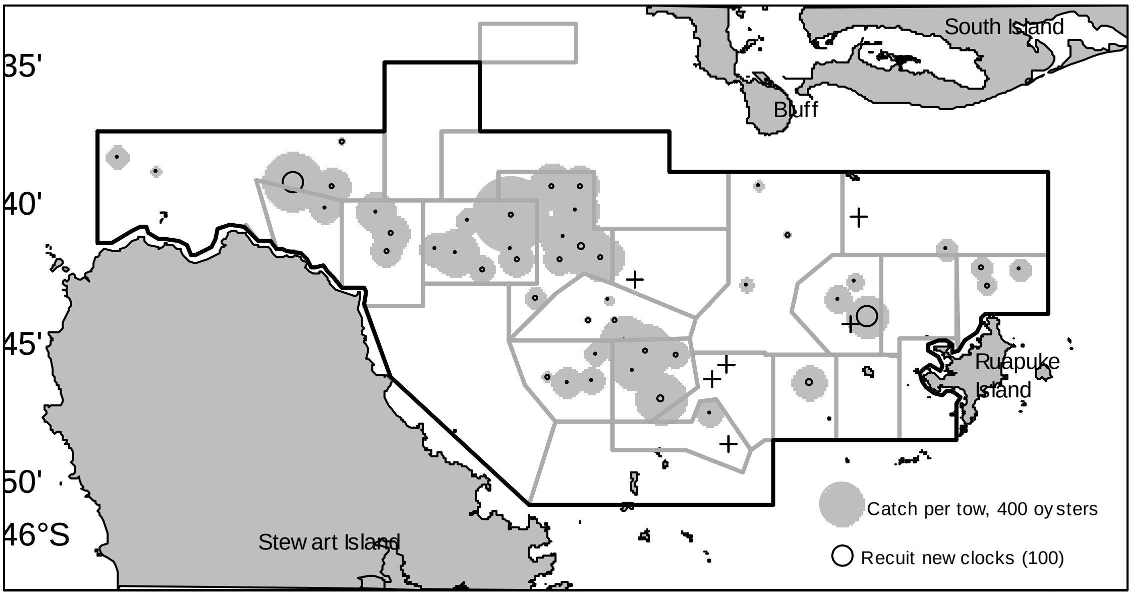

Figure 15: The distribution of recruit sized oysters, new clock, and gaper densities combined (filled grey circles) and the densities of recruit sized new clocks and gapers combined (open black circles) showing the pre-survey mortality in February 2009 from a subset of stations sampled in 2011. Black crosses indicate 2011 stations not sampled in 2009.

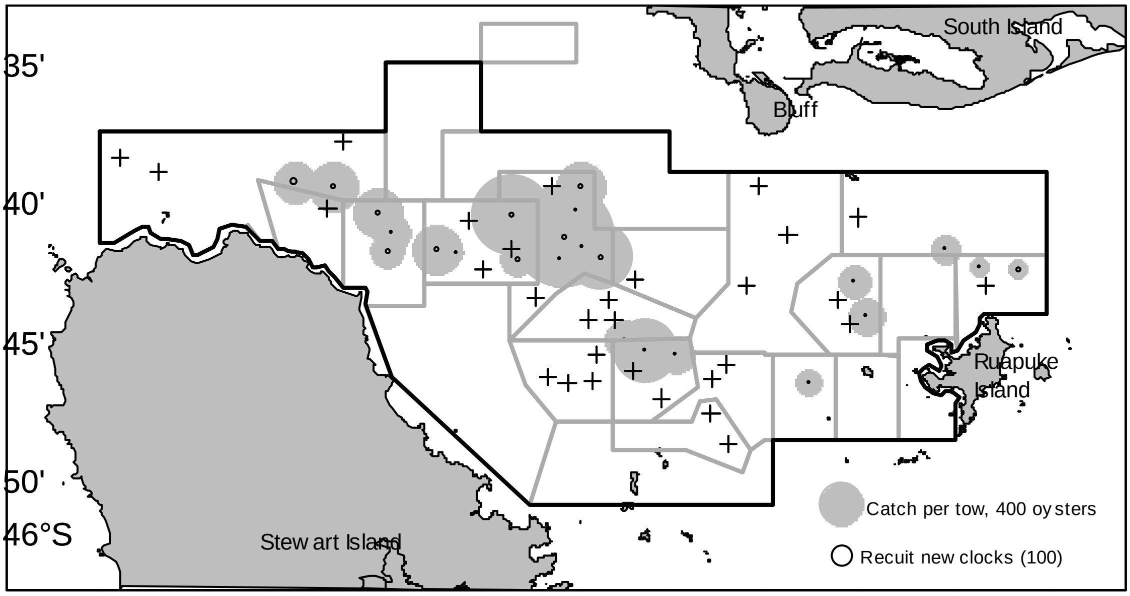

Figure 16: The distribution of recruit sized oysters, new clock, and gaper densities combined (filled grey circles) and the densities of recruit sized new clocks and gapers combined (open black circles) showing the pre-survey mortality in February 2010 from a subset of stations sampled in 2011. Black crosses indicate 2011 stations not sampled in 2010.

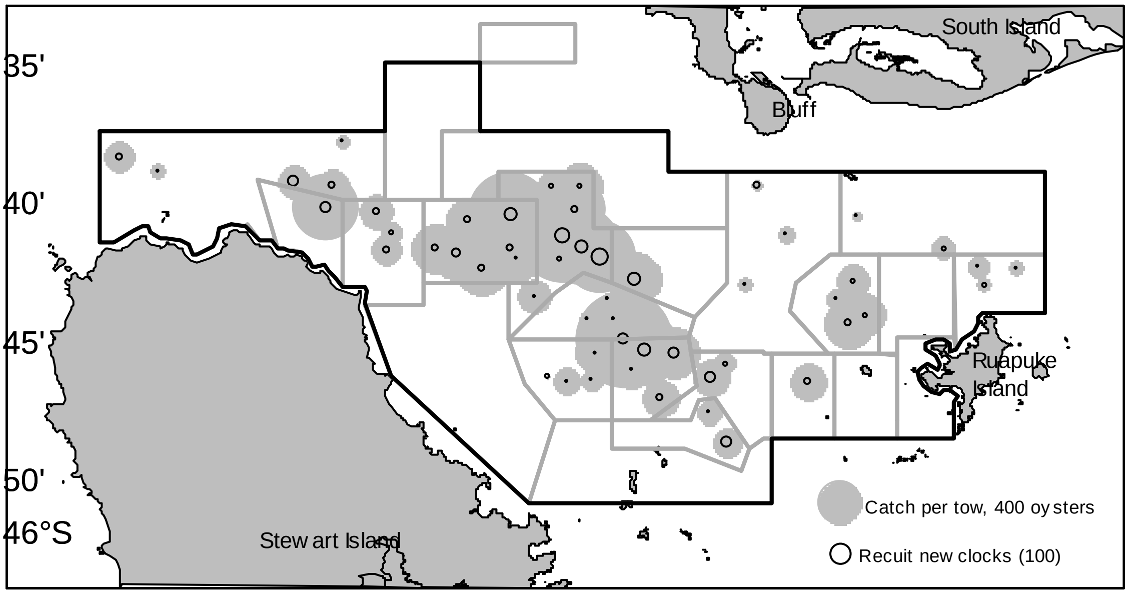

Figure 17: The distribution of recruit sized oysters, new clock, and gaper densities combined (filled grey circles) and the densities of recruit sized new clocks and gapers combined (open black circles) showing the pre-survey mortality in February 2011.

Estimates of recruit-sized new clocks sampled at randomly selected stations from common strata in 2009 and 2011 are shown in Table 4. Pre-survey mortality is estimated to be higher in 2011, 22.5 million new clocks (c.v. of 10%, 95% CI 13.5–35.1); than for 2009, 10.5 million new clocks (c.v. of 40%, 95% CI 2.6–20.5).

Recruit-sized new clock densities were more variable in 2009 than those in 2011. Stratum C3 had the highest density of recruit-sized new clocks (0.12 clocks/m^2, c.v. 0.9) in 2009, and the remaining strata with new clocks ranged from 0–0.03 clocks/m^2 and c.v.s 0.2–0.6. Relatively high new clock densities were found in western (C7), southern (CB8), and eastern (C4) strata.

In 2011, recruit-sized new clock densities were high in strata CB8 (0.14 clocks/m^2, c.v. 0.4), B3 (0.12 clocks/m^2, c.v. 0.3), E2 (0.10 clocks/m^2, c.v. 0.2), and C7 (0.05 clocks/m^2, c.v. 0.2).

Table 4: Recruit-sized new clocks estimated from randomly selected stations (No. stns) from common strata in 2009 and 2011. Population size(Popn.) given in millions of new clocks, coefficient of variation (c.v.), upper and lower 95% confidence limits (U CI and L CI) and the area of each stratum.

	2009					2011					
Stratum	No. stns	Popn.	c.v.	L CI	U CI	No. stns	Popn.	c.v.	L CI	U CI	Area.km^2
B1	11	1.2	0.3	0.4	2.3	4	3.6	0.5	0.1	7.9	114.4
B3	10	0.8	0.3	0.3	1.5	8	5.3	0.3	1.8	9.8	44.7
B7	3	0.7	0.5	0.0	1.5	3	2.1	0.5	0.0	4.7	86.1
B9	5	0.1	0.6	0.0	0.2	3	0.3	0.3	0.1	0.6	34.5
C1A	6	0.1	0.6	0.0	0.3	4	0.3	0.4	0.1	0.7	31.3
C3	4	4.1	0.9	0.0	12.5	3	0.9	0.2	0.5	1.5	32.7
C4	3	0.9	0.2	0.4	1.5	3	0.2	0.6	0.0	0.6	26.3
C7	5	1.1	0.2	0.6	1.8	3	2.0	0.2	1.2	3.1	36.1
CB8	4	0.9	0.3	0.4	1.7	4	3.6	0.4	0.7	7.4	26.8
E2	9	0.6	0.3	0.3	1.1	6	4.1	0.2	2.0	6.9	42.8
All	60	10.5	0.4	2.6	20.5	41	22.5	0.1	13.5	35.1	475.6

3.4 Sampling effectiveness for the prevalence and intensity of infection by bonamia

In 2011, samples of 25 oysters were collected from all stations; comprising of 1324 recruits, 24 pre-recruits, and 2 small oysters, almost all of the samples (98%) were of recruit sized oysters. Samples from station 79 comprised of mainly pre-recruit and small oysters; and stations T10, T11, and 20 had up to eight pre-recruits. The estimates of prevalence may have been underestimated at these stations.

The bonamia scores of the two readers scoring slides were similar and had a high concurrence. Estimates of prevalence of infection were similar, as were estimates of intensity of infection. When estimates of intensity of infection differed, both readers scored the slides, and recorded a consensus score.

3.5 Prevalence and intensity of infection in oysters by bonamia

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 3.1. Bonamia infection in oysters was widespread and variable in February 2011; stations with no detectable infection were interspersed amongst stations with a high prevalence of infection. The distribution of infection was similar to that in February 2010, with increasing prevalence and intensity at some central fishery sites where it was low in 2009 (see Figures 21–23). Of the 1350 oysters examined for bonamia in 2011, 90% had no detectable infection, similar to the 88% in 2010. Of those oysters infected, 3% had light category 1 and 2 infections (4% in 2010), and 7% had category 3+ infections (8% in 2010) that are normally fatal.

Generally, prevalence of infection (the percentage of infected oysters in samples) in 2011 was similar to that in 2010, but lower than 2009 (Figure 18). Fewer stations had high prevalence in 2011. The prevalence of infection ranged from 4% to 52%. The mean prevalence of infection across all stations was lower in 2011 (10%) compared to 2010 (12%), however the medians were the same (8%). The number of uninfected stations was 31% in 2011 (28% in 2010 and 29% in 2009). The percentage of stations with prevalence less than 10% was 28%, 30%, and 37% for 2011, 2010, and 2009 respectively; and for 10–20% prevalence, 26%, 27%, and 26%; and more than 20% prevalence, 15%, 16%, and 8% respectively.

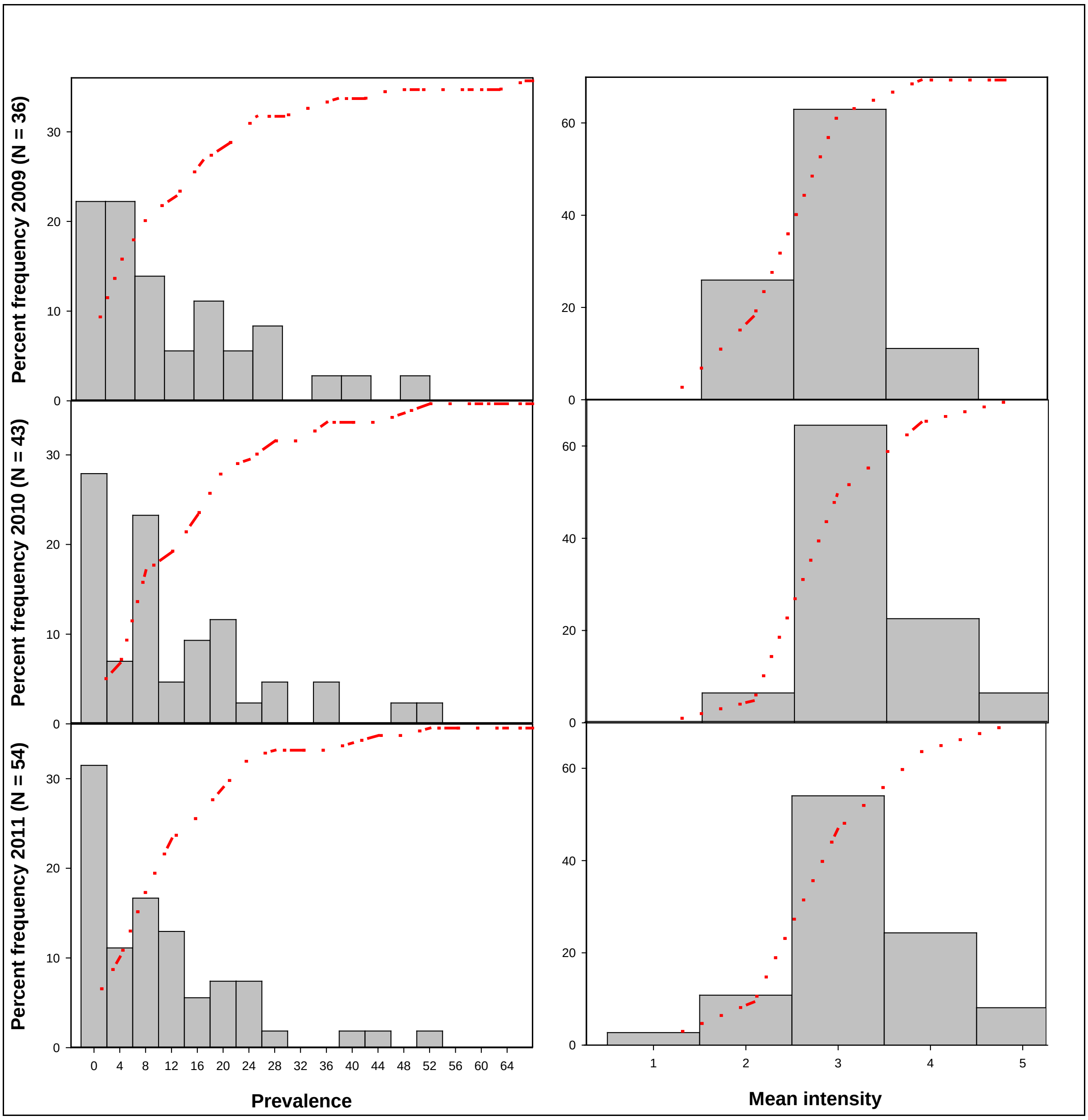

Figure 18: The percent frequency of stations against prevalence (left) and intensity (right) of bonamia infection for 2009–2011 (shown top to bottom respectively). Dashed lines represent cumulative frequencies. Seven of the 43 sites sampled in 2009 were second-phase stations that had high oyster density, but were not sampled for bonamia. Peak prevalence was higher in 2009, 64% compared to 52% in 2010 and 2011.

The mean intensity of infection (3, see Figure 18) was similar for years 2009–2011, but there was a greater proportion of stations with category 4 and 5 infections in 2011. The proportion of stations with category 3+ infections increased from 74% in 2009 to 94% in 2010, and decreased to 86% in 2011. The intensity of infection was highly variable within stations, and patterns of variation were similar both across the fishery area and to those in 2009 and 2010.

3.5.1 Changes in the prevalence and intensity of infection by *bonamia*

Mean prevalence of infection between 2006 and 2011 has been generally low (Figure 19). The distribution of mean prevalence by the numbers of sites varies from year to year with a general pattern of increasing prevalence from 2006 to 2007, declining to 2009, increasing again in 2010, and declining in 2011. Prevalence of infection in February 2011 is similar to that in February 2010, with the numbers of high prevalence stations decreasing from the previous year. At these low levels of infection and assuming average recruitment, the fishery is expected to slowly, but steadily rebuild.

Mean intensity of infection has been generally high since February 2006 (Figure 20), and in 2011 there were fewer stations with high mean intensity of infection. The differences in mean intensity between February 2006 and 2011 may reflect rapid seasonal intensification of infection rather than inter-annual differences, and may be associated with female oyster spawning cycles and the timing of the reabsorption of ova post spawning.

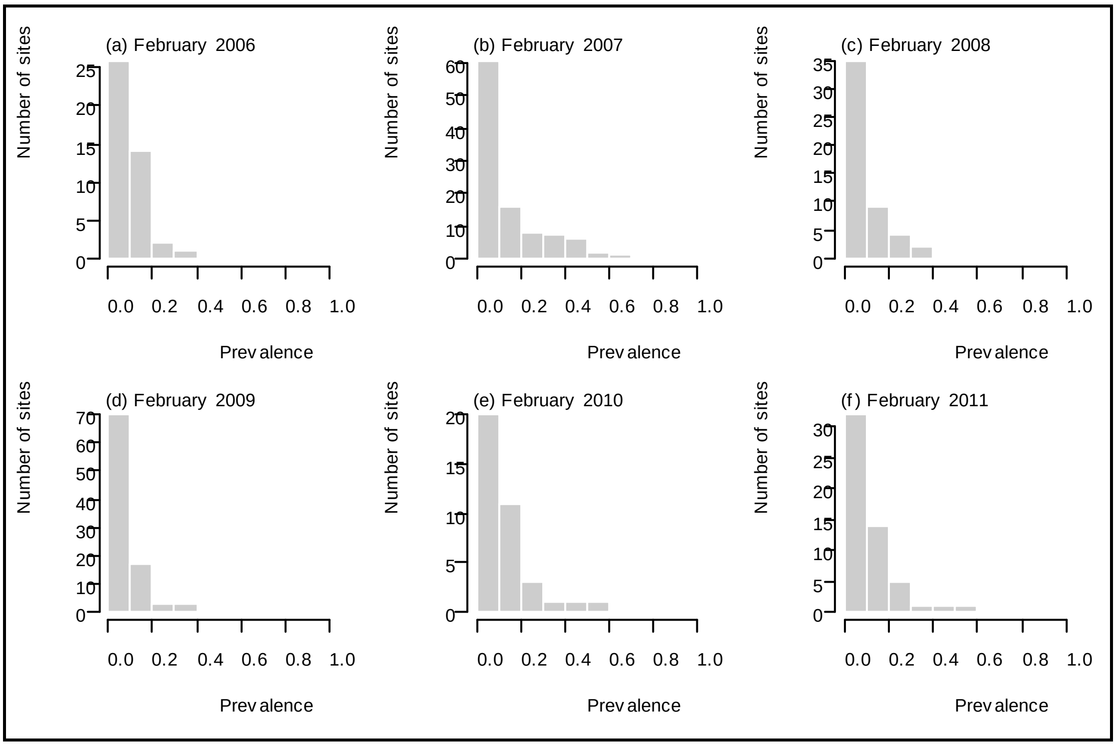

Figure 19: Prevalence of bonamia infection at sites sampled in (a) January 2006, (b) February 2007, (c) February 2008, (d) February 2009, (e) February 2010, and (f) February 2011.

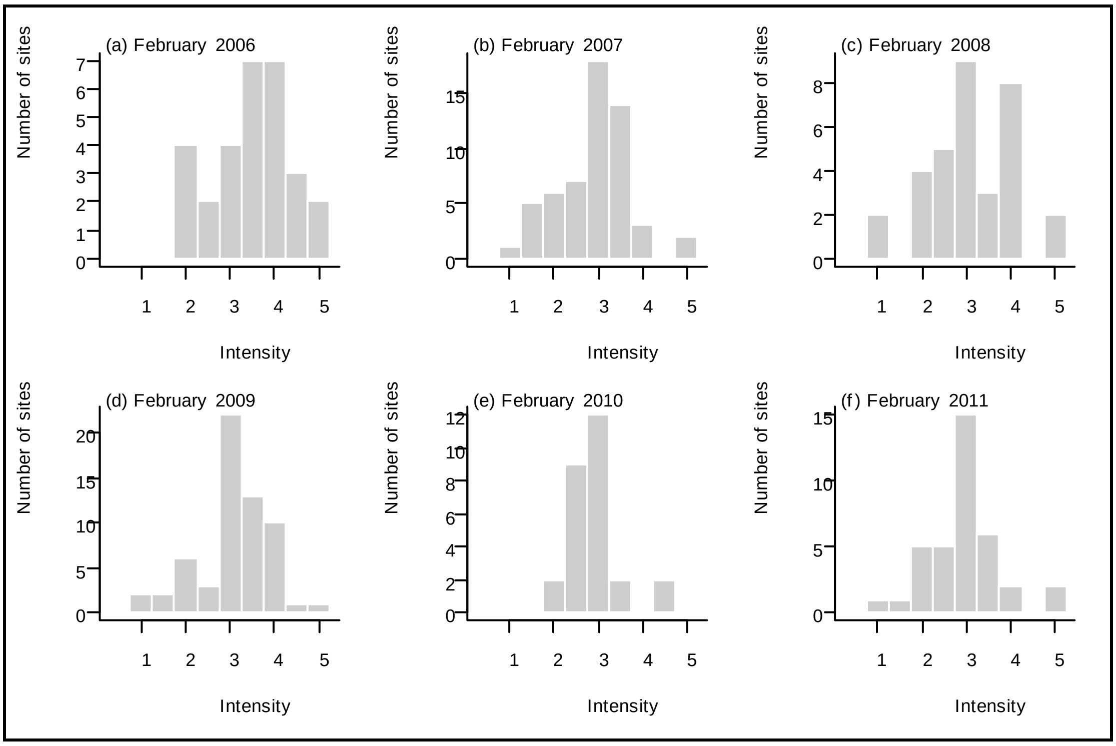

Figure 20: Mean intensity of bonamia infection at sites sampled in (a) January 2006, (b) February 2007, (c) February 2008, (d) February 2009, (e) February 2010, and (f) February 2011.

3.5.2 Changes in the distribution of prevalence and intensity of bonamia infection

During biennial stock assessment surveys (2005, 2007, and 2009) sampling was widespread throughout the fishery area, and in the years between stock assessments, sampling was more limited to commercial fishery areas. In January 2005, there were few infected stations and prevalence was generally low except at some eastern stations with relatively higher oyster densities. The February 2006 and 2007 surveys found widespread infection, with almost all infection east of a line between Bluff Hill and Saddle Point. In February 2008, central fishery areas showed low prevalence, but eastern areas continued to have relatively high prevalence of infection despite their reduced oyster densities.

The intensity of infection between January 2005 and February 2009 varied markedly within sites. Peaks in the mean intensity of infection also probably vary in timing within season. These low prevalence, but high intensity infections have maintained a level of detectable disease mortality in the oyster population. Details of the distribution of prevalence and intensity of bonamia infection from January 2005 to February 2009 are given in Michael et al. (2011).

The distribution of the prevalence and intensity of bonamia infection from February 2009 to February 2011 is shown in Figures 21–23. By February 2009 (Figure 21), prevalence of infection had declined in eastern fishery areas and had begun to increase in southern and western fishery areas where oyster density had also increased. Bonamia infection was widespread and patchy. There were localised sites with both high prevalence and high intensity infections in western and southern fishery areas. By February 2010, bonamia infection had become widespread throughout the fishery, but the prevalence and intensity of infection were highly variable at small spatial-scales. Stations with high prevalence and high intensity of infection were interspersed amongst stations with no detectable infection. Generally both prevalence and intensity of infection had increased especially in central fishery areas

(Figure 22) where recruited oyster density had probably reached pre-1985 levels at some stations. In February 2011, the distribution of infection was widespread and variable, similar to that in 2010, but the prevalence of infection had decreased (Figure 23).

Patterns in the distribution of prevalence and intensity of infection were not consistent with dredging or oyster density; oyster densities are low in the eastern fishery, but the status of infection there is similar to that in other fishery areas, and there were areas of high oyster density with relatively high prevalence and intensity of infection in areas not fished in 2008–2010.

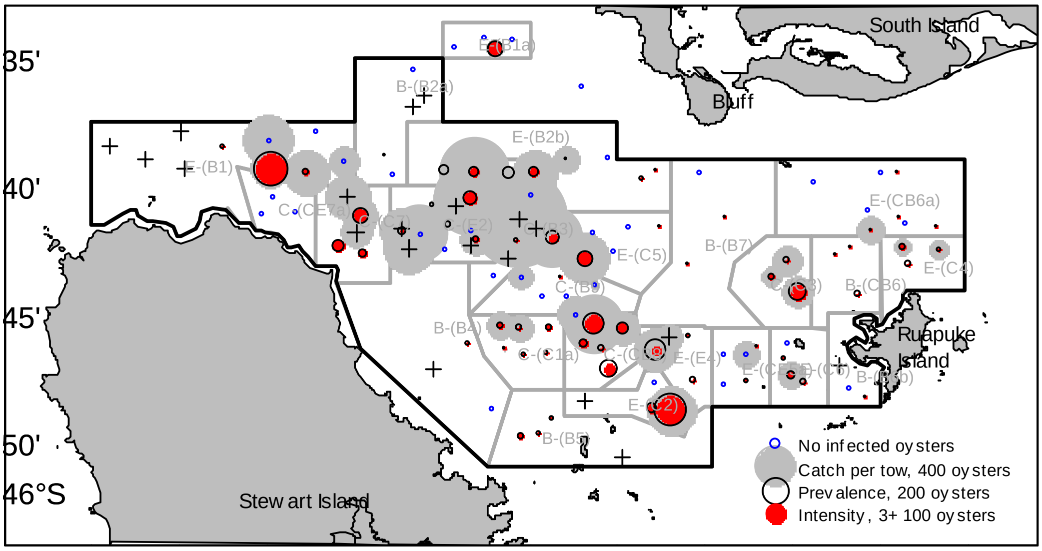

Figure 21: The distributions of oysters and bonamia infection in February 2009 survey. Numbers of oysters (filled grey circles), numbers of oysters with bonamia infection (intensity categories 1–5 combined, open black circles); and fatal infections (intensity categories 3–5 combined, filled red circles). Stations with no bonamia (open blue circles) and stations not sampled for bonamia black crosses. The 2005 survey area (black outer line) and the February 2009 survey strata (grey lines); the 2009 survey stratum designations are shown in brackets. Commercial strata designated by oyster skippers in 2010 have a "C" prefix; exploratory strata "E" prefix, and background strata "B".

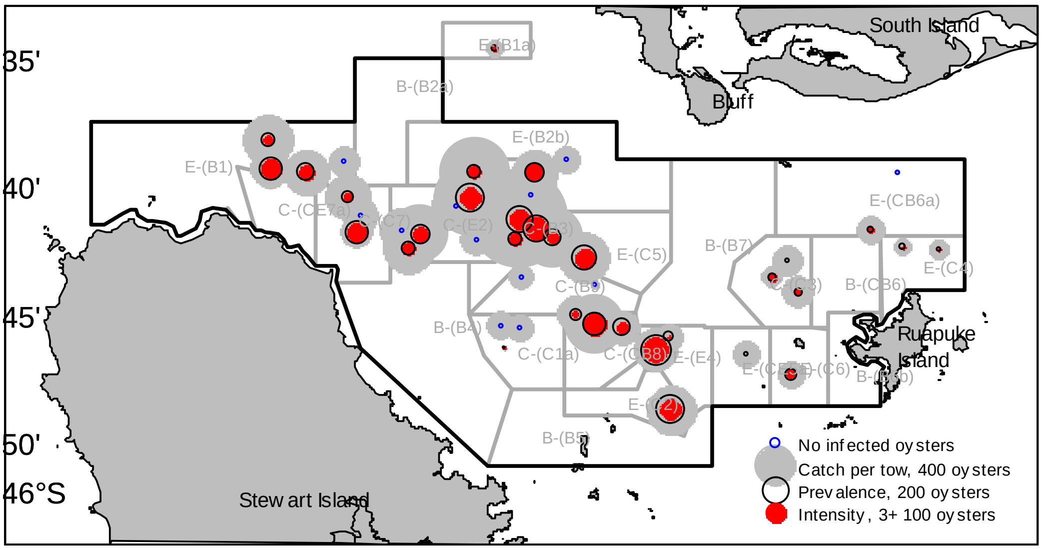

Figure 22: The distributions of oysters and bonamia infection in February 2010 survey. Numbers of oysters (filled grey circles), numbers of oysters with bonamia infection (intensity categories 1–5 combined, open black circles); and fatal infections (intensity categories 3–5 combined, filled red circles). Stations with no bonamia (open blue circles). The 2005 survey area (black outer line) and the February 2009 survey strata (grey lines); the 2009 survey stratum designations are shown in brackets. Commercial strata designated by oyster skippers in 2010 have a "C" prefix; exploratory strata "E" prefix, and background strata "B".

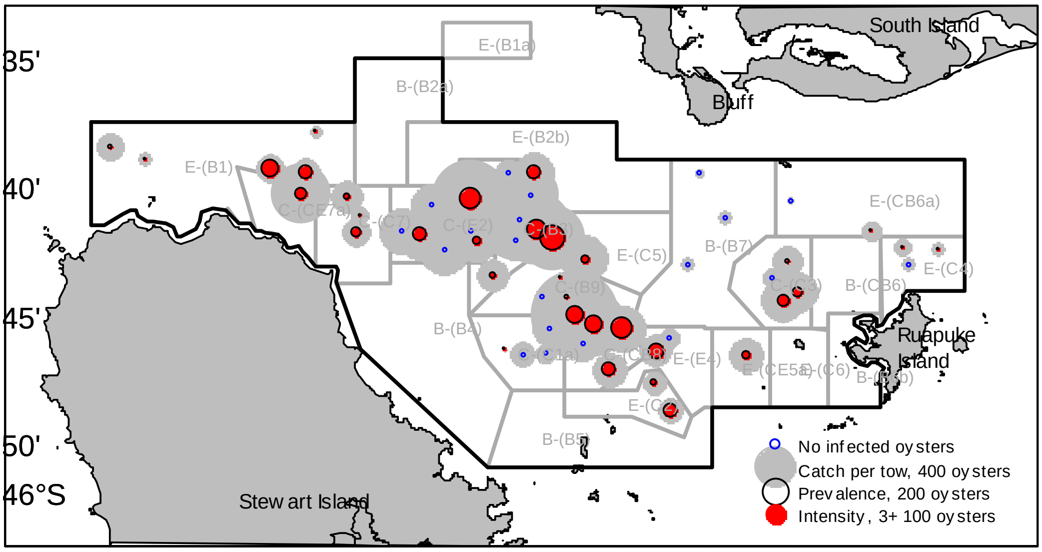

Figure 23: The distributions of oysters and bonamia infection in February 2011 survey. Numbers of oysters (filled grey circles), numbers of oysters with bonamia infection (intensity categories 1–5 combined, open black circles); and fatal infections (intensity categories 3–5 combined, filled red circles). Stations with no bonamia (open blue circles). The 2005 survey area (black outer line) and the February 2009 survey strata (grey lines); the 2009 survey stratum designations are shown in brackets. Commercial strata designated by oyster skippers in 2010 have a "C" prefix; exploratory strata "E" prefix, and background strata "B".

3.5.2 Changes in the estimates of prevalence and intensity of bonamia infection

Mean percent prevalence by stratum for all station 2009–2011 are given in Appendix 3, Table 3.2. The population size of recruited oyster with bonamia infection (all prevalence) and population size of those with category 3+ infections in strata with three or more randomly selected stations in 2009–2011 is given in Table 5. The total numbers of infected oysters increased from 51.9 million in 2009 (c.v. 0.16), to 82.7 million in 2010 (c.v 0.26), and then declined to 70.6 million in 2011 (c.v. 0.25). The total numbers of infected oysters with 3+ infections increased from 33.8 million in 2009 (c.v. 0.15), to 56.0 million in 2010 (c.v 0.26), and then declined to 41.0 million in 2011 (c.v. 0.25), Table 5.

There were six common strata sampled with three or more stations in each of the surveys from 2009 to 2011, B1, B3, C1A, C3, C7, and E2. The total numbers of infected oysters from these strata increased from 24.0 million in 2009, to 82.7 million in 2010, and then declined to 54.8 million in 2011; and the total numbers of infected oysters with fatal infections increased from 18.9 million in 2009, to 56.0 million in 2010, and then declined to 31.2 million in 2011. The differences between all strata surveyed and common strata alone reflect changes in the distributions of infection between surveys. Estimates of scaled prevalence by stratum were relatively imprecise (i.e., had high c.v.s,) and ranged between 15 and 27% for all survey strata combined in each year.

The percentage of the total recruited population infected (Table 6) increased from 8.3% in 2009, to 13.3% in 2010, and declined to 11.2% in 2011. The percentage of 3+ infections followed a similar trend, 5.4% in 2009, 9.0% in 2010, and 6.6% in 2011.

The mean densities of infected oysters were lower in 2011 at stratum levels than in 2010, but generally higher in both 2010 and 2011 than in 2009. Strata CB8, B3, and E2 has the highest densities of infected oysters in 2011 (Table 5).

Table 5: Estimates of the population size of recruit-sized oysters infected with bonamia (prevalence), scaled by catch from randomly allocated stations only in strata with three or more stations, 2009 to 2011. Estimates for year all (e.g. 2009 all) are the total number of infected oysters with categories of infection 1−5, and year 3+ (e.g. 2009 3+) are the numbers of oysters with categories of infection 3−5. The number of survey tows sampled each year (N), the mean density of recruited oysters per m^2 (Mean density) and the coefficient of variation of the density estimates(c.v.), the numbers of oysters (millions) with detectable infections (Mean popn.), upper and lower 95% confidence intervals (Upper and Lower CI), and the area of each stratum (Area).

		2009 all					2009 3+					
Stratum	N	Mean Density	c.v.	Mean popn.	Lower CI	Upper CI	Mean density	c.v.	Mean popn.	Lower CI	Upper CI	Area (km^2)
B1	5	0.02	0.60	2.5	0.0	6.0	0.02	0.63	2.4	0.0	5.9	114.4
B1A	4	0.07	1.00	1.1	0.0	3.5	0.06	1.00	1.0	0.0	3.1	16.0
B2B	5	0.04	0.62	3.1	0.0	7.3	0.01	0.68	0.6	0.0	1.6	83.3
B3	7	0.11	0.34	4.9	1.5	9.3	0.06	0.42	2.6	0.5	5.4	44.7
B6B	3	0.01	0.92	0.2	0.0	0.7	0.01	0.85	0.1	0.0	0.4	19.8
B7	3	0.01	0.66	0.7	0.0	1.8	0.01	0.66	0.7	0.0	1.8	86.1
B9	5	0.00	1.00	0.0	0.0	0.1	0.00	1.00	0.0	0.0	0.1	34.5
C1A	6	0.05	0.18	1.5	0.8	2.3	0.04	0.21	1.3	0.7	2.2	31.3
C3	4	0.14	0.73	4.7	0.0	12.5	0.12	0.70	3.8	0.0	9.8	32.7
C4	3	0.06	0.21	1.6	0.8	2.6	0.04	0.21	1.1	0.6	1.9	26.3
C5	5	0.07	0.95	2.7	0.0	8.4	0.05	0.95	2.0	0.0	6.3	37.7
C6	4	0.05	0.44	1.1	0.2	2.3	0.03	0.47	0.7	0.1	1.5	23.5
C7	3	0.22	0.30	8.1	3.0	14.9	0.19	0.30	7.0	2.6	12.9	36.1
CB6A	6	0.00	0.53	0.2	0.0	0.5	0.00	0.53	0.2	0.0	0.5	77.1
CB8	4	0.35	0.33	9.3	3.1	17.6	0.21	0.28	5.7	2.4	10.2	26.8
CE5A	5	0.03	0.52	0.6	0.0	1.4	0.01	0.48	0.3	0.0	0.7	23.5
CE6	3	0.03	0.70	0.9	0.0	2.2	0.02	0.52	0.5	0.0	1.2	30.0
CE7A	3	0.00	0.00	0.0	0.0	0.0	0.00	0.00	0.0	0.0	0.0	23.6
E2	6	0.05	0.72	2.4	0.0	6.4	0.04	1.00	1.8	0.0	5.8	42.8
E4	3	0.23	0.78	6.4	0.0	17.4	0.06	0.43	1.8	0.3	3.7	28.0
All	87	0.06	0.16	51.9	30.5	84.2	0.04	0.15	33.8	20.3	54.4	838.3

		2010 all					2010 3+					
Stratum	N	Mean Density	c.v.	Mean popn.	Lower CI	Upper CI	Mean density	c.v.	Mean popn.	Lower CI	Upper CI	Area (km^2)
B1	3	0.22	0.54	25.0	0.0	56.7	0.14	0.61	16.3	0.0	39.4	114.4
B3	7	0.53	0.43	23.6	3.9	48.3	0.39	0.44	17.3	2.4	35.7	44.7
C1a	3	0.00	1.00	0.1	0.0	0.4	0.00	1.00	0.1	0.0	0.3	31.3
C3	3	0.09	0.24	3.1	1.5	5.3	0.06	0.58	1.9	0.0	4.5	32.7
C7	3	0.31	0.68	11.1	0.0	28.3	0.22	0.77	7.9	0.0	21.3	36.1
E2	4	0.46	0.52	19.8	0.0	44.1	0.29	0.40	12.6	2.7	25.0	42.8
All	23	0.27	0.26	82.7	38.0	143.0	0.19	0.26	56.0	24.9	97.8	301.9

Table 5: Continued.

Stratum	N	2011 all Mean density	c.v.	Mean popn.	Lower CI	Upper CI	2011 3+ Mean density	c.v.	Mean popn.	Lower CI	Upper CI	Area (km^2)
B1	4	0.14	0.73	15.7	0.0	41.5	0.08	0.73	9.3	0.0	24.8	114.4
B3	8	0.39	0.52	17.4	0.0	38.7	0.21	0.54	9.4	0.0	21.3	44.7
B7	3	0.00	0.00	0.0	0.0	0.0	0.00	0.00	0.0	0.0	0.0	86.1
B9	3	0.02	0.59	0.8	0.0	1.9	0.02	0.59	0.8	0.0	1.9	34.5
C1a	4	0.00	1.00	0.0	0.0	0.1	0.00	1.00	0.0	0.0	0.1	31.3
C3	3	0.10	0.33	3.2	1.1	6.1	0.07	0.67	2.2	0.0	5.6	32.7
C4	3	0.02	0.51	0.6	0.0	1.3	0.01	0.50	0.3	0.0	0.7	26.3
C7	3	0.14	0.59	5.0	0.0	12.0	0.08	0.58	2.9	0.0	6.8	36.1
CB8	4	0.54	0.53	14.5	0.0	32.6	0.32	0.41	8.7	1.7	17.5	26.8
E2	6	0.31	0.41	13.4	2.6	27.2	0.17	0.55	7.4	0.0	17.0	42.8
All	41	0.15	0.25	70.6	32.9	121.9	0.09	0.25	41.0	19.0	71.0	475.6

Table 6: Mean and 95% confidence intervals (95%CI) for the numbers of all infected recruit sized oysters (millions) in the survey population (prevalence) from all survey strata sampled each year, where three or more random stations were sampled in February 2009–2011. Survey population estimates (millions of oysters) and the percentages of populations infected, 95%CIs based on mean prevalence for upper and lower estimates of population size. Mean numbers of infected oysters with 3+ category infections, and the numbers (millions) and percentage of fatally infected oysters are also given for the same data.

Survey	Prev.all			Population size			Percent of population infected		
data	Mean	L95%	U95%	Mean	L95%	U95%	Mean	L95%	U95%
2009	51.9	30.5	84.2	623.5	229.1	1146.9	8.3	4.9	13.5
2010	82.7	38.0	143.0	809.4	509.7	1235.2	13.3	6.1	22.9
2011	70.6	32.9	121.9	595.9	378.5	902.3	11.3	5.3	19.6

Survey	Prev.3+			Population size			Percent of population fatally infected			
data	Mean	L95%	U95%	Mean	L95%	U95%	Mean	L95%	U95%	% fatal
2009	33.8	20.3	54.4	623.5	229.1	1146.9	5.4	3.3	8.7	65.2
2010	56.0	24.9	97.8	809.4	509.7	1235.2	9.0	4.0	15.7	67.7
2011	41.0	19.0	71.0	595.9	378.5	902.3	6.7	3.0	11.4	58.1

3.5.3 Projected mortality from bonamia infections

Post-survey mortality of recruit-sized oysters was estimated in strata with three or more randomly selected stations. The proportion of oysters infected with category 3+ infections in the catch was used to calculate a correction factor for each stratum (Table 7). The post-survey mortality of oysters was projected to reduce the recruited oyster population from 596 million oysters (95% CI 378.5–902.3) at the time of the survey (February 2011) to 556 million oysters (95% CI 353.4–841.5), a loss of 40 million oysters (6.7%), (Table 7).

Table 7: Absolute population estimates for recruited oysters after projected mortality from bonamia based on category 3+ infections: the number of randomly selected stations sampled (No. stations), the correction factor applied to each stratum (Corr. factor), the mean oyster density per m^2 (Mean density), standard deviation (s.d.) of the density estimate, coefficient of variation (c.v.) of the density estimate, mean population size (Mean popn.), upper and lower 95% confidence intervals (CI), and the area of each stratum (Area), by stratum for the February 2011 Foveaux Strait bonamia survey.

Stratum	No. Stations	Corr. factor	Mean density	s.d.	Density c.v.	Mean popn.	Lower 95% CI	Upper 95% CI	Area (km^2)
B1	4	0.87	0.48	0.15	0.32	55.1	19.3	102.1	114.4
B3	8	0.95	3.58	0.88	0.25	159.9	76.9	273.6	44.7
B7	3	1.00	0.22	0.06	0.28	18.7	7.7	33.3	86.1
B9	3	0.92	0.23	0.06	0.25	8.0	3.8	13.9	34.5
C1a	4	1.00	0.74	0.33	0.45	23.0	2.9	48.1	31.3
C3	3	0.95	1.13	0.33	0.29	36.9	14.7	66.0	32.7
C4	3	0.96	0.32	0.07	0.22	8.3	4.2	14.1	26.3
C7	3	0.91	0.91	0.25	0.28	32.9	13.7	58.3	36.1
CB8	4	0.88	2.81	1.01	0.36	75.5	21.5	145.8	26.8
E2	6	0.96	3.21	0.66	0.21	137.6	71.8	228.8	42.8
All	41		1.17	0.13	0.11	556.0	353.4	841.5	475.6

How quickly low level, category 1 and 2 infections progress to category 3+ infections, and the variance amongst individual oysters is not known. Where the prevalence of category 1 and 2 infections is high, and occurs in areas of relatively high oyster density (Figure 24), it is assumed that these areas may eventually be subjected to heightened mortality. These infections are highest in localised central, southern and western fishery areas. The prevalence of these low intensity infections is relatively low compared to recruited oyster density (Figure 24).

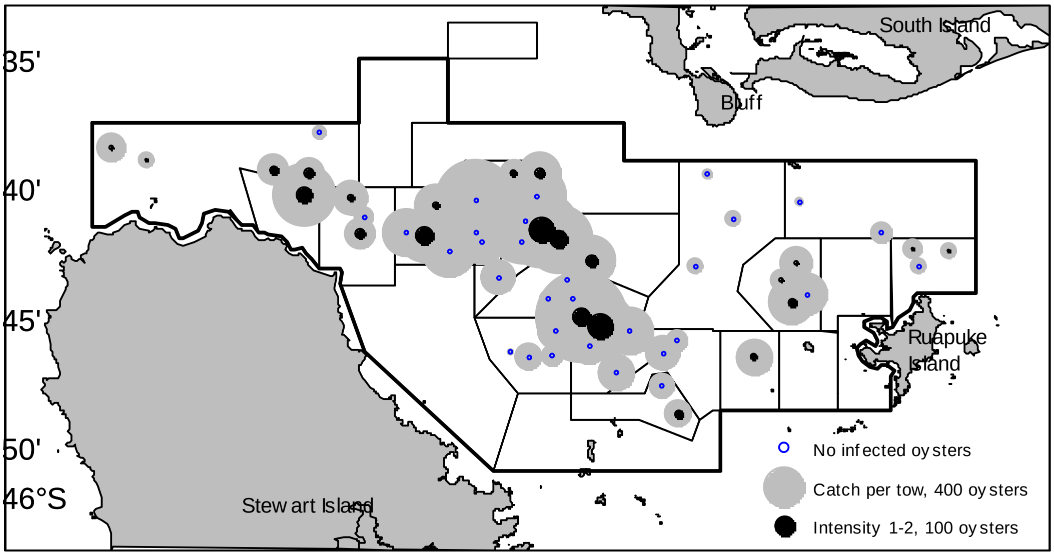

Figure 24: The distribution of recruit-sized oysters (filled grey circles showing numbers per standard tow) and oysters with category 1 and 2 infections (filled black circles, the numbers of oysters scaled to the size of the catch with intensity of infection category 1 and 2) in February 2011. Sites with no bonamia infection are shown by open blue circles.

3.6 Changes in oyster density between 2009 and 2011

Changes in the total numbers of recruited, pre-recruit, and small oysters sampled from standard tows at common stations are sensitive to the combination of sites sampled and year. The numbers of oysters at 24 common stations in 2009, 2010, and 2011 show a decline or similar numbers to 2009; however, at 48 common stations sampled in 2009 and 2011, total numbers are higher or similar to 2009 (Table 8). At these 48 common stations, the percentage of stations with over 400 oysters per tow (previously representing a threshold for commercial oyster densities) was 23% in 2009 and 35% in 2011. For the recruit and pre-recruit sized oysters, most stations had similar numbers of oysters in 2011 to 2009, or had increased between 2009 and 2011 (Table 9). For small oysters the percentage of stations were similar or had decreased over this time (Table 9).

Table 8 The total numbers of recruited, pre-recruit, and small oysters sampled from standard 0.2 nautical mile tows at 24 common stations (recruit1, precruit1, and small1) in 2009, 2010, and 2010; and at 48 common station in 2009 and 2011 (recruit2, precruit2, and small2).

Year	2009	2010	2011
Recruits_1	9 011	4 144	8 505
Pre-recruits_1	13 312	5 042	9 998
Small_1	15 060	5 186	7 186
Recruits_2	12 335	–	20 094
Pre-recruits_2	5 735	–	7 538
Small_2	12 802	–	12 191

Table 9: The percentage of all 48 common stations that increased by more than 50 oysters, were similar (changed by less than 100 oysters), or decreased by more than 50 oysters between 2009 and 2011 for recruited, pre-recruit, and small oysters.

	Percent of all stations		
	Recruits	Pre-recruits	Small
Decreased by more than 50 oysters	17	6	38
Similar, within 100 oysters	48	38	42
Increased by more than 50 oysters	35	56	21

The percentage change in the numbers of recruit and pre-recruit oysters at paired stations between 2009 and 2011 (Figure 25) showed that most sites increased from or were similar to that recorded for 2009. Slightly more than half of the sites showed a decline in small oysters, but some of the sites increased markedly from 2009. There was no general trend in increasing abundance at a fishery scale for recruit and pre-recruit (Figures 26 and 27), but high small spatial-scale variability, probably related to the localised effects of bonamia mortality. Small oyster numbers had declined at more than half the stations (Figure 28), and these declines occurred across the fishery. The few stations where small oysters had increased were in the western and central fishery areas; stations in the eastern fishery area showed static or declining numbers of small oysters.

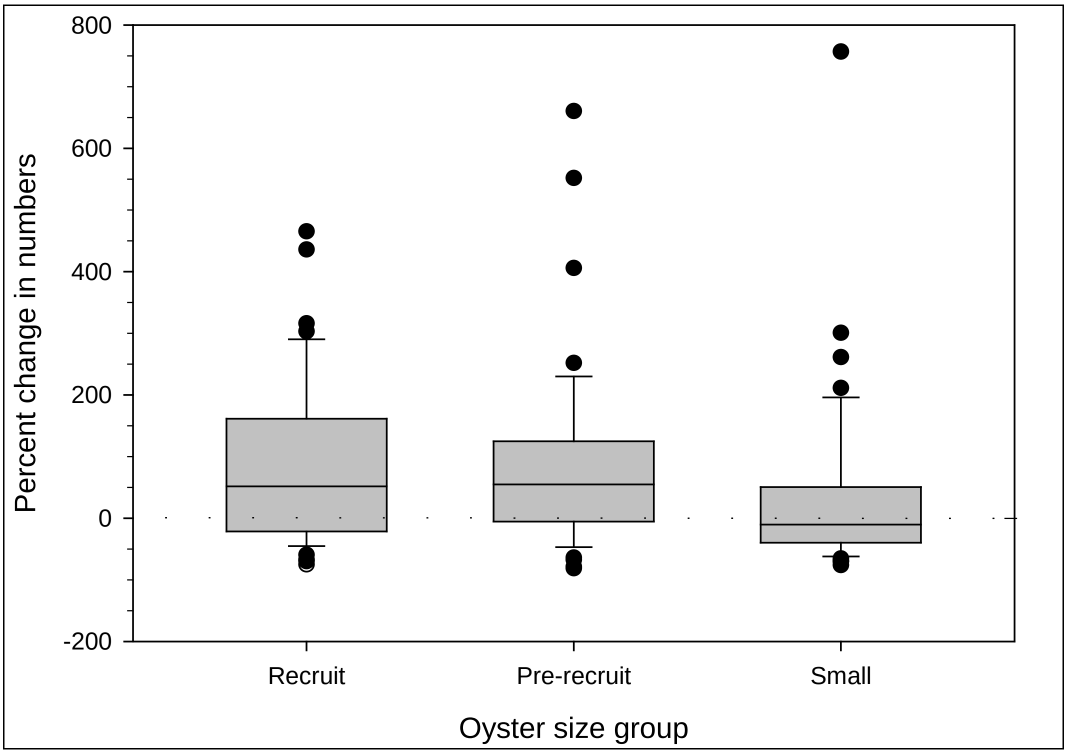

Figure 25: Percentage changes in the numbers of recruit, pre-recruit, and small oysters at all paired stations between February 2009 and February 2011. Box plots show medians (solid horizontal lines), filled boxes represent 25th to 75th percentiles, whiskers at 10th and 90th percentiles, and outliers as filled circles.

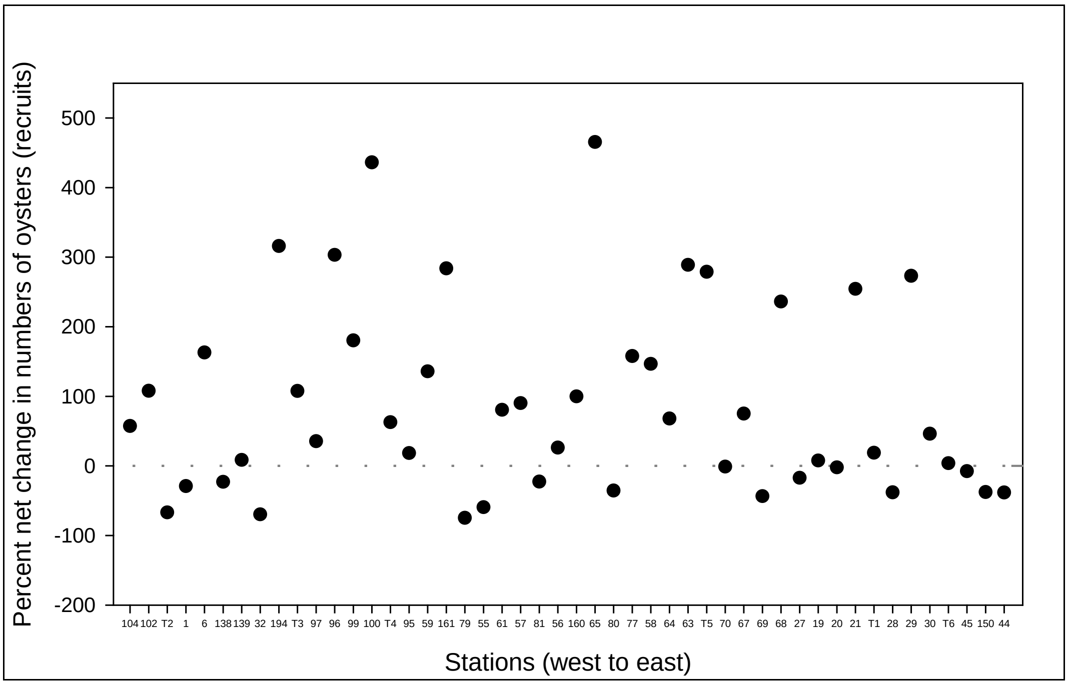

Figure 26: Changes in the percentages of recruited oysters per standard tow, at paired stations between 2009 and 2011.

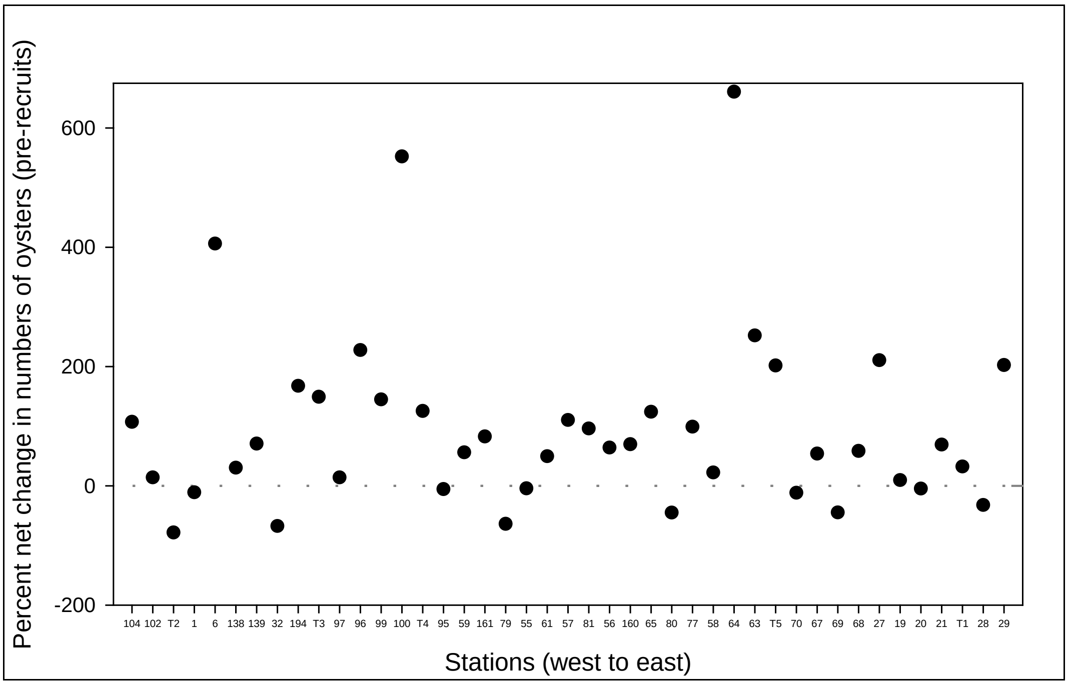

Figure 27: Changes in the percentages of pre-recruited oysters per standard tow, at paired stations between 2009 and 2011.

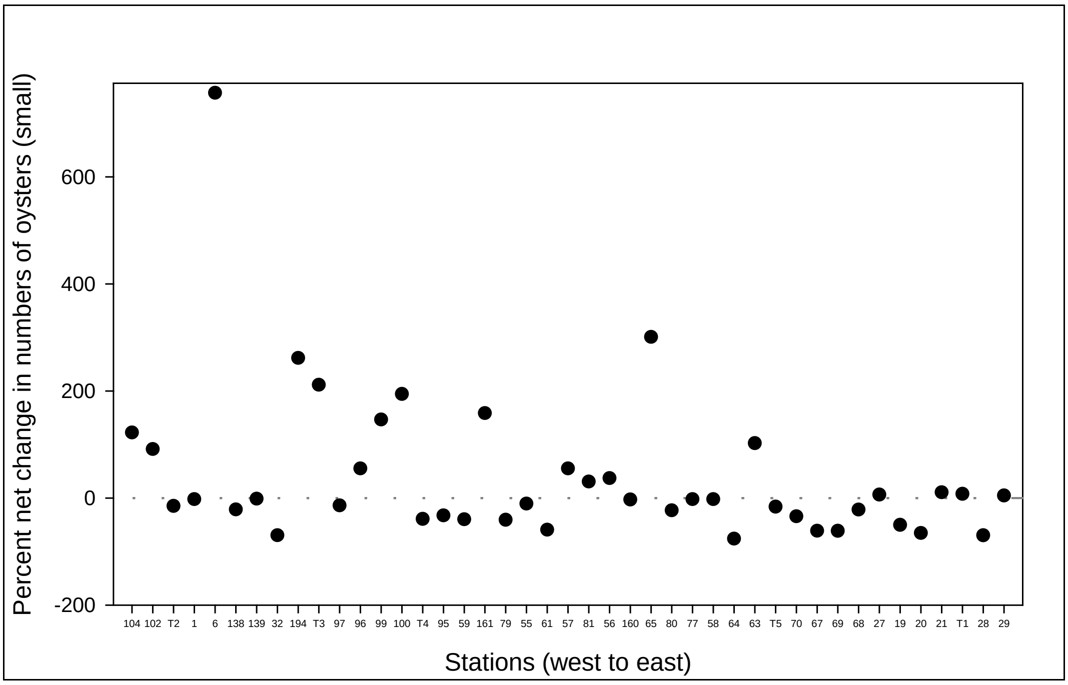

Figure 28: Changes in the percentages of small oysters per standard tow, at paired stations between 2009 and 2011.

3.7 Changes in the distribution of live oysters

There was only limited sampling of random stations in commercial fishery areas in February 2011, and the samples were not enough to provide a consistent or complete coverage of the fishery area, and hence the survey is not likely to have estimated the distributions of oyster density for live recruit, pre-recruit, and small oysters well.

However it appears that the distributions of recruited oyster densities in February 2009, 2010, and 2011 (Figure 29) are similar or have increased in most fishery areas, including within localised areas in the eastern fishery. Some localised areas increased markedly in 2010 and others in 2011 (Figure 29). Localised declines, probably a result of bonamia mortality, are evident in western and southern fishery areas (Figure 29).

The distributions of pre-recruit oyster densities in 2009, 2010, and 2011 (Figure 30) are similar to those for recruits. Generally pre-recruit densities are similar or have increased slightly. Some declines are evident in western, central, and southern fishery areas (Figure 30); pre-recruit oysters are thought to be as vulnerable to bonamia mortality as recruit-sized oysters, and disease mortality of this size group may account for the decreased density in fishery areas with high intensity infections in 2010. Oysters may take one to two years to transition through the pre-recruit size class. Declines in pre-recruit numbers may also be attributed to oysters growing into the recruit size class, but not being replaced by small oysters growing through to pre-recruits.

Anecdotal data suggest that the aerial extent of the commercial oyster fishery area is static, and there are no new fishery areas indicated by the distributions of pre-recruit or small oysters.

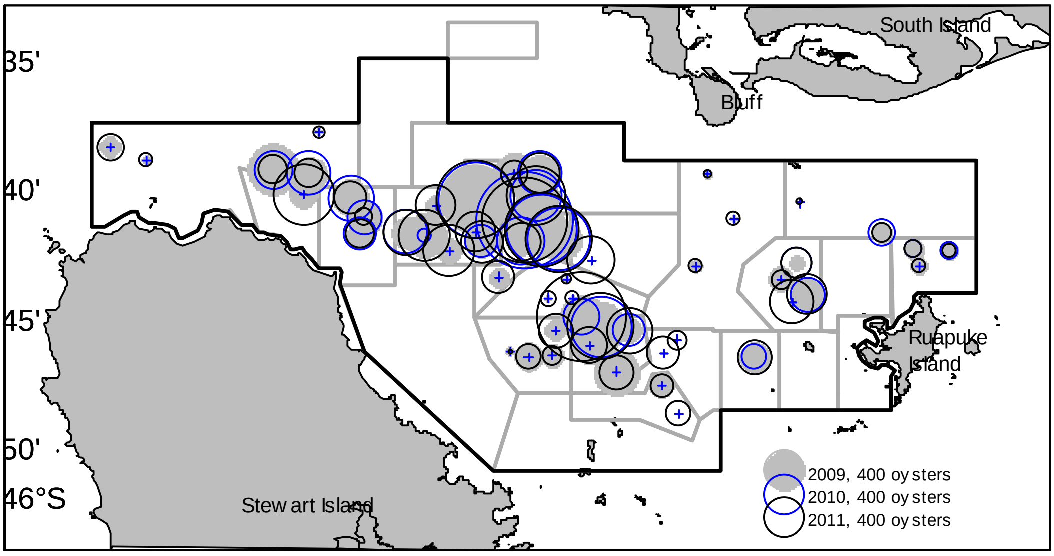

Figure 29: The densities of recruited oysters sampled during February surveys in 2009 (filled grey circles), 2010 (open blue circles), and 2011 (open black circles). Crosses denote no sampling in 2010 (blue) and 2009 (black).

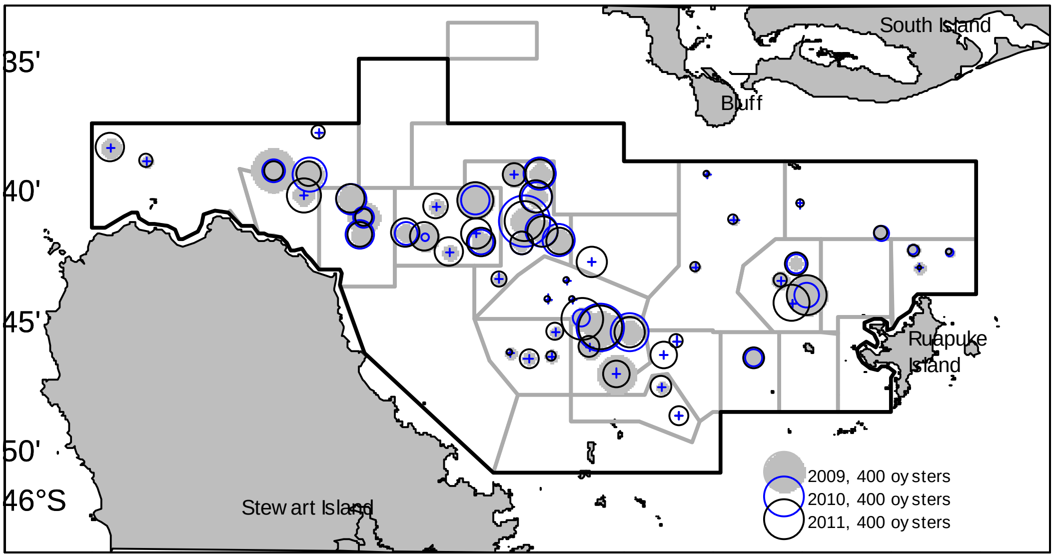

Figure 30: The densities of pre-recruit oysters sampled during February surveys in 2009 (filled grey circles), 2010 (open blue circles), and 2011 (open black circles). Crosses denote no sampling in 2010 (blue) and 2009 (black).

The distributions of small oyster densities in 2009, 2010, and 2011 (Figure 31) are much more variable than for recruit and pre-recruit oysters. Some sites in western and central fishery areas have increased markedly, especially between 2009 and 2010 (Figure 31) while other sites in central and southern areas have declined. These declines are more evident between 2010 and 2011. Most small oysters recorded in dredge surveys are attached to larger oysters, and there can be regional differences in the occurrence of small oysters on larger oysters. Historically, fewer large oysters with small oysters attached (spat and wings) have been recorded from central and western fishery areas than from southern and eastern areas. Since 2006, the numbers of spat and wings in central and western fishery areas have increased significantly.

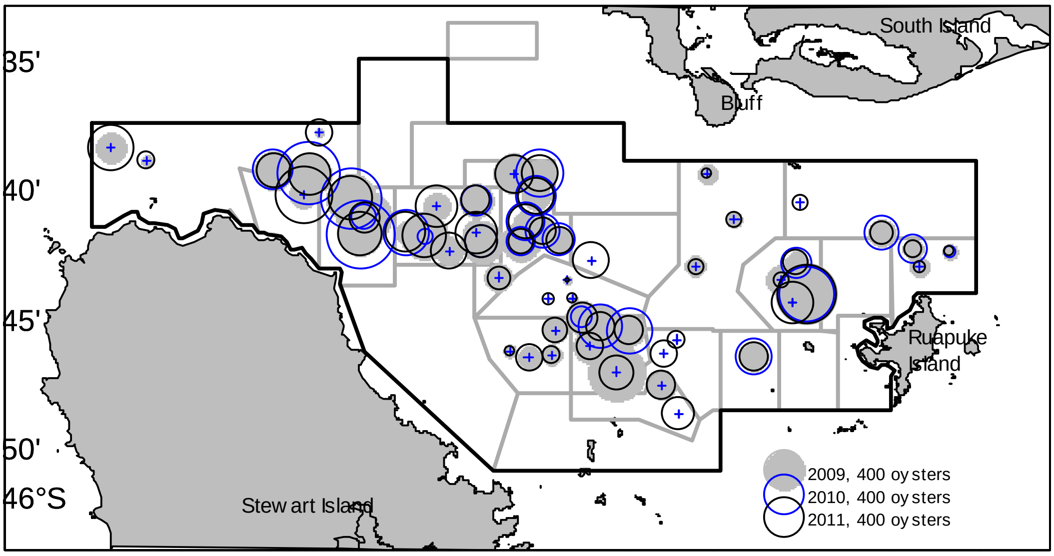

Figure 31: The densities of small oysters sampled during February surveys in 2009 (filled grey circles), 2010 (open blue circles), and 2011 (open black circles). Crosses denote no sampling in 2010 (blue) and 2009 (black).

3.8 Survey estimates of population size

Estimates of population size for recruit, pre-recruit, and small oysters were made in strata with three or more randomly selected stations from the February 2009 survey (Tables 10–15. Estimates of population size from ten common strata (B1, B3, B7, B9, C1a, C3, C4, C7, CB8, and E2) sampled in 2009 and 2011 are compared in Table 16.

Mean population sizes and oyster densities are higher for recruit and pre-recruit oysters in 2011 than those in 2009, but the population size of small oysters is lower in 2011 than it was in 2009. Population size of recruited oysters increased from 443 million oysters in 2009 (Table 10) to 596 million oysters in 2011 (Table 10); and recruit-sized oyster densities increased from 0.9 oysters/m^2 in 2009 to 1.3 oysters/m^2 in 2011 (Tables 10 and 11). The recruit-sized oyster populations and oyster densities increased in strata representing core commercial fishery areas, and decreased in B1, C1a, C4, and C7. Central (B3 and E2) and southern strata (CB8) had the highest recruited oyster densities in 2011, greater than 3 oysters per m^2, and the highest population sizes (Table 10). These strata represent the main areas that have been fished since 2009.

The population of pre-recruits increased from 231 million oysters in 2009 to 278 million oysters in 2011, and oyster densities were similar at 0.5 oysters/m^2 in 2009 and to 0.6 oysters/m^2 in 2011 (Tables 12 and 13). Pre-recruit oyster population sizes increased in all strata; and oyster densities increased in all strata except C3 and C4. The highest population sizes and oyster densities were in most of the same strata as for recruits, strata B1, B3, E2, and CB8.

The population of small oysters decreased from 550 million oysters in 2009 to 516 million oysters in 2011 (Tables 14 and 15), but small oyster densities were similarly low at 1.2 oysters/m^2 and 1.1 oysters/m^2 respectively.

Table 10: Population estimates for recruit-sized oysters from all strata with three or more randomly selected stations in February 2011. The numbers of stations sampled (No. stations), the mean oyster densities per m^2 (Mean density), standard deviation (s.d.) of the density estimate, coefficient of variation (c.v.) of the density estimate, mean population size (Mean population), upper and lower 95% confidence intervals (CI), and the area of each stratum (Area), by stratum.

Stratum	No. Stations	Mean density	Density s.d.	c.v.	Mean population	Lower 95% CI	Upper 95% CI	Area (km^2)
B1	4	0.6	0.2	0.32	63.1	22.1	116.8	114.4
B3	8	3.8	0.9	0.25	169.0	81.3	289.2	44.7
B7	3	0.2	0.1	0.28	18.7	7.7	33.3	86.1
B9	3	0.3	0.1	0.25	8.8	4.1	15.1	34.5
C1a	4	0.7	0.3	0.45	23.0	2.9	48.2	31.3
C3	3	1.2	0.3	0.29	39.0	15.5	69.7	32.7
C4	3	0.3	0.1	0.22	8.7	4.4	14.7	26.3
C7	3	1.0	0.3	0.28	36.0	15.0	63.7	36.1
CB8	4	3.2	1.1	0.36	85.5	24.4	165.3	26.8
E2	6	3.4	0.7	0.21	144.1	75.2	239.6	42.8
All	41	1.3	0.1	0.11	595.9	378.5	902.3	475.6

Table 11: Population estimates for recruit-sized oysters in February 2009, from ten common strata sampled again in February 2011. The numbers of stations sampled (No. stations), the mean oyster densities 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.

Stratum	No. Stations	Mean density	Density s.d.	c.v.	Mean population	Lower 95% CI	Upper 95% CI	Area (km^2)
B1	11	0.8	0.2	0.30	85.9	32.1	157.0	114.4
B3	10	2.0	0.3	0.17	88.8	51.8	140.8	44.7
B7	3	0.1	0.0	0.33	12.5	4.0	23.4	86.1
B9	5	0.2	0.1	0.36	6.0	1.7	11.7	34.5
C1A	6	0.8	0.2	0.23	24.6	12.2	41.8	31.3
C3	4	0.8	0.2	0.25	27.7	12.8	47.6	32.7
C4	3	0.4	0.0	0.08	11.8	7.7	17.6	26.3
C7	5	1.3	0.2	0.15	47.7	28.5	74.9	36.1
CB8	4	2.1	0.5	0.26	55.6	25.3	97.4	26.8
E2	9	1.9	0.6	0.31	82.0	29.8	150.2	42.8
All	60	0.9	0.1	0.10	442.6	285.5	665.2	475.6

Table 12: Population estimates for pre-recruit oysters from all strata with three or more randomly selected stations in February 2011. The numbers of stations sampled (No. stations), the mean oyster densities 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.

Stratum	No. Stations	Mean density	Density s.d.	c.v.	Mean population	Lower 95% CI	Upper 95% CI	Area (km^2)
B1	4	0.5	0.2	0.31	60.0	21.6	110.4	114.4
B3	8	1.0	0.2	0.16	44.1	26.3	69.2	44.7
B7	3	0.1	0.0	0.27	11.6	5.0	20.4	86.1
B9	3	0.1	0.0	0.02	2.6	1.8	3.8	34.5
C1a	4	0.3	0.1	0.38	8.9	2.3	17.6	31.3
C3	3	0.9	0.4	0.47	31.0	2.4	66.3	32.7
C4	3	0.1	0.0	0.45	2.8	0.3	5.9	26.3
C7	3	0.9	0.2	0.23	30.9	15.2	52.2	36.1
CB8	4	1.5	0.5	0.33	39.9	13.5	74.8	26.8
E2	6	1.1	0.1	0.09	46.2	30.1	69.5	42.8
All	41	0.6	0.1	0.11	278.1	177.7	420.5	475.6

Table 13: Population estimates for pre-recruit oysters in February 2009, from ten common strata sampled again in February 2011. The numbers of stations sampled (No. stations), the mean oyster densities 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.

Stratum	No. Stations	Mean density	Density s.d.	c.v.	Mean population	Lower 95% CI	Upper 95% CI	Area (km^2)
B1	11	0.5	0.2	0.31	58.2	21.1	107.0	114.4
B3	10	0.8	0.2	0.24	33.8	16.4	57.6	44.7
B7	3	0.1	0.0	0.18	9.3	5.2	15.1	86.1
B9	5	0.0	0.0	0.34	1.6	0.5	3.1	34.5
C1A	6	0.2	0.0	0.09	6.8	4.4	10.2	31.3
C3	4	0.7	0.5	0.62	24.4	0.0	59.1	32.7
C4	3	0.2	0.0	0.24	5.2	2.5	9.0	26.3
C7	5	0.8	0.2	0.25	27.8	12.9	47.9	36.1
CB8	4	1.2	0.3	0.23	32.8	16.2	55.8	26.8
E2	9	0.7	0.2	0.22	31.6	16.1	53.0	42.8
All	60	0.5	0.1	0.12	231.5	145.2	353.4	475.6

Table 14: Population estimates for small oysters from all strata with three or more randomly selected stations in February 2011. The numbers of stations sampled (No. stations), the mean oyster densities 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.

Stratum	No. Stations	Mean density	Density s.d.	c.v.	Mean population	Lower 95% CI	Upper 95% CI	Area (km^2)
B1	4	1.4	0.4	0.31	156.8	57.8	287.0	114.4
B3	8	1.2	0.2	0.13	55.5	34.7	85.0	44.7
B7	3	0.3	0.1	0.25	24.0	10.9	41.7	86.1
B9	3	0.1	0.1	0.42	4.6	0.8	9.3	34.5
C1a	4	0.6	0.2	0.32	18.9	6.8	35.2	31.3
C3	3	1.7	1.1	0.64	54.2	0.0	133.7	32.7
C4	3	0.3	0.1	0.28	6.7	2.7	12.0	26.3
C7	3	2.1	0.4	0.21	74.1	39.3	122.2	36.1
CB8	4	1.3	0.1	0.10	34.3	22.0	51.8	26.8
E2	6	2.0	0.4	0.17	86.9	49.4	139.1	42.8
All	41	1.1	0.1	0.12	516.0	322.1	790.3	475.6

Table 15: Population estimates for small oysters in February 2009, from ten common strata sampled again in February 2011. The numbers of stations sampled (No. stations), the mean oyster densities 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.

Stratum	No. Stations	Mean density	Density s.d.	c.v.	Mean population	Lower 95% CI	Upper 95% CI	Area (km^2)
B1	11	1.1	0.3	0.29	130.3	50.9	235.4	114.4
B3	10	1.2	0.2	0.15	54.7	33.1	85.4	44.7
B7	3	0.5	0.1	0.18	41.4	23.0	67.3	86.1
B9	5	0.1	0.0	0.25	4.0	1.9	6.8	34.5
C1A	6	0.7	0.1	0.15	22.0	13.1	34.5	31.3
C3	4	2.0	1.0	0.50	64.7	0.5	142.3	32.7
C4	3	0.5	0.1	0.18	13.0	7.3	21.2	26.3
C7	5	2.4	0.6	0.23	85.7	42.0	144.8	36.1
CB8	4	2.4	0.6	0.26	65.2	28.9	114.9	26.8
E2	9	1.6	0.2	0.15	68.7	40.6	108.1	42.8
All	60	1.2	0.1	0.11	549.7	350.6	831.6	475.6

Table 16: Estimates of population size for recruited, pre-recruit, and small oysters from ten common strata (B1, B3, B7, B9, C1a, C3, C4, C7, CB8 and E2) sampled in 2009 and 2011. Mean population size (millions of oysters) with upper and lower 95% confidence intervals in parentheses.

Year	Recruits Mean popn.	95%CI	Pre-recruits Mean popn.	95%CI	Small Mean popn.	95%CI
2009	442.6	(285.5–665.2)	231.5	(145.2–353.4)	549.7	(350.6–831.6)
2011	595.9	(378.5–902.3)	278.1	(177.7–420.5)	516.0	(322.1–790.3)

Population estimates for recruit, pre-recruit, and small oysters are also given for six common strata (B1, B3, C1a, C3, C7, and E2) sampled in 2009, 2010, and 2011 (Table 17). The population size of recruits increased from 357 million oysters in 2009 to 809 million oysters in 2010, then declined to 474 million oysters in 2010. Recruit-sized oyster densities increased from means of 1.2 oysters/m^2 in 2009 to 2.7 oysters/m^2 in 2010, and decreased to 1.6 oysters/m^2 in 2011. The population sizes of pre-recruits and small oysters show similar trends (Table 17). The 2010 estimates may be influenced by markedly high catches at some sample sites; strata B3 and E 2 had mean recruit-sized oyster densities of 5.35 oysters/m^2 and 43.4 oysters/m^2 respectively, and B1 a density of 2.28 oysters/m^2 that was scaled up over 114.4 km^2. Mean oyster densities in B1 and B3 were much lower in 2011, probably the result of heightened bonamia mortality at those sites post-survey in 2010.

Table 17: Estimates of recruit, pre-recruit, and small oysters for six common strata (B1, B3, C1a, C3, C7, and E2) sampled in 2009, 2010, and 2011; mean oyster density (density), mean population size (Popn.) in millions of oysters, with upper and lower 95% confidence intervals in parentheses.

	Recruits			Pre-recruits			Small		
Survey	density	Popn.	95% CI	density	Popn.	95% CI	density	Popn.	95% CI
2009	1.2	357	(226–542)	0.6	183	(111–284)	1.4	426	(265–656)
2010	2.7	809	(510–1235)	1.2	367	(241–546)	3.1	939	(611–1404)
2011	1.6	474	(298–725)	0.7	221	(140–337)	1.5	446	(273–694)

The trend in population estimates at common strata from 2009 to 2011 show consistent patterns of increases in population size and density between 2009 and 2010, and decreases between 2010 and 2011. The recent slowing of the oyster fishery rebuild may be attributed to heightened bonamia mortality combined with reduced recruitment.

3.9 Survey estimates of the commercial population size

In 1995 and 1997, the commercial population used to estimate yield was estimated as the percentage of the population above a density of 400 oysters per tow (equivalent to about 6–8 sacks per hour during commercial dredging) over the entire survey areas. This threshold was based on a historical, economic catch rate, and when the catch rate dropped below 6 sacks per hour, fishers would move to new fishery areas. Although this method is no longer used for stock assessment, estimates of commercial population size allow some comparison with previous years; so the Shellfish Working Group requested that these estimates be included in this report.

Estimates of commercial population size (using catch at each site minus 400 oysters) from ten common strata (B1, B3, B7, B9, C1a, C3, C4, C7, CB8 and E2) with three or more randomly selected tows sampled in 2009 and 2011 are given in Table 18. Four of these strata supported commercial densities in 2009, and three in 2011. The commercial population size was 352 million oysters in 2011, compared to 190 million in 2009. Oyster densities have increased in all strata between 2009 and 2011 except B1.

Table 18: Estimates of the size of the oyster population above a density of 400 oysters per survey tow (equivalent to about 6–8 sacks per hour in commercial dredging) from ten common strata (B1, B3, B7, B9, C1a, C3, C4, C7, CB8 and E2) with three or more randomly selected tows sampled in 2009 and 2011. The numbers of stations sampled (No. stations), the mean oyster densities per m^2 (Mean density), standard deviation (s.d.) of the density estimate, coefficient of variation (c.v.) of the density estimate, mean population size (Mean population), upper and lower 95% confidence intervals (CI), and the area of each stratum (Area), by stratum.

2009 Stratum	No. Stations	Mean density	s.d.	Density c.v.	Mean population	Lower 95% CI	Upper 95% CI	Area (km^2)
B1	11	0.2	0.2	1.0	25.1	0.0	80.6	114.4
B3	10	1.6	0.5	0.3	72.0	29.8	128.8	44.7
CB8	4	1.5	0.8	0.6	39.2	0.0	91.7	26.8
E2	9	1.3	0.7	0.6	53.8	0.0	127.1	42.8
All	60	0.4	0.1	0.3	190.1	84.3	333.0	475.6
2011 Stratum	**No. Stations**	**Mean density**	**s.d.**	**Density c.v.**	**Mean population**	**Lower 95% CI**	**Upper 95% CI**	**Area (km^2)**
B1	4	0.0	0.0	0.0	0.0	0.0	0.0	114.4
B3	8	3.5	1.0	0.3	157.1	60.0	285.4	44.7
CB8	4	2.4	1.5	0.6	63.9	0.0	158.0	26.8
E2	6	3.1	0.9	0.3	131.3	53.0	234.4	42.8
All	41	0.7	0.2	0.2	352.3	185.7	580.3	475.6

3.10 Recruitment

Small oysters settle and remain attached to settlement surfaces up to a size of about 40 mm in length. Most small oysters are found on live oysters, possibly because survival of juveniles is better on large live oysters. Relatively few small oysters are found on other settlement surfaces. The median numbers of small oysters per recruited oyster have slightly declined since 2009 (Figure 32), suggesting recruitment to the commercial population may be slowing. This is consistent with the trend of declining numbers of small oysters sampled from the commercial catch in 2009 and 2010, and the static numbers of small oysters from surveys (516 million in 2009 and 550 million in 2011).

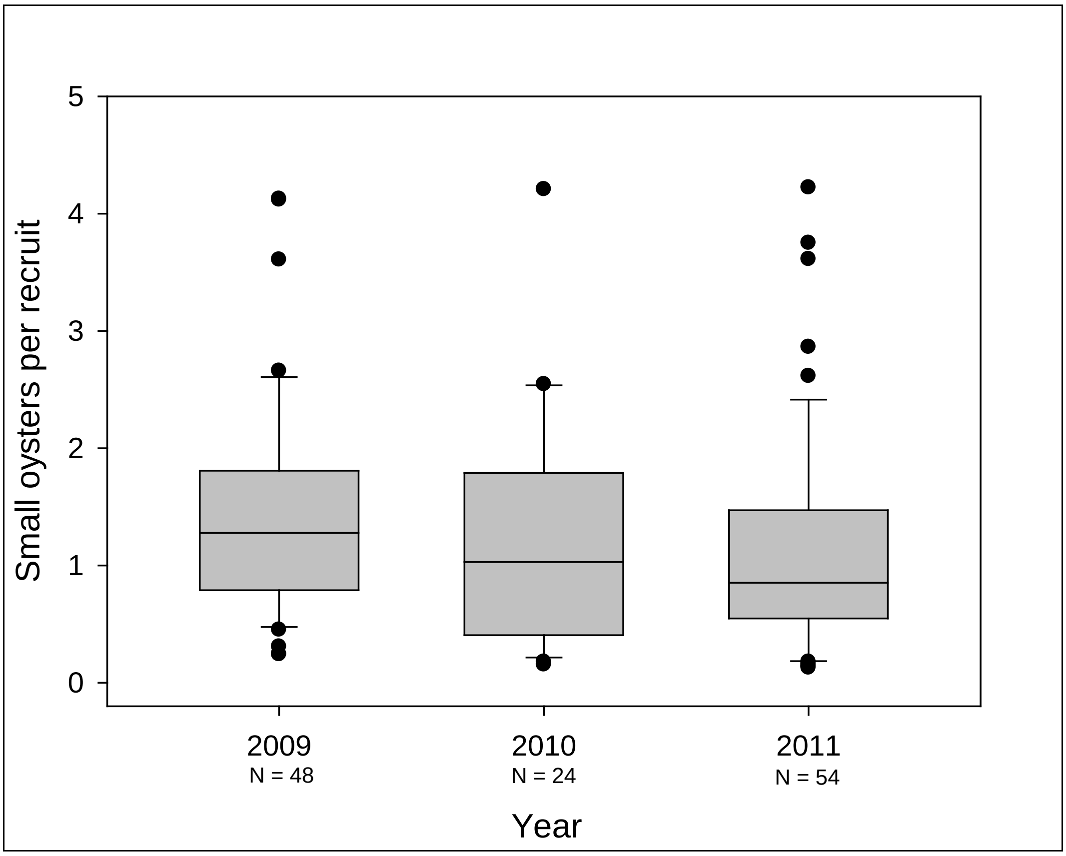

Figure 32: The numbers of small oysters per recruited oyster sampled at common stations between 2009 and 2011. The numbers of stations sampled each year varies.

4. DISCUSSION

4.1 The February 2011 survey

The February 2011 bonamia survey sampling performance is consistent with previous years; and the data are comparable and a valuable addition to the OYU 5 survey time series. Although a different vessel, skipper, and crew were used on the survey, the same dredge was used. It is not known whether the change in vessel has any influence on the data. Comparisons between vessels during multi-vessel surveys in 1990 and 1992 found no significant difference in the data sampled from 10 common stations by different vessels including the *FV Golden Quest* (Doonan et al. 1992). Sea conditions, tow length, and dredge fullness were all within the ranges assumed for effective sampling, and not likely to increase variance in dredge efficiency. Sampling was abandoned if the sea conditions deteriorated to levels assumed to affect sampling efficiency.

The peak mortality of oysters from bonamia infection is thought to occur between January and May, but can occur at other times (Hine 1991). Although the duration and timing of mortality may vary seasonally during epizootics, late January–early February has generally proved to be the most reliable period for detecting bonamia infections. Estimates of new clocks in February 2011 showed higher pre-survey mortality than in 2009 and 2010; and oysters with category 3+ infections were fewer, 40 million recruit-sized oysters compared with 53 million in 2010.

4.2 Estimates of population size, density, and distribution

Estimates of population size are indicative only, and comparisons should be made with caution. The February 2009 survey was a two-phase stratified random stock assessment survey while the February 2010 and 2011 surveys were single-phase bonamia surveys that sampled both target stations and a random selection of stations sampled in 2009. There were markedly fewer stations sampled in common strata in 2011 than in 2009, and fewer still in 2010. Some strata in 2009 received second-phase stations to reduce the variance of the estimates. Estimates are presented for strata where there were three or more randomly selected stations (no target stations were used to estimate population size). Although coefficients of variation (c.v.s) in some of the common strata were high, the c.v.s for estimates of oyster population sizes in all strata combined were comparable, 11.0%, 10.6%, and 12.4% for recruit, pre-recruit, and small oysters respectively in 2011 compared to 9.9%, 12.1%, and 10.7% in 2009.

Mean oyster densities were higher in 2011 compared to 2009, but were lower than in 2010, probably as a result of heightened disease mortality. The lower population sizes of pre-recruit and small oysters may limit the levels of future increases in recruit-sized oyster density.

The survey design focused on commercial fishery areas, and the small number of stations sampled limited the value of these data in describing distribution of oyster density. Oyster density is rebuilding most quickly and extensively in central and western fishery areas. Southern areas are rebuilding more slowly as they are subjected to higher levels of bonamia mortality, and the rebuilding of eastern areas has been slow because of the low oyster densities there and high levels of bonamia mortality.

4.3 Status of infection

Since 2005, levels of bonamia mortality have been low, generally about 10%. Annual mortality from bonamia is the sum of pre-survey mortality estimated from new clocks and gapers, and post-survey mortality projected from category 3+ infections. Estimates of total bonamia mortality (the scaled numbers of recruit-sized new clocks, gapers, and the scaled numbers of oysters with category 3 infections and higher) from the 2007 and 2009 stock assessment surveys were 8.5% and 8.2% respectively. Total mortality estimated from the 2010 bonamia survey was about 7.5%, 60 million oysters, of which about 7 million died before the survey (new clocks and gapers) and about 53 million oysters were expected to die post-survey. The total bonamia mortality from the 2011 survey was 10%, 62 million oysters, of which about 22 million oysters (95% CI 13–35 million) died before the survey (new clocks and gapers) and about 40 million oysters (95% CI 26–61 million) were expected to die post-survey from category 3+ infections. This level of disease mortality is slightly higher than for 2007–2010.

The catchability (dredge efficiency) and persistence at the location of death is likely to vary spatially for new clocks, and their classification as new (from old clocks with fouling organisms on the inner shells) can be difficult at times. The eastern fishery area is characterised by strong tidal currents and gravel substrates, and an unknown proportion of the new clocks are probably transported out of the area, thus underestimating mortality. In western fishery areas, the sand substrate can be mobile and the shells of dead oysters may be buried in sand, initially underestimating mortality, but may eventually be scoured out of the substrate some time later and may be mistaken as new clocks as their burial has preserved the articulation of the hinge and prevented the settlement of fouling organisms used to distinguish between new and old clocks. If new clocks have been buried for some time, the lustre of the inner shell, a character used to separate new and old clocks, is lost and reduces misidentification.

Post survey mortality alone was estimated to be 6.7% in February 2011; similar to the levels since 2007; 6.9%, 3.3%, 6.3%, and 6.6% respectively for 2007–2010. At this range of bonamia mortality, the oyster population has shown the capacity to continue to rebuild.

4.4 Status of the OYU 5 fishery

The Foveaux Strait oyster fishery is very productive and stock assessment shows that at the currently low levels of exploitation (less than the TACC of 15 million oysters), these harvest levels are likely to have little effect on the future status of the oyster population. If recruitment remains near the long-term average, and disease mortality is absent from the fishery, the oyster population can rebuild rapidly. During epizootics, oyster mortality caused by the oyster disease *Bonamia exitiosa* is the principal driver of oyster population abundance in Foveaux Strait. The population size of recruit-sized oysters provides information on how well the fishery is rebuilding, and the population sizes of pre-recruit, and small oysters provide indications of how well it will continue to rebuild. Projections of future disease mortality determine the trajectory of the future stock size, and catch rates from the fishery provide an overall indicator of fishing success. Recently, CPUE may also have been influenced by other factors such as daily vessel catch limits; and vessels preferentially fishing areas with lower catch rates (but higher market value oysters), resulting in more conservative estimates of relative CPUE than in previous years.

The densities of recruit sized oysters in key commercial strata have increased since 2009 but are similar or lower than in 2010, mainly as result of recent bonamia mortality. A station by station comparison of recruit-sized oyster densities at the time of survey in 2011 and adjusted for likely bonamia mortality, compared with oyster densities from 2009 (Figure 33) show some localised declines, but overall a net gain in the portion of the fishery area sampled.

The population size of recruits has increased by 40% at ten common strata representing the main commercial fishery areas since 2009, up from 443 million oysters to 596 million. The population size of recruits in six common strata is lower in 2011 than in 2010 (down from 809 million in 2010 to 474 million), but this difference is influenced by the selection of sites, some unusually high catches in some strata in 2010, and heightened levels of bonamia mortality after the 2010 survey. The size of the commercial fishery area has remained static since 2009.

Projection from the 2009 stock assessment (Fu & Dunn 2009) and updated model runs with new data (commercial catch, unstandardised CPUE, and commercial catch length frequencies) in 2010 predicted recruit-sized stock abundance would increase up to 16% in 2011 from 2009 and up to 9% from 2010 for expected bonamia mortality of 10% or less. The oyster population appears to have increased to a higher level, possible due to the better than average growth observed in the fishery that may have resulted in small oysters growing through to recruits over the summer of 2009/2010. Total disease mortality in recruit-sized oysters (new clocks and gapers; and those oysters with category 3+ infections) has been 10% or below since the 2009 assessment, 7.5% and 10% in 2010 and 2011respectively. The recruit-sized oyster population size in 2011 is 40% higher than in 2009; and the percentage of spawning stock population was projected to remain at about 26-28% B_0 between 2009 and 2011 at 10% disease mortality. The 2010 update of the 2009 assessment showed the percentage of spawning stock population has increased to 29% and was projected to be at about 30% B_0 in 2011 at similar levels of disease mortality. At the current levels of disease mortality, the fishery should continue to rebuild. Fishery indicators also suggest an improvement in the fishery. Commercial catch for 2009 and 2010 (8.23 million oysters and 9.54 million oysters, respectively) is up, as is unstandardised CPUE for 2009 and 2010 (3.12 sacks per hour (s/h) and 4.16 s/h respectively).

The population size of pre-recruits is slightly higher in 2011 than in 2009, and the population size of small oysters similar (see Tables 11 and 12), but both of these are below recent levels. The pre-recruit population is at about 30% of that in 2000 and small oyster population at 40%. These data suggest that recruitment is lower than the long-term average and may slow the rebuilding of the fishery. The standard model (Figure 34) and revised model (Figure 35) expect the oyster fishery to continue to rebuild at the current levels of catch and disease mortality.

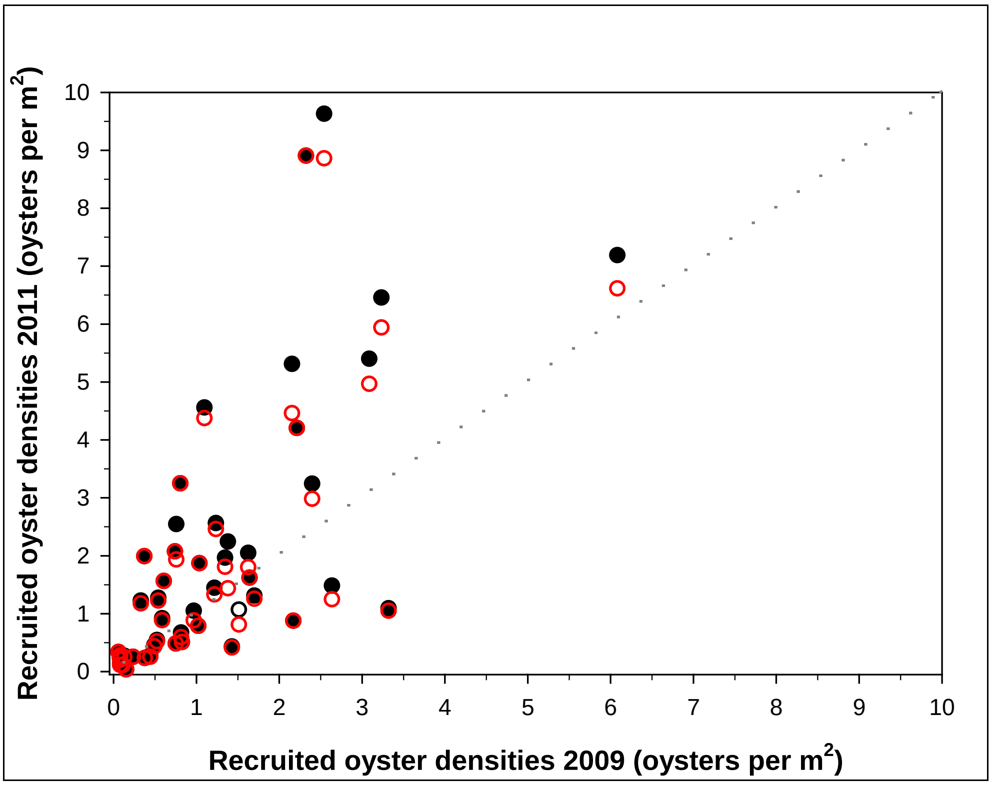

Figure 33: Densities of live recruit-sized oysters at paired stations sampled in February 2009 and 2011. Black filled circles above the diagonal, dashed line indicate an increase in density in 2011 from 2009. Open circles denote adjusted oyster densities after projected bonamia mortality based on category 3+ infections have been subtracted.

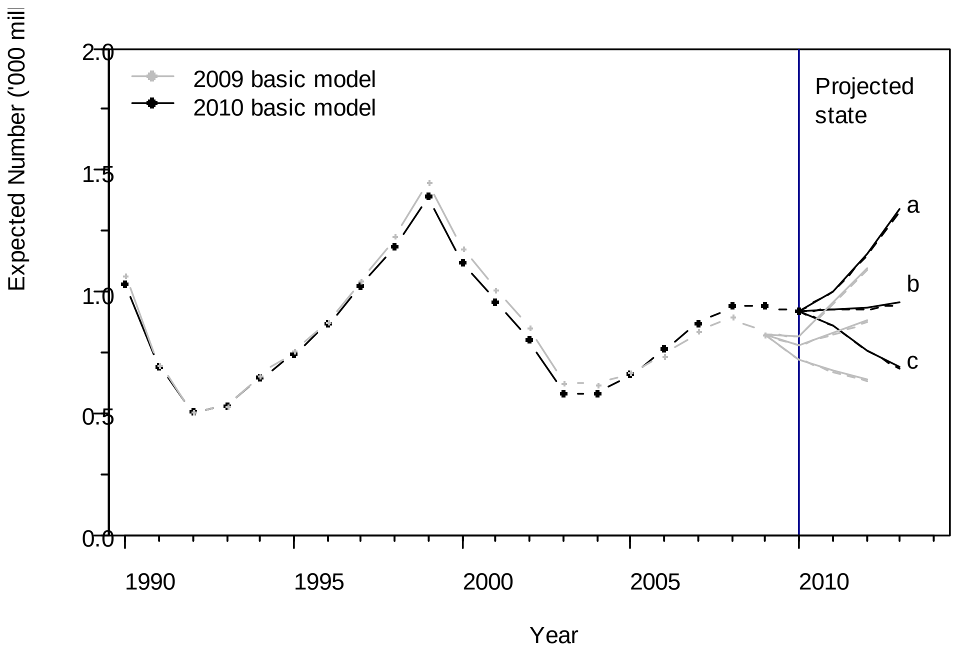

Figure 34: The 2009 basic model estimates of recent recruit-sized stock abundance and projected recruit-sized stock abundance for 2010–12 (grey), and the 2010 basic model estimates and projected abundance for 2011–13 (black). Projections of future abundance with a catch of 7.5 (dashed line) and 15 million oysters (solid line), under assumptions of (a) no disease mortality, (b) disease mortality of 0.10 y^{-1}, and (c) disease mortality of 0.20 y^{-1}.

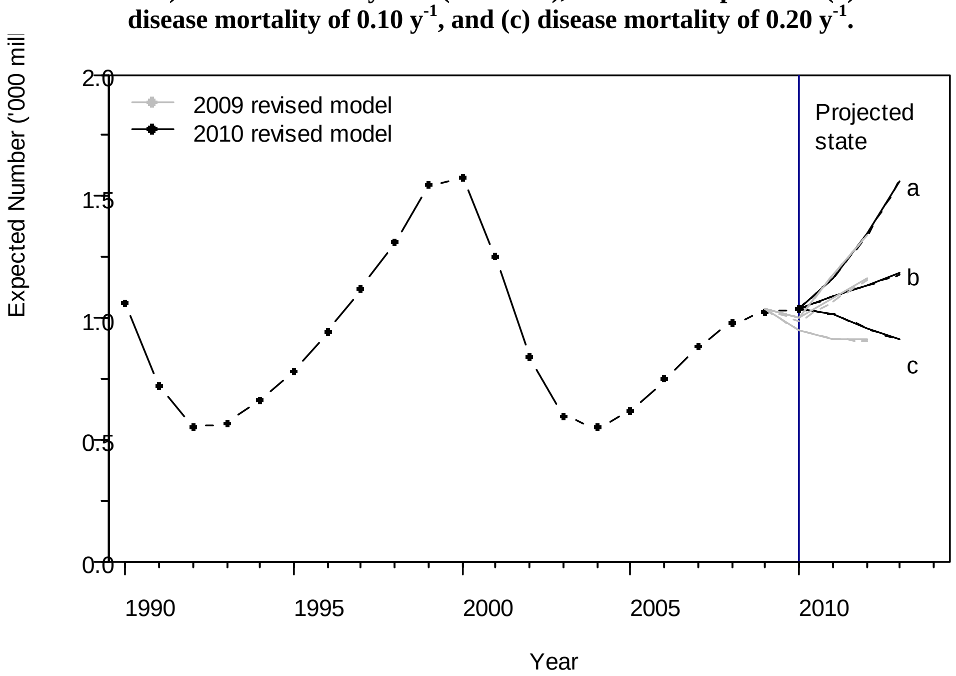

Figure 35: The 2009 revised model estimates of recent recruit-sized stock abundance and projected recruit-sized stock abundance for 2010–12 (grey), and the 2010 revised model estimates and projected abundance for 2011–13 (black). Projections of future abundance with a catch of 7.5 (dashed line) and 15 million oysters (solid line), under assumptions of (a) no disease mortality, (b) disease mortality of 0.10 y-1, and (c) disease mortality of 0.20 y-1.

5. ACKNOWLEDGMENTS

We thank Alistair Dunn for developing scripts for the analyses of these data, reviewing this report, and his contribution; and Stephen Hawke and his crew, and Brian Sanders for the long days at sea; and Graeme Wright (Bluff Oyster Management Company) for facilitating the survey. Also Dean Stotter, Matt Voyles, Steve Mercer, Christopher Dick and others who helped process oyster samples at NIWA Wellington (Greta Point).This investigation was funded by the Ministry of Fisheries under Project OYS2009/01B, objective 1. Thanks to Marianne Vignaux (MPI) for her editorial input.

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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 ___

Date

Station no.	Day	Month	Year	Time NZST

Recorder

....

Comments

Oyster no	Length (mm)	Height (mm)	Size category [4]	Heat imprint score	Histology sample

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 3.1: Estimated prevalence and intensity of infection by bonamia, February 2011, by stratum and station. For each station, where r is the number of recruited oysters infected with bonamia and N the number of recruited 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), density of oysters per m^2, 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).

Stratum	Station	r	N	Prevalence	95% CI	Density	Intensity
B1	1	10	25	0.40	(0.21-0.61)	0.18	2.8
B1	6	1	25	0.04	(0.00-0.20)	0.04	5.0
B7	19	0	25	0.00	(0.00-0.14)	0.04	NA
B7	20	0	23	0.00	(0.00-0.15)	0.02	NA
B7	21	0	25	0.00	(0.00-0.14)	0.05	NA
C2	27	3	25	0.12	(0.03-0.31)	0.11	3.3
C3	28	2	25	0.08	(0.01-0.26)	0.09	1.5
C3	29	2	25	0.08	(0.01-0.26)	0.21	2.5
C3	30	2	25	0.08	(0.01-0.26)	0.33	3.0
C7	32	1	25	0.04	(0.00-0.20)	0.07	5.0
C4	44	3	25	0.12	(0.03-0.31)	0.05	3.0
C4	45	2	25	0.08	(0.01-0.26)	0.08	2.5
B3	55	2	25	0.08	(0.01-0.26)	0.15	2.0
B3	56	5	25	0.20	(0.07-0.41)	0.34	3.6
B3	57	0	25	0.00	(0.00-0.14)	0.71	NA
B3	58	6	25	0.24	(0.09-0.45)	0.89	3.5
B3	59	1	25	0.04	(0.00-0.20)	0.21	3.0
B3	61	0	25	0.00	(0.00-0.14)	0.31	NA
B9	63	4	25	0.16	(0.05-0.36)	0.05	3.5
B9	64	4	25	0.16	(0.05-0.36)	0.02	3.8
B9	65	0	25	0.00	(0.00-0.14)	0.06	NA
CB8	67	6	25	0.24	(0.09-0.45)	0.91	2.2
CB8	68	6	25	0.24	(0.09-0.45)	0.43	3.7
CB8	69	4	25	0.16	(0.05-0.36)	0.25	3.3
CB8	70	0	25	0.00	(0.00-0.14)	0.27	NA
C1a	77	0	25	0.00	(0.00-0.14)	0.26	NA
C1a	79	2	10	0.20	(0.03-0.56)	0.01	2.7
C1a	80	0	25	0.00	(0.00-0.14)	0.08	NA
C1a	81	0	25	0.00	(0.00-0.14)	0.13	NA
E2	95	2	25	0.08	(0.01-0.26)	1.21	3.0
E2	96	0	25	0.00	(0.00-0.14)	0.54	NA
E2	97	5	25	0.20	(0.07-0.41)	0.54	3.2
E2	99	1	25	0.04	(0.00-0.20)	0.35	1.0
E2	100	0	25	0.00	(0.00-0.14)	0.33	NA
B1	102	3	25	0.12	(0.03-0.31)	0.05	3.0
B1	104	2	25	0.08	(0.01-0.26)	0.15	2.5
C7	138	2	25	0.08	(0.01-0.26)	0.22	3.0
C7	139	7	25	0.28	(0.12-0.49)	0.18	2.3

Table 3.1 continued.

C4	150	0	25	0.00	(0.00-0.14)	0.04	NA
B3	160	5	25	0.20	(0.07-0.41)	1.08	2.0
B3	161	0	25	0.00	(0.00-0.14)	1.49	NA
E2	194	3	25	0.12	(0.03-0.31)	0.76	2.3
CE5a	T1	3	25	0.12	(0.03-0.31)	0.24	3.0
B1	T2	11	25	0.44	(0.24-0.65)	0.18	3.0
E2	T3	0	25	0.00	(0.00-0.14)	0.43	NA
E2	T4	1	25	0.04	(0.00-0.20)	0.38	4.0
CB8	T5	2	25	0.08	(0.01-0.26)	1.61	3.0
CB6a	T6	1	25	0.04	(0.00-0.20)	0.09	3.0
C2	T7	13	25	0.52	(0.31-0.72)	0.13	2.9
C3	T8	3	25	0.12	(0.03-0.31)	0.40	3.0
C5	T9	3	25	0.12	(0.03-0.31)	0.47	2.0
CB6a	T10	0	17	0.00	(0.00-0.20)	0.01	NA
E4	T11	0	24	0.00	(0.00-0.14)	0.09	NA
E4	T12	6	25	0.24	(0.09-0.45)	0.23	4.2

Table 3.2: The estimated prevalence for infection (Prev.all) and the prevalence of intensity 3+ infections (Prev.3+), February 2009–2011 by stratum. For each stratum, the area is given in km^2, number of tows (No. tows), the coefficients of variation (c.v.) and minimum (Min) and maximum (Max) prevalence of stations in that stratum.

2009

Stratum	Area	No. tows	Prev.all	c.v.all	Min	Max	Prev.3+	c.v.3+
B1	114.4	5	3.2	103.8	0.0	8.0	2.4	149.1
B1A	16.0	4	8.0	200.0	0.0	32.0	7.0	200.0
B2B	83.3	5	4.8	69.7	0.0	8.0	2.4	149.1
B3	44.7	7	5.1	86.5	0.0	12.0	2.9	105.8
B6B	19.8	3	7.4	108.7	0.0	16.0	4.8	88.5
B7	86.1	3	5.3	86.6	0.0	8.0	5.3	86.6
B9	34.5	5	1.1	223.6	0.0	5.3	1.1	223.6
C1A	31.3	6	7.4	53.0	4.0	12.0	6.7	61.4
C3	32.7	4	14.3	99.4	0.0	33.3	11.5	94.5
C4	26.3	3	13.3	34.6	8.0	16.0	9.3	24.7
C5	37.7	5	6.4	136.9	0.0	16.0	4.8	136.9
C6	23.5	4	11.0	90.9	0.0	24.0	7.0	97.6
C7	36.1	3	17.3	35.3	12.0	24.0	14.7	31.5
CB6A	77.1	6	4.6	130.7	0.0	14.3	4.6	130.7
CB8	26.8	4	17.0	40.2	8.0	24.0	11.0	34.8
CE5A	23.5	5	4.7	107.4	0.0	11.5	2.4	91.3
CE6	30.0	3	5.4	42.0	4.0	8.0	4.1	2.4
CE7A	23.6	3	0.0	-	0.0	0.0	0.0	-
E2	42.8	6	2.0	109.5	0.0	4.0	0.7	244.9
E4	28.0	3	16.0	25.0	12.0	20.0	8.0	50.0
All	838.3	87	7.1	108.8	0.0	33.3	5.1	117.8

2010

Stratum	Area	No. tows	Prev.all	c.v.all	Min	Max	Prev.3+	c.v.3+
B1	114.4	3	8.0	100.0	0.0	16.0	5.3	114.6
B3	44.7	7	9.1	74.6	0.0	20.0	6.9	80.5
C1A	31.3	3	8.0	173.2	0.0	24.0	5.3	173.2
C3	32.7	3	10.7	78.1	4.0	20.0	8.0	132.3
C7	36.1	3	20.0	140.0	0.0	52.0	14.7	150.2
E2	42.8	4	8.7	76.8	0.0	16.0	6.0	66.7
All	301.9	23	10.4	111.8	0.0	52.0	7.5	123.1

2011

Stratum	Area	No. tows	Prev.all	c.v.all	Min	Max	Prev.3+	c.v.3+
B1	114.4	4	16.0	102.1	4.0	40.0	10.0	95.2
B3	44.7	8	9.5	107.8	0.0	24.0	5.0	126.5
B7	86.1	3	0.0	-	0.0	0.0	0.0	-
B9	34.5	3	10.7	86.6	0.0	16.0	10.7	86.6
C1a	31.3	4	3.0	200.0	0.0	12.0	2.0	200.0
C3	32.7	3	8.0	0.0	8.0	8.0	4.0	100.0
C4	26.3	3	6.7	91.7	0.0	12.0	4.0	100.0
C7	36.1	3	13.3	96.4	4.0	28.0	8.0	86.6
CB8	26.8	4	16.0	70.7	0.0	24.0	12.0	86.1
E2	42.8	6	7.3	105.9	0.0	20.0	3.3	118.0
All	475.6	41	9.2	106.1	0.0	40.0	5.8	118.4