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The Foveaux Strait oyster (*Ostrea chilensis*, OYU5) stock assessment survey and status of bonamia infection and mortality, February 2012

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The February 2012 oyster stock assessment and bonamia (*Bonamia exitiosa*) surveys were undertaken to provide population estimates for oysters in three size groups (recruit-sized, pre-recruit, and small oysters) for stock assessment, and to monitor the status of infection and oyster mortality. This survey was a joint programme between the Bluff Oyster Management Company and NIWA, and continues a series of collaborative surveys of the oyster population and bonamia infection. Projections of disease mortality from oysters with category 3 and higher infections will be used to estimate the effects of disease mortality on future stock status during the 2012 OYU5 stock assessment.

A two-phase stratified random sampling design was used with additional target stations sampled to maintain time series data. The survey area and strata were the same as in previous surveys, and sampling and operational procedures were also comparable to previous surveys. Two of the strata were partitioned to reduce the effects of variable catches and large stratum areas. The survey sampled 158 stations (114 first-phase, 32 second-phase, and 12 target stations) for oyster density and bonamia infection using standard Foveaux Strait oyster survey methods. Bonamia samples were taken from 72 stations (60 first-phase and 12 target).

The population of recruit-sized oysters increased from 724.8 million oysters (95% CI 475.6−1081.2) in 2009 to 918.4 million oysters (95% CI 600.1−1383.7) in 2012. The coefficient of variation (c.v.) of 8%, was well below the target c.v. of 20%. Recruit-sized oyster densities were slightly higher in 2012 than in 2009 (0.86 oysters/m^2, compared with 0.68 oysters/m^2). The population size in strata designated as commercial by oyster skippers increased from 361 million (95% CI 227–549) in 2009 to 537 million (95% CI 346−812) in 2012; as did the proportion of the population above 400 oysters per standard tow, 257.2 million oysters (95% CI 129−441 million oysters) in 2009 compared to 473.9 million oysters (95% CI 274−760 million oysters) in 2012.

Coefficients of variation for pre-recruit and small oysters in 2009 and 2012 ranged between 10% and 14%. Population size and oyster density were similar for pre-recruits, 357.9 million oysters (95% CI 232.3−573.4, 0.33 oysters/m^2,) in 2009 and 414.3 million oysters (95% CI 267.8−629.0, 0.39 oysters/m^2) in 2012; and were lower for small oysters, 907.8 million oysters (95% CI 588.7−1366.7, 0.85 oysters/m^2,) in 2009 and 612.2 million oysters (95% CI 370.38−967.9, 0.57 oysters/m^2) respectively.

Bonamia infection was widespread in the fishery and highly variable at small spatial-scales. The numbers of oysters infected increased from 68.5 million oysters in 2009 (9.5% of the recruit-sized population) to 118.7 million in 2012 (12.9% of the recruit-sized population); and those with fatal infections increased from 46.1 million in 2009 (6.3% of the recruit-sized population) to 81.1 million in 2012 (8.8% of the recruit-sized population). These estimates were sensitive to sampling effort. The numbers of infected oysters estimated using data from random bonamia stations only were lower in 2012, 83.2 million (9.1%); and those with fatal infections 56.9 million in 2012 (6.2%).

Total bonamia mortality in 2007, 2009, and 2012 was 8.5%, 8.2%, and 12.0% of the recruit-sized oyster population respectively; 111 million oysters in 2012, of which about 30 million died before the survey (new clocks and gapers) and about 81 million oysters are expected to die post-survey. Fishers observed high localised mortality (up to 70%) of recruit-sized oysters early in the 2012 oyster season. Post-survey mortality (8.8% of the recruit-sized oyster population) in 2012 was higher than for 2007–2011 when mortality was 6.9%, 3.3%, 6.3%, 6.6%, and 6.7% of the recruit-sized population respectively. The numbers of recruit-sized oysters killed between the 2009 and 2012 surveys was about 198 million oysters.

The oyster population has shown the capability to continue to rebuild at levels of post-survey mortality of about 10%; and at this level of mortality the 2009 stock assessment predicted an increase in recruit-sized stock abundance of 11% by 2012. The population size of recruit-sized oysters has increased by 21% between 2009 and 2012. If the estimated post-survey mortality in 2012 (81 million oysters) is taken into account, the population size of recruit-sized oysters increased by 13.5%, consistent with projections of future stock size made during the 2009 stock assessment.

1. INTRODUCTION

1.1 General overview

The Foveaux Strait oyster fishery is a high value, iconic fishery that has been fished for about 140 years. Oysters (*Ostrea chilensis*) are an important customary (taonga), recreational, and commercial species, and important to the socioeconomics of Bluff and Invercargill. Before the recent bonamia (*Bonamia exitiosa*) epizootics began in 1985 (Doonan et al. 1994), the long-term, average landings from the fishery were about 80 million oysters with an annual value about $30 million. This value has fallen to about $10 million due to reduced catch limits. The first of two bonamia epizootics between 1985 and 1992 reduced the oyster population to probably less than 10% of the pre-disease level. In 1993, the fishery was closed to allow the population to rebuild.

The fishery was reopened in 1996 with a reduced catch limit of 15 million oysters to allow the fishery to continue to rebuild, and the catch has remained unchanged since then. Projections from the OYU 5 stock assessment model show that this level of harvest is unlikely to have any effect on future stock levels, and mortality from bonamia will primarily determine future stock size (assuming that recruitment to the fishery remains near the long-term average). The model makes projections of the absolute, recruit-sized oyster population size and does not consider the distribution of oyster density important to commercial catch rates. The recreational and customary fishers 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 stock assessment survey showed an increase in the total population size from 622 million oysters in 2007 to 720 million oysters in 2009, 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 increase was reflected in oyster vessel catch rates (2.1 to 3.3 sacks per hour). This improvement in the status of the fishery prompted BOMC to unshelve 10% of the shelved quota, and the oyster fishery landed 8.22 million oysters in the 2009 oyster season. A further 10% of shelved quota was caught in 2010 when 9.54 million oysters were landed. In 2011, 10.57 million oysters were landed, 9.53 million oysters as part of the regular season and 1.04 million oysters under a special permit for the Rugby World Cup.

As densities of recruit-sized oysters increase, so does the risk of further bonamia outbreaks and disease mortality (as shown by the recurrence of a bonamia epizootic in 2000). Continued rebuilding of the oyster populations is primarily dependent on low levels of oyster mortality from bonamia; less than about 0.1 y^{-1}. Monitoring the status of infection is critical to determining trends in population abundance. Further, time series data are important for modelling the interactions between bonamia infection and oyster mortality, and maintaining regular monitoring is an important source of data for management of the fishery.

1.2 Changes in bonamia infection and oyster abundance since 2000

Mortality from the haplosporidian parasite *B. exitiosa* (bonamia) is the principal driver of oyster population abundance in Foveaux Strait during epizootics. Between 2000 and 2005, widespread mortality from bonamia reduced oyster density to the historically low levels of the early 1990s. Six surveys of the status of bonamia infection and oyster mortality and the status of the oyster population found that mortality 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). A survey of bonamia infection 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 only, based on a categorical scale, see Table 2) had decreased significantly from those in January 2004 (Michael et al. 2005). Few new clocks or gaping oysters (see the methods section for a description) were sampled in January 2005, indicating low mortality before the survey. Based on the small numbers of oysters with fatal (category 3 and higher) infections, little disease mortality was expected over that summer. Bonamia infection was more widespread in the fishery in February 2006 compared with that in January 2005 (Michael et al. 2005). The prevalence of infection was similar; however, the intensity of infection was higher in 2005 than in 2006. The status of infection in February 2007 was similar to that in February 2006. Few oysters sampled for bonamia had detectable infections, but most of the infected oysters had intense infections likely to be fatal. Almost all sample sites with bonamia infections were in eastern fishery areas (east of a line between Bluff Hill and Saddle Point) where oyster densities were already low from disease mortality. In February 2008, central fishery areas showed low prevalence of infection, but eastern areas continued to have relatively high prevalence despite their reduced oyster densities. In February 2009, bonamia infection was widespread and variable; stations with no infection were interspersed with stations with low and high mean intensities of infection. The pattern of infection was similar in 2010, and 2011. Prevalence of bonamia infection was generally low from 2009 to 2011, however, infected stations generally had increasingly higher mean intensities of infection from 2009 to 2011, especially in some central and western fishery areas.

Mean mortality from category 3 and higher 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 February 2010 and 2011 surveys were not stock assessment surveys and estimates of population size are indicative only and should be viewed with caution. Total mortality for the 2010 summer was about 7.3% and in 2011 it was about 10.1%. The 2009 stock assessment gave a median projected status in 2012 ranging from about 30% more than the 2009 level (with no disease mortality) to 23% below the 2009 level (assuming disease mortality of 0.2 y^{-1}). Indicative estimates of population size suggested that the population had increased and based on the numbers of pre-recruits, would continue to increase.

The mean recruit-sized oyster densities increased from 1.2 oysters/m^2 in 2009 to 2.7 oysters/m^2 in 2010; and indicative population size increased from 357 million oysters in 2009 to 809 million oysters in 2010 (c.v. 12%). Pre-recruit and small oysters increased by similar levels (Michael et al. 2011). Observed increases in the densities and populations of recruit-sized, pre-recruit, and small oysters in 2010 suggested that densities and population sizes would continue to increase, increasing the risk of heightened disease mortality in the near future.

1.3 Research objectives

A strategic research plan for Foveaux Strait oysters (OYU 5) revised in 2009 (Michael 2010) recognised bonamia as the main driver of oyster density and distribution, and that oyster mortality from bonamia determined commercial catch rates in the fishery and the number and sizes of commercial fishery areas available to fishers. A key objective of this research plan is to continue to monitor the status of bonamia infection in the oyster population, and from these data make projections of future oyster mortality and the effects of bonamia on future stock status.

Stock assessment surveys have generally been undertaken every two years since 1990. Surveys of the status of bonamia infection have been undertaken concurrently with stock assessment surveys and in the years between biennial assessment surveys since 2000. The February 2011 stock assessment and population survey was deferred until February 2012, in line with the Foveaux Strait Dredge Oyster Fisheries Plan (and with the consensus of the Shellfish Working Group). This survey provided estimates of oyster density and population size for the stock assessment. An updated assessment will give the current status of the fishery and projections of future stock status made from up-to-date estimates of recruit, pre-recruit and small oysters, and of bonamia mortality.

Since 2000, annual surveys have determined “the distribution, prevalence and intensity of infection by *Bonamia exitiosa*”. A time-series of these data has allowed the current epizootic to be tracked through the fishery: spatial and temporal changes in the distribution of mean prevalence and mean intensity of infection, oyster mortality from bonamia, and changes in oyster densities, especially in commercial fishery areas where oyster densities are highest and the effects of disease mortality are greatest. Biennial stock assessments have used different levels of bonamia mortality, typically no mortality, 10%, and 20%, for projections of future stock size.

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) and 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 intensity of infection estimates the proportions of infected oysters with non-fatal and fatal infections (see Section 2.7.1). Estimates of oyster densities allow the status of commercial fishery areas to be determined in the context of disease mortality on localised populations and recruitment.

Biennial stock assessments (Fu & Dunn 2009) provide information on the status of the stock and make projections of future stock status based on expected recruitment, levels of harvest, and projections of oyster mortality, including mortality caused by bonamia. The assumed levels of post-survey disease mortality are based on the proportion of the population with category 3 and higher infections at the time of survey. In years following stock assessments, bonamia surveys provide information on the status of bonamia infection, and estimate the total disease mortality to determine whether it is within the assumed range of mortality used in the stock assessment, and therefore provide confidence in the projections of future stock status. The timing of summer mortality events can vary between years and so the total summer mortality is the pre-survey mortality estimated from new clocks and gapers and the proportion of the population likely to die shortly after the survey based on category 3 and higher bonamia infections combined.

This report documents collaborative stock assessment and bonamia surveys between NIWA and BOMC of the status of the oyster fishery (estimates of oyster population sizes and oyster densities) and the status of bonamia infection in oysters. It in part fulfils the Ministry of Fisheries project OYS2009/01C, objectives 1and 2, milestones 5 and 11.

2. OBJECTIVES

1. To carry out a survey in February 2012 to determine the distribution and population sizes of recruit, pre-recruit and small oysters in the Foveaux Strait oyster (*Ostrea chilensis*) fishery (OYU 5) with sampling primarily in designated commercial fishery areas for 2012. Also to determine the distribution, prevalence, and intensity of infection by *Bonamia exitiosa*, and to estimate total disease mortality over the summer of 2011/2012. These data will be used to update projections from the OYU5 stock assessment model for recruit-sized stock abundance under different catch limits and levels of bonamia mortality.

3. METHODS

3.1 Sampling design

The February 2012 oyster population survey continued a time series of stratified random surveys undertaken in October from 1995 to 2002 (the 1990 multi-vessel survey, and 1992 and 1993 surveys were grid surveys), and in February from 2004 onwards. Since 2002, the surveys have used a standard Foveaux Strait oyster stock assessment survey area (1054 km^2) and core stratification, with an additional area (stratum B1a, 16 km^2) outside this survey boundary introduced by oyster skippers in 2007 (Figure 1). The survey retained strata from previous surveys to provide a time series of oyster density data in commercial fishery areas. In 2012, two of the 2009 strata were split to better define areas of similar oyster densities. Stratum B1 was split into B1b to the west, designated as a background area and B1 to the east, designated as commercial. Stratum B2a was split into B2a to the north, as a background stratum and B2 to the south, as an exploratory stratum (Figure 2).

Stratum designations are reviewed by oyster skippers for each oyster population survey to better define commercial fishery areas. (Figure 1 shows designations for the 2009 survey strata). Stratum designations were updated based on fishers' and survey data and in collaboration and agreement with oyster skippers (Figure 2). Commercial strata were primarily designated from the distributions of recruit-sized and pre-recruit oyster densities from survey data between 2009 and 2011 (Figures 3 and 4), and also designated from the 2010 and 2011 fishers' logbook data. The percentage annual catch by logbook recording grid (one nautical mile squares) was plotted over the survey strata to provide information on commercial and rebuilding fishery areas (Figures 5 and 6). These data do not represent a complete summary of the distribution of oyster densities because fishers preferentially target high-market value oysters, often occurring at lower densities than oysters of lower market value. Exploratory strata were defined from changes in the distribution of pre-recruit sized oysters from survey data between 2009 and 2011 (Figure 4). Background strata were designated as those strata remaining from the 26 strata and not already designated to commercial and exploratory strata. Strata for the 2012 survey and their designations are shown in Table 1 (see Figure 2).

The February 2012 bonamia survey was carried out concurrently with the stock assessment survey, and at a time of year when the prevalence and intensity of infection by bonamia is thought to be near its peak, and the mortality of oysters at its highest. During two-phase, stratified random stock assessment surveys, bonamia was sampled from a subset of randomly chosen first-phase stations only, along with all target stations. More stations were sampled for bonamia infection from commercial fishery areas (with relatively high oyster density), and especially those strata with relatively high prevalence bonamia infection in 2011. Oysters with fatal, category 3 and higher infections (Figure 7) were expected to have died after the 2011 survey. Oysters with category 1 and 2 infections (Figure 8) could progress to fatal infections in 2012, and we therefore allocated proportionately more sample stations to these areas as they may have a higher risk of heightened disease mortality and therefore pose more risk to the stock (and catch rates).

The survey aimed to sample a total of about 145 stations. About 116 random stations (approximately 80%, excluding any stations to be sampled in the recreational area) were allocated to the first-phase (see Figure 2), and we expected to sample about 25 stations (approximately 20%) in the second-phase. Twelve target stations were also to be sampled (see Figure 2). The allocation of stations to strata was based on their designation (estimates of recruit and pre-recruit sized oyster densities), and the size of the stratum area (Table 1). Samples of oysters to determine the status of Bonamia infection were to be collected from about 70 stations.

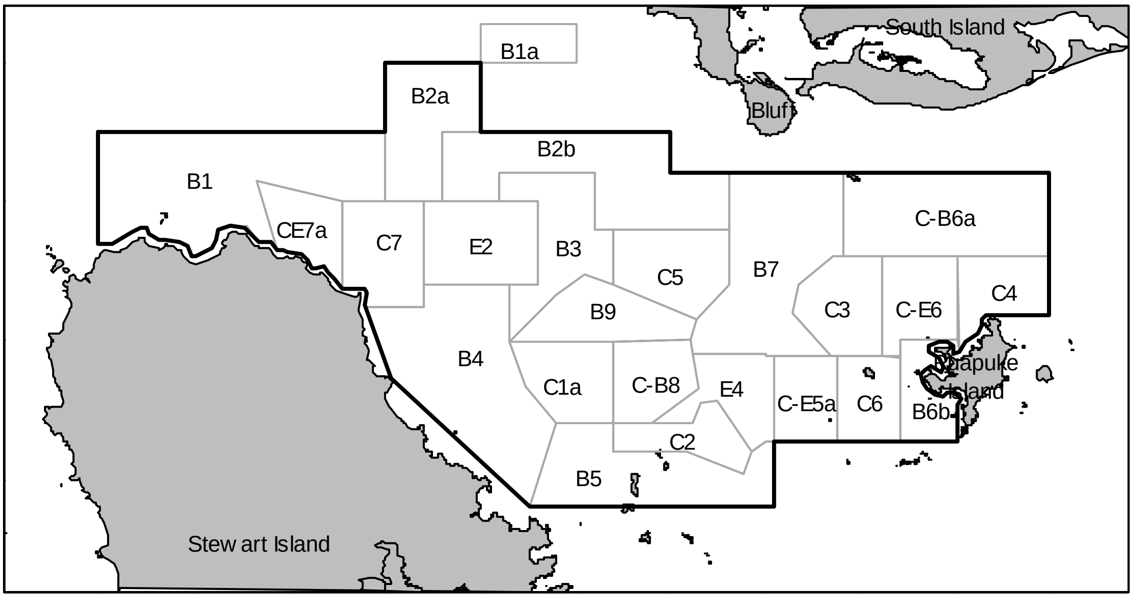

Figure 1: The 2002 survey area (black outer line) and the February 2009 survey strata (grey lines); the 2009 survey stratum designations (black text). Commercial strata designated by oyster skippers in 2011 have a "C" prefix; exploratory strata "E" prefix, and background strata "B".

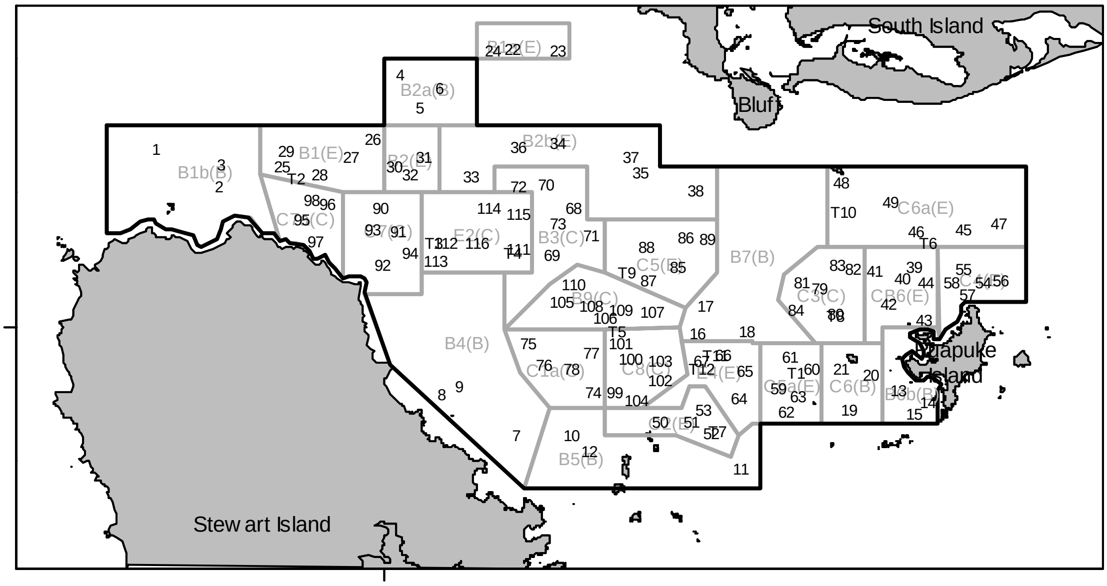

Figure 2: The 2012 survey area (black outer line) and survey strata (grey lines). Commercial strata designated by oyster skippers in 2012 have a "C" suffix; exploratory strata "E" suffix, and background strata "B". First-phase survey stations numbers shown as black text, and target stations have a "T" prefix.

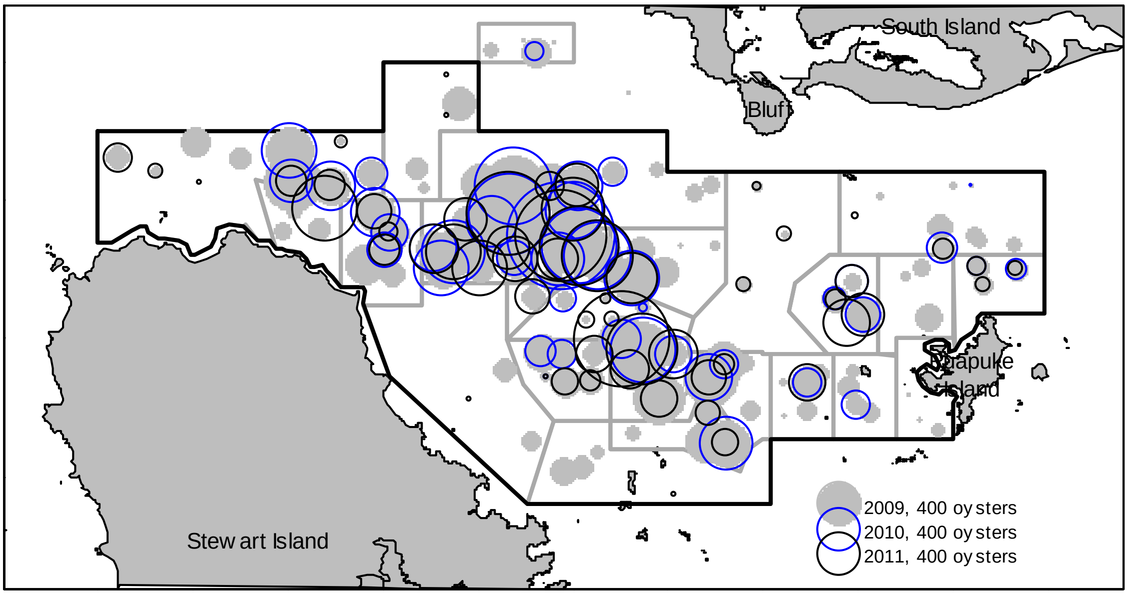

Figure 3: Densities (oysters/m^2) of recruit-sized oysters sampled from all stations during February surveys in 2009 (filled grey circles), 2010 (open blue circles), and 2011 (open black circles).

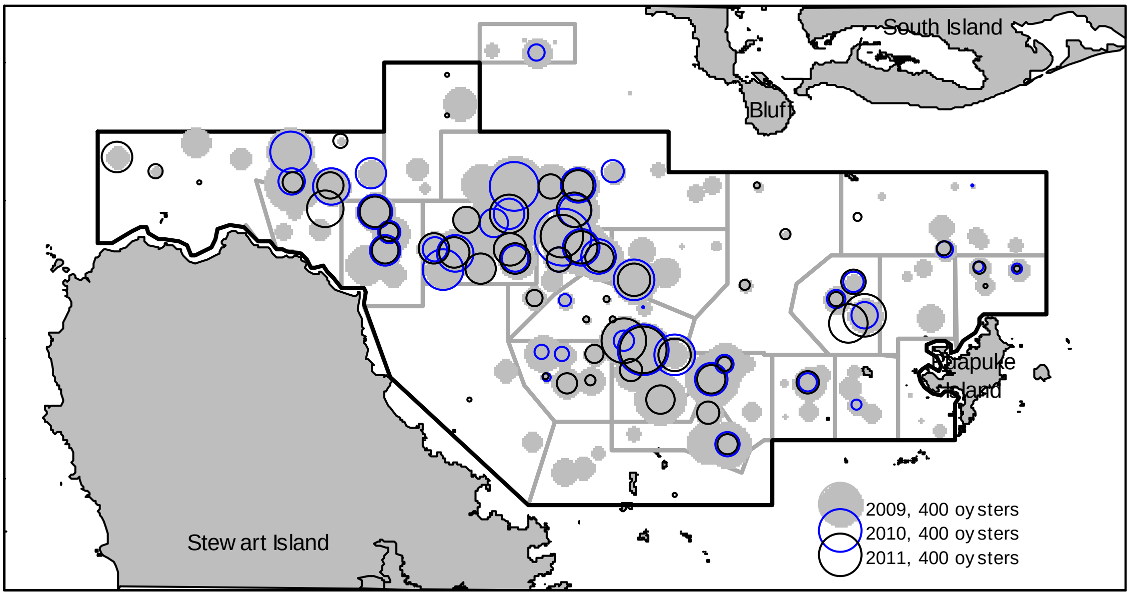

Figure 4: Densities of pre-recruit oysters sampled from all stations during February surveys in 2009 (filled grey circles), 2010 (open blue circles), and 2011 (open black circles).

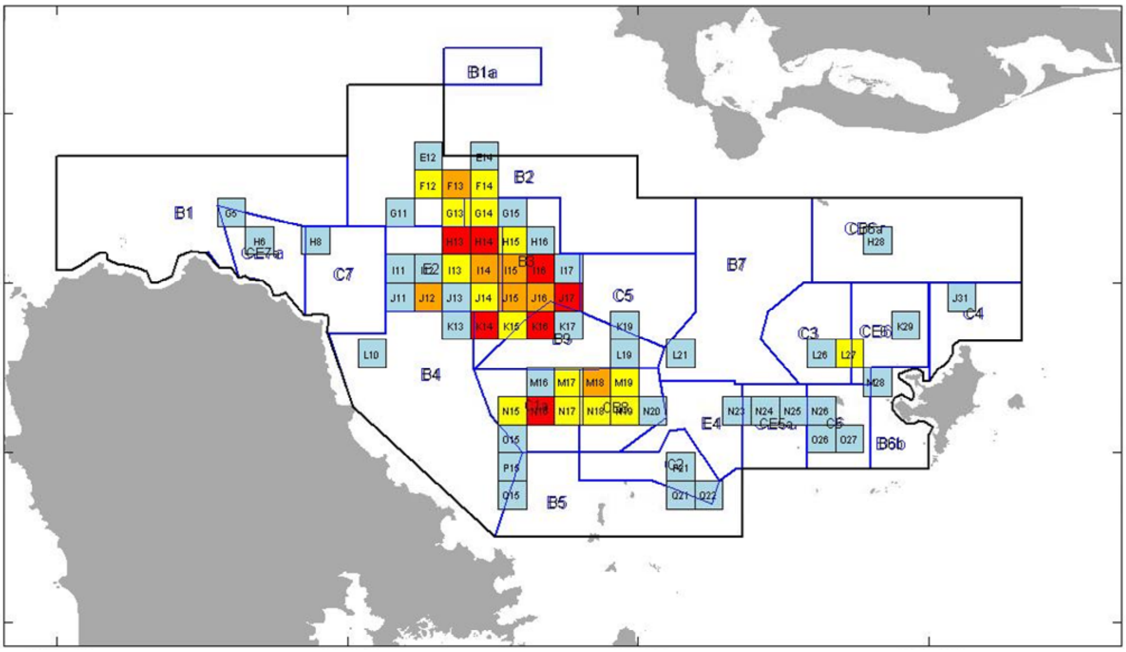

Figure 5: Distribution of catch as a percentage of the total annual catch from each grid in 2010; for commercial and prospecting tows. 5–10% shown in (red), 3–4.9% (orange), 1–2.9% (yellow), and <1% (light blue). Grid cells where no fishing took place are not shown and represented by the white background.

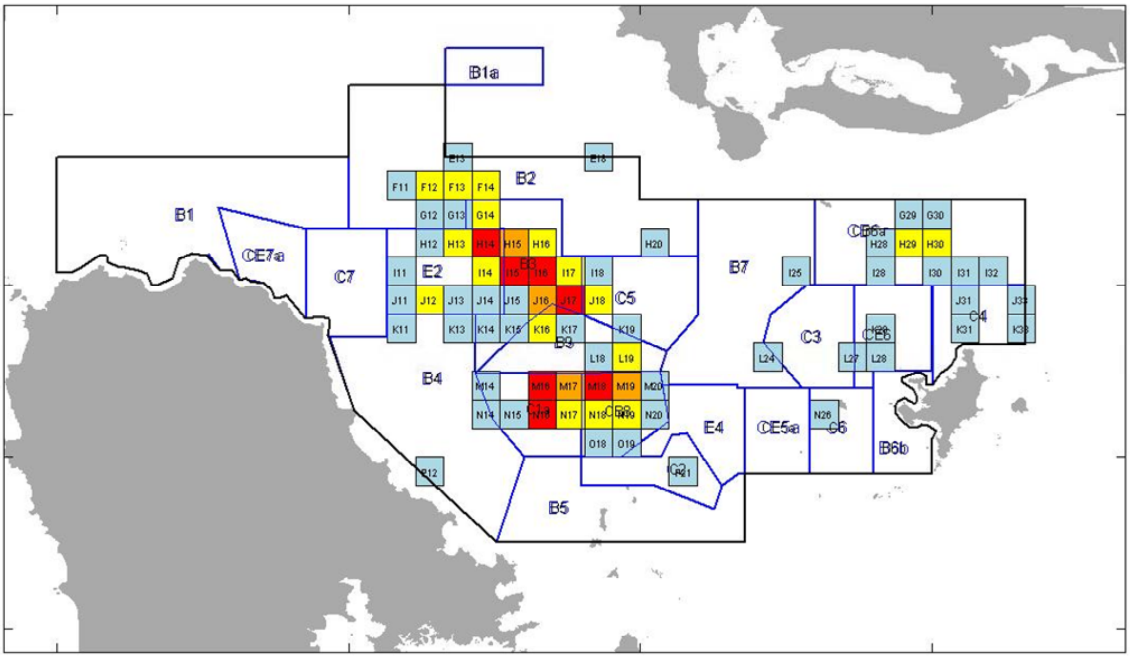

Figure 6: Distribution of catch as a percentage of the total annual catch from each grid in 2011; for commercial and prospecting tows. 5–10% shown in (red), 3–4.9% (orange), 1–2.9% (yellow), and less than 1% (light blue). Grid cells where no fishing took place are not shown and are represented by the white background.

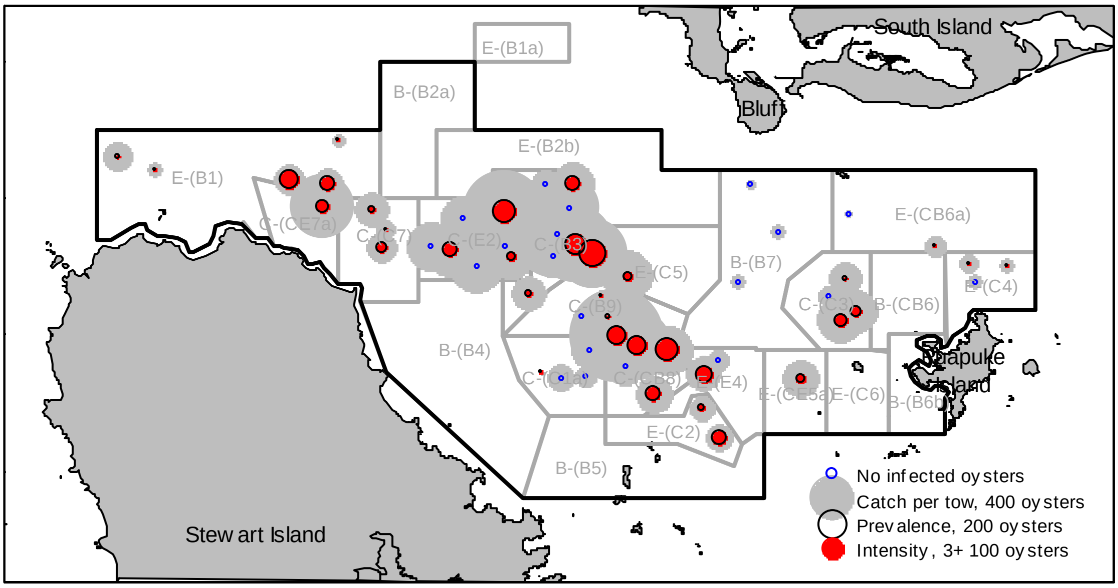

Figure 7: Distributions of oysters and bonamia infection in February 2011 survey. Numbers of oysters (filled grey circles), numbers of oysters with bonamia infection (intensity categories 1–5 combined, open black circles); and fatal infections (intensity categories 3–5 combined, filled red circles). Stations with no bonamia (open blue circles).

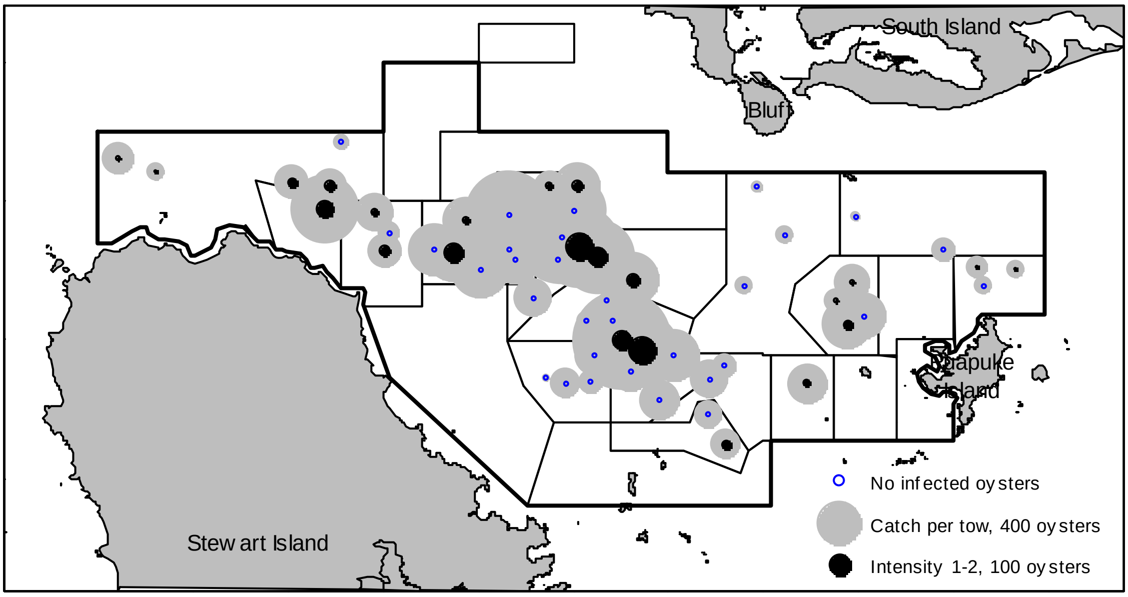

Figure 8: Distribution of recruit-sized oysters (filled grey circles showing numbers per standard tow) and oysters with non-fatal infections (filled black circles, the numbers of oysters scaled to the size of the catch with intensity of infection category 1 and 2) in February 2011. Sites with no bonamia infection are shown by open blue circles.

Table 1: Stratum area, designation (commercial strata "C"; exploratory strata "E", background strata "B"), and numbers of first-phase, bonamia and target stations for the 2012 survey. Mean recruit-sized oyster densities by stratum are shown for 2011 (2011 (oys/m^2) and for 2009 (2009 oys/m^2).

Stratum	Area (km^2)	Designation	First-phase	Bonamia	Target	2011 (oys/m^2)	2009 (oys/m^2)
B1	78.2	B	5	3	1	0.6	0.75
B1a	16.0	E	3	1	0	-	0.29
B1b	36.2	E	3	1	0	0.6	0.75
B2	17.9	E	3	1	0	-	0.21
B2a	29.8	B	3	1	0	-	0.21
B2b	83.3	E	6	3	0	-	0.59
B3	44.7	C	6	3	0	3.8	1.99
B4	98.7	B	3	1	0	-	0.34
B5	63.6	B	3	1	0	-	0.43
B6	30.0	E	6	3	0	-	0.43
B6b	86.1	B	3	1	0	-	0.09
B7	31.3	B	3	1	0	0.2	0.15
C1a	21.9	C	5	3	0	0.7	0.79
C2	32.7	E	4	2	1	-	1.37
C3	26.3	C	6	3	1	1.2	0.85
C4	37.7	E	5	3	0	0.3	0.45
C5	23.5	C	5	3	1	-	0.81
C5a	23.5	E	5	3	1	-	0.36
C6	77.1	B	3	1	0	-	0.37
C6a	19.8	E	5	3	2	-	0.23
C7	36.1	C	5	3	0	1	1.32
C7a	23.6	C	4	3	0	-	0.29
C8	26.8	C	6	3	1	3.2	2.07
C9	34.5	C	6	3	0	0.3	0.17
E2	42.8	C	6	3	2	3.4	1.91
E4	28.0	E	4	2	2	-	1.44
Total	1070.3		116	56	12		
Mean						1.3	0.68

3.2 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 a standard survey dredge (commercial dredge 3.35 m wide and weighing 430 kg). NIWA staff ensured consistency of procedures.

3.3 Navigation

The survey used standalone high-resolution GPS position fixing (Garmin GPS 17-HVS, position fixing within 5 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), and later saved to file to provide a backup.

3.4 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 calculated. This differs to the elliptical tows used by commercial oyster fishers, who fish down tide, then tow 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.

Tows that could not be dredged because of foul ground were replaced with spare sites in the same stratum. Tows were repeated with the same site number when the dredge became tangled or 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).

3.5 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.

New clocks are usually defined in the October surveys, as those shells that have clean inner valves and have retained their lustre without any sign of fouling (fouling organisms are thought to settle over the late spring and summer). In this February survey, new clocks were defined as those that had clean inner valves that had retained their lustre, but may have had some minor speckling of fouling organisms (Figure 9). 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 10 and 11). 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 1 and 3 years previously (Cranfield et al. 1991). The classification of old clocks may vary depending on habitat. Old clocks from sand habitats may be older as they may be filled with sand preventing the settlement of fouling organisms and reducing physical forces on the hinge and 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.

The catch was further sorted into two size groups: recruit (unable to pass through a 58 mm internal diameter ring), and pre-recruits (able to pass through a 58 mm internal diameter ring, but unable to pass through a 50 mm ring). Live oysters were sorted into a third size group, small oysters (able to pass through a 50 mm internal diameter ring and down to 10 mm in length). Reference rings (58 mm and 50 mm internal diameter) were used to ensure accurate allocation to each size group.

Samples of up to 30 randomly selected recruit-sized oysters from each site were collected for heart imprints and histology to estimate levels of bonamia infection. 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.

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

Figure 10: Recent old clock (with hinge intact), glossy inner valve with light fouling.

Figure 11: Old clock with hinge intact. No gloss on inner valve and heavy fouling.

3.6 Processing of samples, heart imprints, and histology protocols

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

Site and sample data were recorded on bonamia sampling forms (Appendix 2), and the total numbers of live and dead oysters in the samples noted. A subsample of up to 25 recruit-sized oysters from each site was taken for heart imprints to estimate the prevalence and intensity of bonamia in oysters. Each oyster in the sample was assigned a unique number from 1 to 25, and assigned a size category using oyster size rings, and oysters were measured for length and height (Figure 12) using callipers, and the measurement truncated to the lower whole millimetre. If samples contained insufficient recruit-sized oysters, pre-recruits were used in preference to small oysters. Recruit-size oysters were denoted with an R, pre-recruit oysters with P, and small oysters with an O. Gaping oysters with valves of the shell apart, but which 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 13) with fine forceps, draining excess water and fluid on filter paper, and lightly dabbing the heart on a slide to deposit a small amount of haemolymph. Three rows of 8 to 10 imprints were made on labelled slides. Slides were placed in slide racks to air dry for at least 5 minutes. The slides were stained with Hemacolor © and oven dried at 60 °C.

Histological samples were taken from the first five oysters processed for heart imprints. A section was taken through the digestive gland (Figure 13) and fixed in a quantity of 10% formalin in seawater equal to at least five times the tissue volume of the sample. Samples of hearts and gills from each of the oysters sampled for heart imprints were stored in alcohol for future DNA analysis. All histology and DNA samples were archived at NIWA.

3.7 Analysis

3.7.1 Analysis of oyster heart imprint data

Examination of heart imprints is at least as sensitive as histology, but whereas histology is time consuming and expensive, heart imprints can be screened rapidly and are comparatively inexpensive. Correlation studies with in-situ hybridisation have shown that the prevalence of bonamia estimated from heart imprints can underestimate the true infection rate by about 30% (Diggles et al. 2003).

The prevalence and intensity of bonamia was 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.

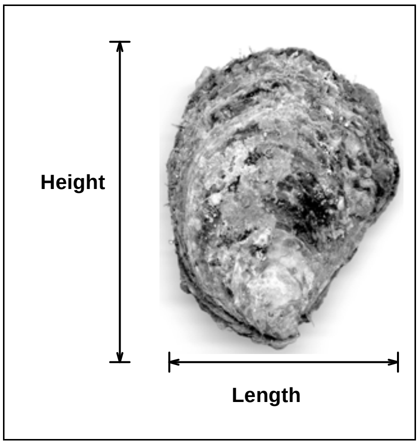

Figure 12: An oyster showing length (anterior-posterior axis) and height (dorsal-ventral axis) dimensions.

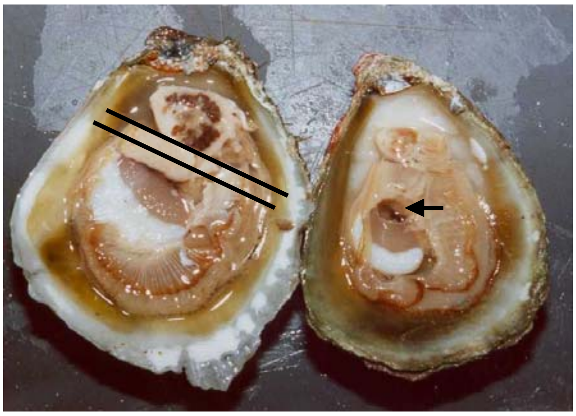

Figure 13: Lines on left oyster show location of 5 mm thick standard section taken for histology. The arrow on the oyster on the right shows the heart, a black organ adjacent to the adductor muscle.

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 stages 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 recruit-sized 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:

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

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

3.7.2 Estimates of oyster density and population size

The February 2012 stock assessment survey used standard sampling procedures that provided estimates of oyster densities that were comparable to previous surveys. Estimates of the total oyster population for live oysters (recruit-sized, pre-recruit, and small oysters), and recruit-sized new and old clocks and gapers used only strata with three or more randomly selected tows sampled in February 2012. No target stations were used to estimate population size. Two estimates of the commercial population were also made. One used estimates of recruit-sized oyster density in designated commercial strata only (B3, C1a, C3, C5, C7, C7a, C8, C9, and E2). The Shellfish Working Group requested estimates of commercial population size (using the standardised catch of recruit-sized oysters at each station minus 400 oysters) for all strata with three or more randomly selected stations. This estimate of commercial population size was used to estimate yield prior to 2004 and continues this historical time series for comparison of the commercial population size and the distribution of high oyster density important to catch rates in the oyster fishery.

Estimates of absolute abundance and variance from stratified random sampling theory (Jolly & Hampton 1990) assumed a mean dredge efficiency, re-estimated from the 1990 data, of 0.17 (95% confidence intervals 0.13–0.22).

The estimates of population size for recruit-sized, pre-recruits, and small oysters are presented separately. The absolute population size of each size group of oysters was estimated using the combined population sizes in each stratum:

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

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*. Estimates of population sizes are also presented by stratum separately.

The coefficient of variation (c.v.) for each stratum is calculated from the standard deviation and mean oyster density alone, and the same calculation is used for the total survey area:

$$s(\bar{x}) = \left(\sum W_i^2 s(\bar{x}_i)^2\right)^{1/2}$$

where $s(\bar{x})$ is the standard deviation for the estimated population size and $s(\bar{x}_i)$ is the standard deviation for the mean density in stratum *i*.

The 95% confidence intervals of the population means are estimated by bootstrapping using the variance of the population size and the error of the estimated dredge efficiency (Cranfield et al. 1999), both were assumed to be normally distributed. Only the error in the relative population size is required when we compare population estimates between dredge surveys as the error in dredge efficiency cancels out.

3.7.3 Patterns of recruitment

Recruitment to the fishery was investigated from changes in the population estimates of pre-recruit and small oysters, and from changes in the patterns of distribution of small oyster densities, between the February 2009 and February 2012 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 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 numbers of small oysters per recruit-sized oyster were estimated to investigate trends in recruitment between 2009 and 2012.

3.7.4 Population estimates of bonamia infection

We used bonamia infection data from strata with three or more randomly selected stations only i.e., we did not include target stations. 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. Stations with no bonamia samples (second-phase stations in 2012) were excluded from the estimates of population prevalence and intensity (rather than assuming 0), but oyster numbers sampled there were included for estimating the population size of each stratum and the total population. 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. Variance for prevalence and intensity was estimated using standard methods as for population estimates.

3.7.5 Estimates of mortality

Total summer mortality is the sum of pre-survey mortality estimated from new clocks and gapers; and projections of post-survey mortality from the proportion of the population with category 3 and higher bonamia infections. Pre-survey mortality for the oyster population was estimated as the total, scaled numbers of recruit-sized new clocks and gapers.

The catchability (dredge efficiency) and persistence at the location of death varies spatially for new clocks, and their classification as new (from old clocks with fouling organisms on the inner shells) can be difficult. 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, therefore 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 is lost and this is used to separate new and old clocks, and reduce misidentification.

Bonamia studies (Diggles et al. 2003) suggest that category 3 bonamia infections are elevated and systemic, and assumed to quickly progress to category 4 and 5 infections, quickly leading to death (soon after the survey). The mean proportion of oysters with category 3−5 infections in each stratum is used as a correction factor, i.e. 1 - mean proportion of category 3−5 infections. Population estimates for each stratum and the total survey area are recalculated to account for the projected mortality. Total projected mortality is the difference between the total population size at the time of survey and the population corrected for projected bonamia mortality (at the end of summer).

As a stock assessment survey was undertaken this year, only projections of oysters expected to die post-survey from category 3 and higher infections will be used to infer the most likely trajectory of the future status of the recruited stock.

4. RESULTS

4.1 Survey operational detail

The oyster vessel F V *Golden Quest* skippered by Stephen Hawke, her crew, and two NIWA staff, successfully sampled 115 first phase-stations (station 50 couldn't be sampled because of foul ground), 31 second-phase stations, and 12 target stations. One bonamia station (50) couldn't be sampled and the bonamia sample was instead taken from station 52. Sampling began on the 5th of February 2012 and was completed on the 21st of February, sampling on 10 days over this period. The first-phase was completed in eight full days and the second-phase was completed in two days after a break of 7 days to complete other oyster research. Survey tows completed are shown in Figure 14, and the numbers of first-phase, second phase, and target stations sampled in each stratum are shown in Table 3.

Samples of up to 30 oysters were collected from all stations to determine the status of bonamia infection. Samples of oysters were also collected for Victoria University studies. Oyster samples were couriered to NIWA, Greta Point (Wellington) where they were processed for heart imprints. Oyster tissues were also taken for histology and for DNA studies; and these were archived for future research.

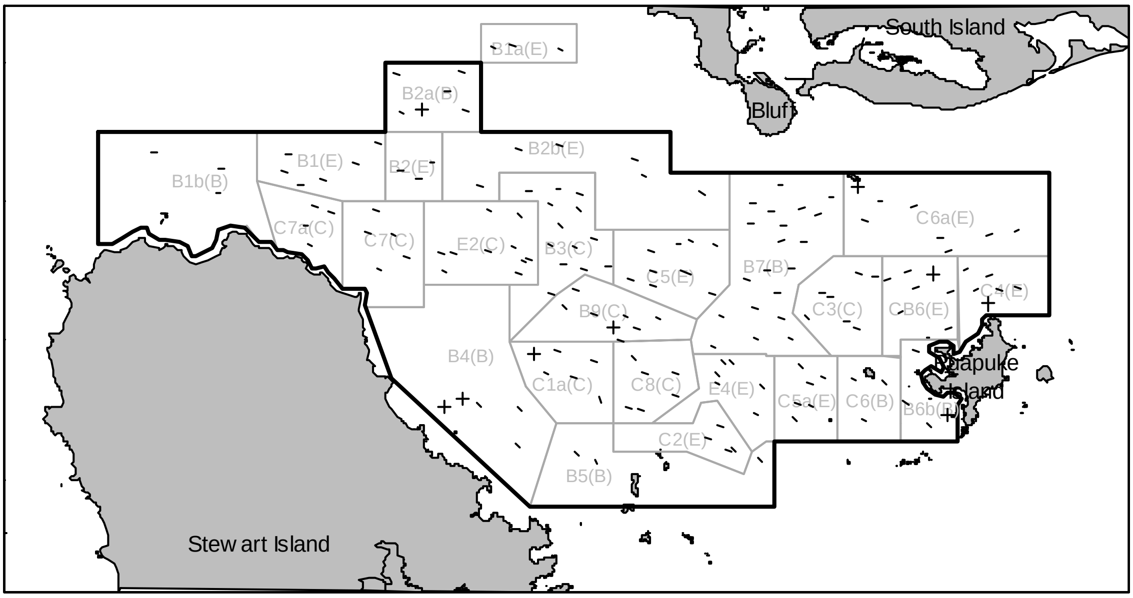

Figure 14: The survey tows (black lines) sampled in February 2012 to estimate oyster density and determine the status of bonamia infection and oyster density. Stations that could not be dredged because of foul ground are shown as crosses. The 2002 survey area is bound by the outer black line and the February 2012 survey strata are bound by the grey lines; stratum B1a was added to the survey area in 1997. The 2012 survey stratum designations are shown in brackets. Commercial strata designated by oyster skippers in 2012 have a "C" prefix; exploratory strata have an "E" prefix, and background strata have a "B" prefix.

Table 3: The numbers of random first-phase and second-phase stations, and the numbers of target stations by stratum, sampled in February 2012 survey.

Stratum	First-phase	Second-phase	Target stations	Total
B1	5	0	1	6
B1a	3	0	0	3
B1b	3	0	0	3
B2	3	0	0	3
B2a	3	2	0	5
B2b	6	0	0	6
B3	6	7	0	13
B4	3	0	0	3
B5	3	0	0	3
B6	6	0	0	6
B6b	3	0	0	3
B7	3	17	0	20
C1a	5	0	0	5
C2	3	0	1	4
C3	6	0	1	7
C4	5	0	0	5
C5	5	3	1	9
C5a	5	0	1	6
C6	3	0	0	3
C6a	5	0	2	7
C7	5	0	0	5
C7a	4	0	0	4
C8	6	0	1	7
C9	6	0	0	6
E2	6	2	2	10
E4	4	0	2	6
Total	115	31	12	158

4.1.1 Survey comparability

Dredge tow lengths were closely clustered around the 0.2 nautical mile (370 m) standard tow length (Figure 15). 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, 87% of tows in less than 10 knots, 97% less than 15 knots, and all stations in less than 20 knots (Figure 16). The median wind force was 1 on the Beaufort scale (1–2 knots), with 5 and 95 percentiles of Beaufort scale 0 (less than 1 knot) and 2 (3–6 knots) respectively. These wind and resulting sea conditions were lighter than sampling conditions on previous surveys and on average dredge efficiency is likely to be similar or slightly higher than in previous years.

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 and 14 dredge tows 70% full. Dredge fullness ranged from 1 to 80% with a median fullness of 30% (95% CI 2−70%), suggesting that dredge saturation may not have had a large effect on sampling effectiveness and the survey (Figure 17). 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 70% dredge fullness.

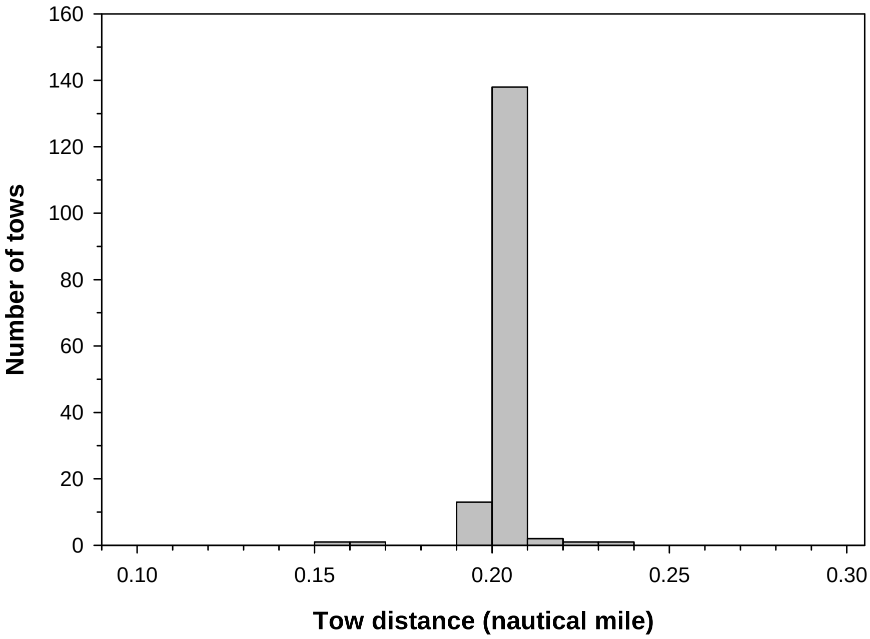

Figure 15: Distribution of tow lengths from the February 2012 survey. The standard tow length was 0.2 nautical mile (370 m).

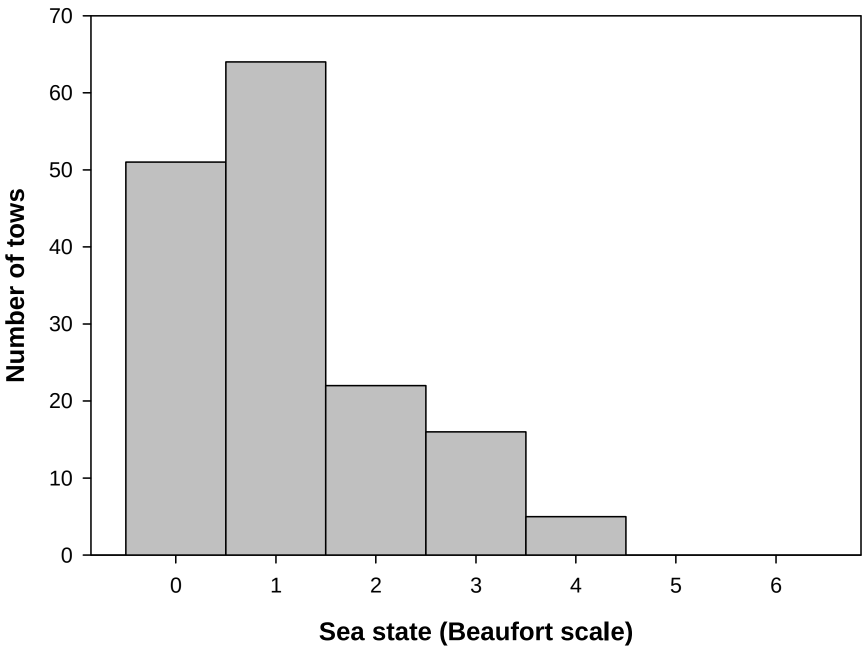

Figure 16: Distribution of sea state (Beaufort scale) recorded during survey tows in February 2012. Beaufort scale: 0, less than 1 knot; 1, 1−2 knots; 2, 3−6 knots; 3, 7−10 knots; 4, 11−15 knots; 5, 16−20 knots; and 6, 21−26 knots.

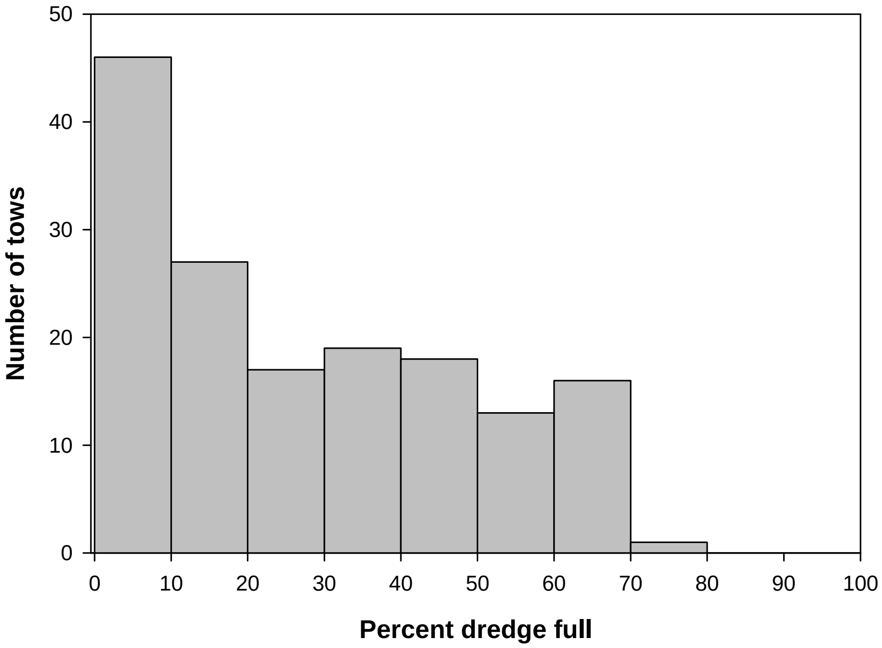

Figure 17: Distribution of dredge fullness recorded for survey tows in February 2012. One of the tows was landed with a dredge fullness of greater than 70%, suggesting that it may have saturated before the end of the tow leading to an underestimate of oyster density. It is likely from video data that dredge saturation may occur below 70% full.

4.2 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 numbers of gapers were low. These observations suggest detectable levels of bonamia mortality before the February 2012 survey.

Growth and recruitment to the commercial oyster populations has been variable between 2009 and 2012. Increases in recruit-sized 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 and 2012 surveys suggest there has been little increase in recruit-sized oyster density or recruitment to commercial populations over the summers of 2010/2011 and 2011/2012, possibly due to a combination of increased mortality and slower growth through to commercial sized oysters (recruitment to commercial population). Dredge catches in the western, central, and southern fishery areas had relatively high recruit-sized oyster densities compared with 2009. Recruit-sized oyster densities in eastern areas are increasing slowly, but are still generally low in the far eastern fishery areas.

With the exception of a couple of surveys tows, catches of small oysters continue to decline, even in eastern fishery area where a majority of oysters usually had spat and wings (small oysters) attached.

4.3 Changes in oyster densities between 2009 and 2012

More random stations were sampled in 2012 (N=147) than in 2009 (N=116), especially in background stratum B7 (N=20). Boxplots of oyster density from all random stations sampled (Figure 18, left panel) show similar densities for recruit and pre-recruit oysters for 2009 and 2012, but there are more stations with high catches in 2012, and fewer small oysters in 2012 compared with 2009 (Figure 18). Boxplots of oyster density from commercial strata only (Figure 18, right panel) show higher densities for recruit, similar densities for pre-recruit oysters, with a larger number of stations with high catches in 2012, and fewer small oysters in 2012 (Figure 18).

Changes in mean oyster density (oysters per m^2) for recruit, pre-recruit, and small sized oysters from all strata sampled between 2009 and 2012 show similar trends to standardised tows (Figure 19). Recruit-sized oyster densities in 2012 are similar or higher than 2009, especially in commercial strata. Pre-recruit sized oyster densities have remained similar in commercial strata and in exploratory and background strata combined. Small-sized oyster densities have mostly remained similar or declined with no differences between strata categories (Figure 19), only stratum C7a showed a marked increase in oyster density.

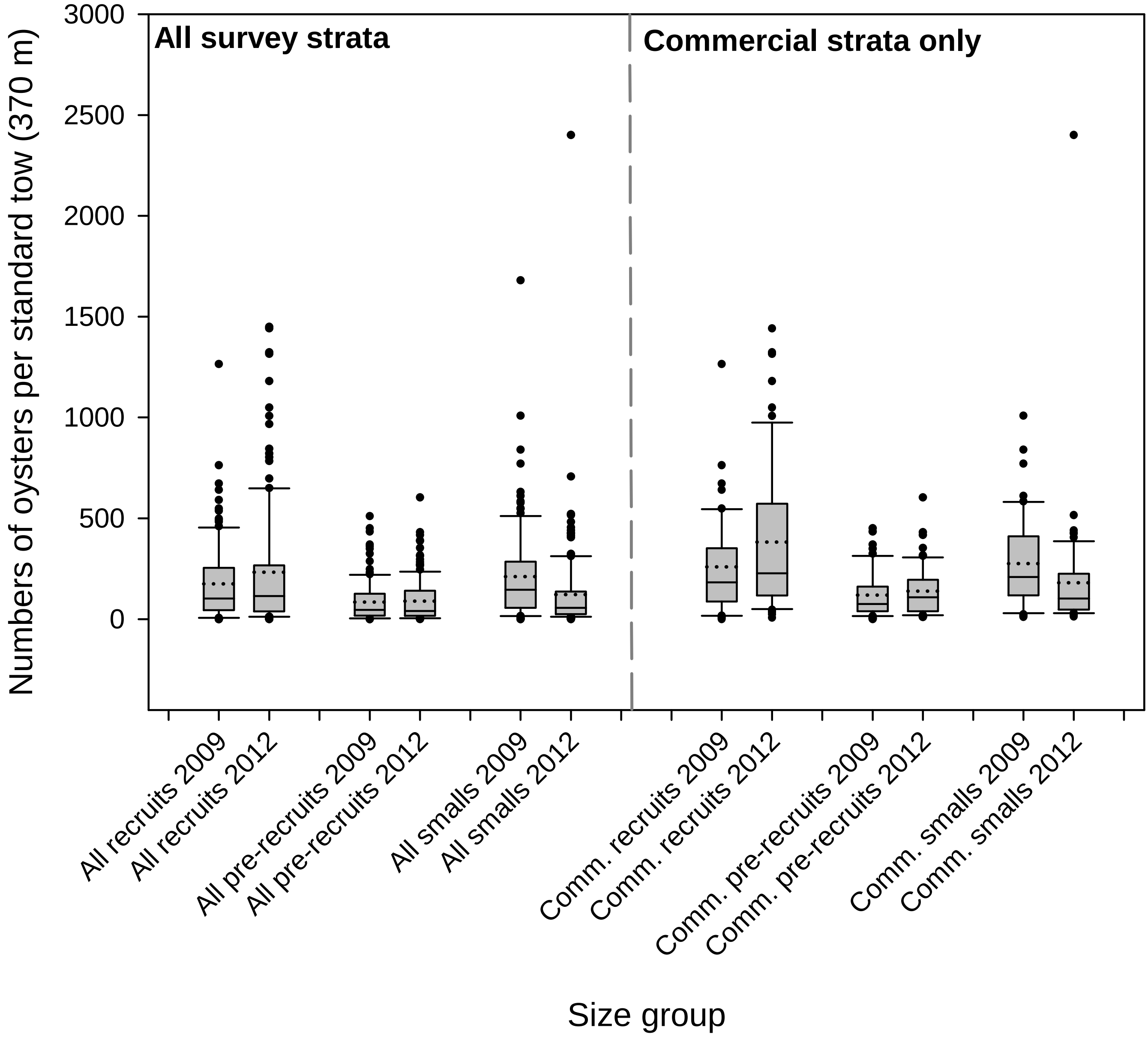

Figure 18: Boxplots of standardised numbers of oysters per tow for recruit, pre-recruit, and small sized oysters, from all strata sampled in 2009 survey (N=116) and 2012 survey (N=147) on the left; and from commercial strata only (N=52) and 2012 survey (N=61) on the right. Medians shown as solid lines, means as dotted lines, boxes represent 50 percentiles and whiskers 75 percentiles, and outliers as filled circles.

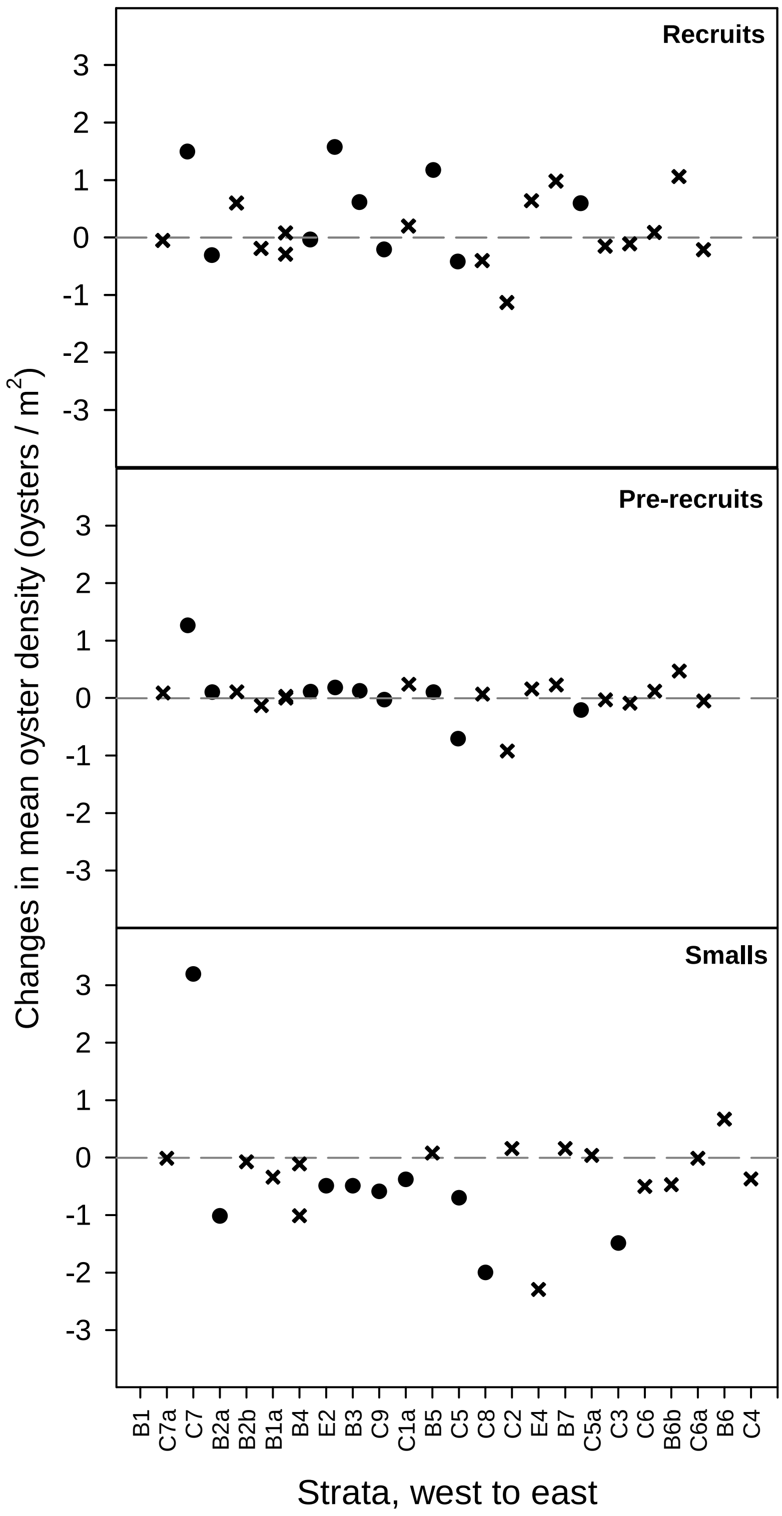

Figure 19: Changes in mean oyster density (oysters per m^2) for recruit, pre-recruit, and small sized oysters, from all strata sampled between 2009 and 2012 survey. Changes in mean oyster densities for strata designated as commercial in 2012 shown as filled circles, and for those designated as exploratory and background strata are shown as crosses. Strata are shown form west to east on the x axis.

4.4 Survey estimates of population size

Survey estimates of population size for recruit, pre-recruit, and small oysters from the February 2012 survey by strata are shown in Tables 4–6. Table 7 compares survey estimates for recruit, pre-recruit, and small oysters from population surveys between 1999 and 2012 within the 1999 survey area only (excludes stratum B1a).

In February 2012, the central fishery areas (strata B3, C5, and E2) that had sustained the most fishing over the last three years had the highest densities of recruit-sized oysters (1.9–3.6 oysters/m^2) followed closely by western (C7a, 1.8 oysters/m^2), southern (C8, 1.7 oysters/m^2), and eastern strata (C3, 1.4 oysters/m^2) (Table 4). The central area strata B3, E2, and C5 also had the highest population sizes 158.9, 80.3, and 74.5 million oysters respectively. Some eastern fishery areas are showing signs of rebuilding; stratum C3 had a population size of 47.1 million oysters. Some strata such as B7 and B1 also had high population sizes (69.9 and 5.6 million oysters respectively) as a result of their large stratum areas (86.1 km^2 and 73.2 km^2 respectively).

Pre-recruit oyster densities (Table 5) are lower than for recruit-sized oysters and the highest pre-recruit densities were recorded in central and western areas, strata C7a, B3, C7, and E2 with (0.8−1.4 oysters/m^2). The western fishery area (stratum B1) had the highest pre-recruit population at 46.6 million oysters as a result of its large stratum area, and central and western areas C7a, B3, C7, and E2 also had high population sizes between 31.6 and 41.8 million oysters. Strata in eastern fishery areas (C3, C4, and B6) that have historically had good recruitment and large numbers of small oysters had relatively lower densities.

The highest densities and population sizes of small oysters (Table 6) were in western fishery areas (strata C7a, 4.0 oysters/m^2; C7, B1b, B1, and E2, 1.1−1.4 oysters/m^2), and a southern stratum C2, 1.4 oysters/m^2. Population sizes ranged between 30.3 million and 95.5 million oysters in these strata. Mean densities for recruit-sized, pre-recruit and small oysters were 0.9, 0.4, and 0.6 oysters/m^2 respectively in 2012, higher than in 2011 0.7, 0.3, and 0.9 oysters/m^2 respectively, even though more sampling was carried out in exploratory and background strata that would be expected to lower mean oyster densities for the survey area (Table 6).

The estimates of mean population size of recruit-sized oysters in the 1999 survey area has continually increased from 408 million oysters in January 2005 to 913 million oysters in February 2012 (Table 7). Mean oyster density for this survey area also increased from 0.39 oysters/m^2 to 0.87 oysters/m^2 over the same period. Although pre-recruit oysters increased from 414 million oysters in 2005 to 463 million in 2007, the population declined to 410 million oysters in 2012. Pre-recruit oyster densities were similar in 2005 and in 2012, 0.39 oysters/m^2. Small oysters decreased from 1 344 million in 2005 oysters to 607 million in 2012 (Table 7), and mean small oyster density from 1.28 oysters/m^2 to 0.58 oysters/m^2 in 2012. The low numbers of pre-recruit and small oysters is thought to represent temporal lags from low recruit-sized oyster numbers around 2005, and suggests continued reduced larval retention or spawning, reduced settlement and or survival of oyster spat. Populations of recruit-sized oysters have increased from 2005, but pre-recruit and small oysters have either remained about the same or declined (Figure 20). Although the increase in the recruit-sized oyster population from the low point in 2005 is similar to the level of rebuilding between 1993 and 1997, future levels of rebuilding may be slower than 1997 to 2001. The numbers of pre-recruits and small oysters are lower, and bonamia mortality is present in the fishery at low levels (there was no heightened mortality apparent between 1997 and 2001).

Table 4: Absolute population estimates for recruit-sized oysters: the number of stations sampled (No. stations), the mean oyster density per m^2 (Mean density), standard deviation (s.d.) of the density estimate, coefficient of variation (c.v.) of the density estimate, mean population size in millions of oysters (Mean population), upper and lower 95% confidence intervals (CI), and the area of each stratum (Area), by stratum for the February 2012 Foveaux Strait oyster survey.

Stratum	No. stations	Mean Density	Density s.d.	c.v.	Mean Population	Lower 95% CI	Upper 95% CI	Area (km^2)
B1	5	0.70	0.24	0.34	54.6	17.3	103.2	78.2
B1a*	3	0.37	0.21	0.58	5.9	0.0	13.7	16.0
B1b	3	0.21	0.21	0.99	7.7	0.0	24.3	36.2
B2	3	0.43	0.14	0.33	7.7	2.6	14.6	17.9
B2a	5	0.81	0.61	0.75	24.1	0.0	64.4	29.8
B2b	6	0.40	0.20	0.49	33.7	1.5	73.0	83.3
B3	13	3.56	0.70	0.20	158.9	85.3	263.7	44.7
B4	3	0.05	0.03	0.67	4.5	0.0	11.3	98.7
B5	3	0.63	0.31	0.49	39.9	1.9	86.5	63.6
B6	6	1.15	0.50	0.44	34.4	4.5	71.0	30.0
B6b	3	0.04	0.02	0.45	0.8	0.1	1.7	19.8
B7	20	0.81	0.36	0.44	69.9	8.9	146.4	86.1
C1a	5	0.58	0.23	0.39	18.2	4.0	36.6	31.3
C2	3	0.97	0.16	0.17	21.2	12.3	34.1	21.9
C3	6	1.44	0.41	0.29	47.1	19.5	85.3	32.7
C4	5	0.24	0.06	0.23	6.3	3.1	10.7	26.3
C5	8	1.98	0.53	0.27	74.5	31.9	131.2	37.7
C5a	5	1.34	0.86	0.64	31.6	0.0	79.9	23.5
C6	3	0.22	0.15	0.69	5.3	0.0	13.5	23.5
C6a	5	0.32	0.06	0.20	24.7	13.4	40.5	77.1
C7	5	1.01	0.18	0.18	36.4	20.2	59.1	36.1
C7a	4	1.78	0.76	0.43	42.0	6.9	86.8	23.6
C8	6	1.65	0.64	0.39	44.3	9.7	88.0	26.8
C9	6	1.04	0.49	0.47	35.8	2.1	76.9	34.5
E2	8	1.87	0.49	0.26	80.3	35.5	142.0	42.8
E4	4	0.31	0.22	0.70	8.8	0.0	22.7	28.0
All	146	0.86	0.07	0.08	918.4	600.1	1383.7	1070.3

* Stratum B1A is outside the boundaries of the 1999 survey area and has been sampled only in the 2006, 2007, and 2009 surveys.

Table 5: Absolute population estimates for pre-recruit oysters: the number of stations sampled (No. stations), the mean oyster density per m^2 (Mean density), standard deviation (s.d.) of the density estimate, coefficient of variation (c.v.) of the density estimate, mean population size in millions of oysters (Mean population), upper and lower 95% confidence intervals (CI), and the area of each stratum (Area), by stratum for the February 2012 Foveaux Strait oyster survey.

Stratum	No. stations	Mean density	Density s.d.	c.v.	Mean population	Lower 95% CI	Upper 95% CI	Area (km^2)
B1	5	0.60	0.21	0.35	46.6	14.0	89.0	78.2
B1a*	3	0.26	0.19	0.76	4.1	0.0	11.0	16.0
B1b	3	0.48	0.48	1.00	17.5	0.0	55.8	36.2
B2	3	0.15	0.05	0.34	2.8	0.9	5.3	17.9
B2a	5	0.21	0.13	0.61	6.3	0.0	15.2	29.8
B2b	6	0.12	0.04	0.31	10.3	3.7	19.0	83.3
B3	13	0.94	0.14	0.15	41.8	24.8	66.5	44.7
B4	3	0.11	0.07	0.65	11.0	0.0	27.3	98.7
B5	3	0.38	0.24	0.65	23.9	0.0	59.5	63.6
B6	6	0.52	0.29	0.55	15.5	0.0	35.5	30.0
B6b	3	0.02	0.00	0.00	0.4	0.3	0.6	19.8
B7	20	0.21	0.09	0.45	18.2	2.2	38.2	86.1
C1a	5	0.19	0.05	0.26	6.0	2.6	10.6	31.3
C2	3	0.65	0.20	0.31	14.3	5.4	26.5	21.9
C3	6	0.53	0.16	0.29	17.5	7.1	31.9	32.7
C4	5	0.15	0.05	0.35	3.9	1.2	7.6	26.3
C5	8	0.58	0.13	0.22	21.8	11.0	36.5	37.7
C5a	5	0.36	0.24	0.67	8.4	0.0	21.7	23.5
C6	3	0.08	0.05	0.65	1.8	0.0	4.5	23.5
C6a	5	0.21	0.07	0.33	16.5	5.5	31.0	77.1
C7	5	0.87	0.15	0.17	31.6	17.7	51.1	36.1
C7a	4	1.39	0.52	0.37	32.9	8.8	64.6	23.6
C8	6	0.51	0.13	0.26	13.7	6.0	24.1	26.8
C9	6	0.26	0.10	0.40	9.0	1.8	18.1	34.5
E2	8	0.85	0.31	0.37	36.2	9.3	71.3	42.8
E4	4	0.08	0.04	0.54	2.1	0.0	4.9	28.0
All	146	0.39	0.04	0.10	414.3	267.8	629.0	1070.3

* Stratum B1A is outside the boundaries of the 1999 survey area and has been sampled only in the 2006, 2007, and 2009 surveys.

Table 6: Absolute population estimates for small oysters: the number of stations sampled (No. stations), the mean oyster density per m^2 (Mean density), standard deviation (s.d.) of the density estimate, coefficient of variation (c.v.) of the density estimate, mean population size in millions of oysters (Mean population), upper and lower 95% confidence intervals (CI), and the area of each stratum (Area), by stratum for the February 2012 Foveaux Strait oyster survey.

Stratum	No. stations	Mean density	Density s.d.	c.v.	Mean population	Lower 95% CI	Upper 95% CI	Area (km^2)
B1	5	1.13	0.40	0.36	88.0	24.2	169.9	78.2
B1a*	3	0.35	0.24	0.70	5.5	0.0	14.3	16.0
B1b	3	1.16	1.15	0.99	42.0	0.0	133.3	36.2
B2	3	0.20	0.06	0.28	3.6	1.5	6.5	17.9
B2a	5	0.20	0.07	0.37	5.9	1.6	11.4	29.8
B2b	6	0.16	0.06	0.41	13.1	2.5	26.5	83.3
B3	13	0.73	0.12	0.17	32.8	18.8	53.1	44.7
B4	3	0.20	0.11	0.57	19.5	0.0	45.3	98.7
B5	3	0.42	0.22	0.53	26.6	0.0	59.8	63.6
B6	6	0.74	0.34	0.45	22.1	2.1	46.4	30.0
B6b	3	0.01	0.01	0.62	0.2	0.0	0.5	19.8
B7	20	0.27	0.10	0.36	23.6	6.8	45.6	86.1
C1a	5	0.32	0.07	0.24	9.8	4.7	16.9	31.3
C2	3	1.38	0.58	0.42	30.4	5.6	62.9	21.9
C3	6	0.49	0.16	0.32	16.1	5.8	30.0	32.7
C4	5	0.12	0.03	0.23	3.2	1.6	5.4	26.3
C5	8	0.55	0.12	0.22	20.9	10.6	35.0	37.7
C5a	5	0.52	0.28	0.53	12.2	0.0	28.2	23.5
C6	3	0.10	0.04	0.40	2.4	0.5	4.8	23.5
C6a	5	0.20	0.06	0.30	15.3	6.0	27.7	77.1
C7	5	1.36	0.29	0.21	49.2	25.4	82.6	36.1
C7a	4	4.04	2.56	0.63	95.5	0.0	235.4	23.6
C8	6	0.43	0.12	0.27	11.7	5.0	20.6	26.8
C9	6	0.30	0.09	0.30	10.3	3.8	18.9	34.5
E2	8	1.11	0.36	0.33	47.5	15.8	89.7	42.8
E4	4	0.18	0.08	0.46	4.9	0.4	10.4	28.0
All	146	0.57	0.08	0.14	612.2	370.3	967.9	1070.3

* Stratum B1A is outside the boundaries of the 1999 survey area and has been sampled only in 2006, 2007, and 2009 surveys.

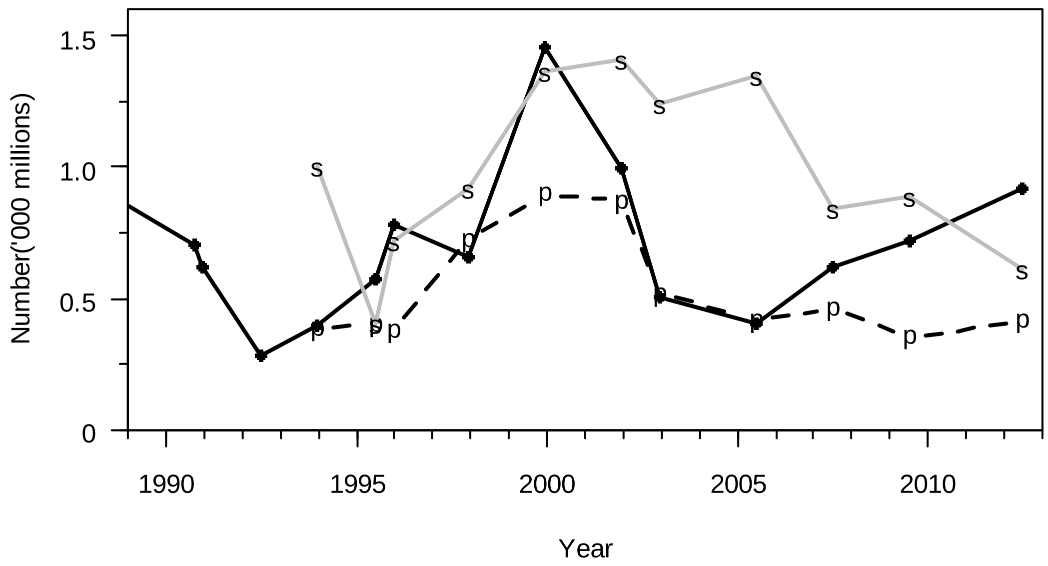

Figure 20: Estimates of mean population size (millions of oysters) for recruit-sized, pre-recruit, and small oysters 1990–2012.

Table 7: Absolute population estimates for recruit-sized, pre-recruit, and small oysters 1999–2012; mean population size (millions of oysters) with upper and lower 95% confidence intervals in parenthesis. Estimates exclude stratum B1A.

Survey		Recruits		Pre-recruits		Small
1999 (October)	1461	(872–2334)	899	(570–1387)	1373	(874–2115)
2001 (October)	995	(632–1511	871	(548–1330	1410	(884–2156)
2002 (October)	502	(310–785)	520	(333–795)	1243	(806–1884)
2005 (January)	408	(253–628)	414	(247–652)	1344	(845–2056
2007 (February)	622	(398–947)	463	(293–708)	842	(546–1273)
2009 (February)	720	(470–1085)	354	(228–538)	889	(574–1351)
2012 (February)	913	(603–1376)	410	(268–623)	607	(369–952)

4.4.1 Survey estimates of the commercial population size

Estimates for recruit-sized oysters in designated commercial fishery areas (strata E2, C9, C8 , 7a, C7, C5, C3, C1a, and B3) between 1999 and 2012 are compared in Table 8. Oyster densities in 2012 ranged from 0.6–3.6 oysters/m^2 compared with 0.4–0.7 oysters/m^2 in 2009. The mean density over all designated commercial fishery areas in February 2012 was 1.7 oysters/m^2, higher than in 2009 (1.0 oysters/m^2), and in 2007 (0.5 oysters/m^2), which was similar to most exploratory and background areas at that time.

Estimates of population size for recruit-sized oysters in designated commercial areas have increased from 164 million oysters in January 2005 to 537 million oysters in February 2012 (Table 8). The size of the combined commercial areas was slightly smaller in 2012 compared to 2009 (310 km^2 compared with 372 km^2)(Table 8).

Table 8: Population estimates for recruit-sized oysters in designated commercial areas, 1999–2012; the number of stations sampled (No. stations), the mean oyster density per m^2 (Mean density), standard deviation (s.d.) of the density estimate, coefficient of variation (c.v.) of the density estimate, mean population size in millions of oysters (Mean population with upper and lower 95% confidence intervals in parentheses), and the area of each survey (Area).

Year	No. stations	Mean density	s.d.	c.v.	Mean population	95% CI	Area km^2
1999	135	2.41	0.36	0.16	275	(184–408)	103
2001	103	2.48	0.18	0.07	295	(196–441)	119
2002	92	0.83	0.08	0.09	144	(93–216)	173
2005	80	0.44	0.05	0.12	164	(103–252)	366
2007	52	0.53	0.06	0.12	196	(124–300)	367
2009	57	0.97	0.11	0.12	361	(227–549)	372
2012	61	1.73	0.18	0.10	537	(346−812)	310

In 1995 and 1997, the commercial population used to estimate yield represented the population above a baseline density of 400 oysters per tow (equivalent to about 6–8 sacks per hour during commercial dredging) over the entire survey area. Although this method is no longer used for stock assessment, the Shellfish Working Group requested that these estimates were included in this report (Table 9) to allow some comparison with previous years (Table 10).

Table 9: The oyster population representing the proportion of the recruit-sized oyster population above a density of 400 oysters per survey tow (equivalent to about 6–8 sacks per hour in commercial dredging) in February 2012. The number of stations sampled (No. stations), the mean oyster density per m^2 (Mean density), standard deviation (s.d.) of the density estimate, coefficient of variation (c.v.) of the density estimate, mean population size in millions of oysters (Mean population), upper and lower 95% confidence intervals (CI), and the area of each stratum (Area), by stratum for the February 2012 Foveaux Strait oyster survey.

Stratum	No. stations	Mean density	Density s.d.	c.v.	Mean population	Lower 95% CI	Upper 95% CI	Area (km^2)
B2a	5	0.64	0.64	1.00	19.1	0.0	61.3	29.8
B3	13	3.22	0.81	0.25	143.7	67.9	247.1	44.7
B6	6	0.88	0.57	0.65	26.4	0.0	65.1	30.0
B7	20	0.49	0.38	0.77	42.1	0.0	116.2	86.1
C3	6	0.89	0.57	0.63	29.2	0.0	71.7	32.7
C5	8	1.33	0.68	0.51	50.1	0.0	110.9	37.7
C5a	5	0.95	0.95	1.00	22.3	0.0	71.4	23.5
C7a	4	1.00	1.00	1.00	23.6	0.0	75.0	23.6
C8	6	1.16	0.74	0.64	31.2	0.0	76.9	26.8
C9	6	0.58	0.58	1.00	19.9	0.0	63.6	34.5
E2	8	1.55	0.60	0.39	66.4	15.3	132.3	42.8
All	146	0.44	0.08	0.17	473.9	274.4	759.6	1070.3

Almost half of the strata had a mean oyster density above 400 oysters per tow in 2012 (mean density of 0.44 oysters/m^2) compared to less than one third of strata in 2009 (mean density of 0.24 oysters/m^2) (Table 10). The highest densities and the highest oyster population sizes were found in the central fishery area, in strata B3, C5, C7a, C8 and E2 (Table 9), similar to 2009. The highest commercial population sizes were in strata B3, E2, and C5 despite their relatively small stratum areas (Table 9).

Table 10: Estimates of population size for the proportion of the recruit-sized oyster population above 400 oysters per standard survey tow over the entire fishery area between 2001 and 2012; the number of stations sampled (No. stations), the mean oyster density per m^2 (Mean density), standard deviation (s.d.) of the density estimate, coefficient of variation (CV) of the density estimate, mean population size in millions of oysters (Mean population with upper and lower 95% confidence intervals in parentheses), and the area of each survey (Area).

Year	No. stations	Mean density	s.d.	c.v.	Mean population		Area km^2
2001	192	0.59	0.1	0.17	624	(359–1012)	1054
2002	155	0.17	0.06	0.33	178	(57–331)	1054
2005	80	0.03	0.02	0.58	33	(0–78)	1054
2007	104	0.19	0.07	0.36	204	(60–403)	1070
2009	115	0.24	0.06	0.23	257	(129–441)	1070
2012	146	0.44	0.08	0.17	474	(274–760)	1070

Estimates of the oyster population size above a threshold of 400 oysters per standard survey tow (using catch at each site less 400 oysters; the number of oysters available to the fishery before density is reduced below the historical threshold level) was 474 million oysters in 2012, continuing an upward trend from 33 million in 2005 (Table 10). In 1997, four years after the low population levels of 1993, the commercial population was 109 million oysters, less than quarter the size in 2012 (Cranfield et al 1999). These data suggest that oyster density is increasing in commercial fishery areas, but the size and number of commercial areas may be relatively small compared to the pre-epizootic fishery (prior to 1986).

4.5 Changes in the distribution of oysters

The distributions of recruit-sized oyster densities in February 2012 (Figure 21) are similar to or have increased in most fishery areas from 2009, including localised areas in the eastern fishery. The areas that have sustained most of the commercial fishing between 2009 and 2011 in the central fishery area are continuing to rebuild and expand. Localised declines were evident in western and southern fishery areas where bonamia mortality has been persistent between 2009 and 2012 (Figure 21). There has been no fishing in strata C7, C7a, and B1b where oyster densities have declined.

The distributions of pre-recruit oyster densities in 2012 (Figure 22) are similar to or have declined from densities in 2009. There are declines are evident across all fishery areas (Figure 22); 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 2011. Oysters may take one to two years to transit 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 recruitment to the commercial oyster fishery area is static, and there are no new fishery areas indicated by the distributions of pre-recruit or small oysters.

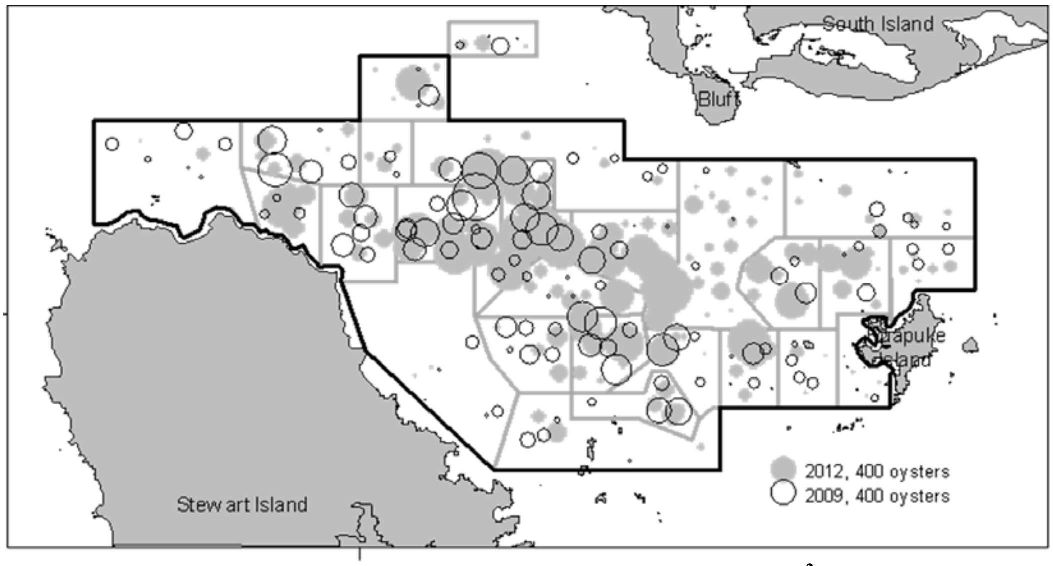

Figure 21: The densities (numbers of oysters per standard tow, 1221 m^2) of recruit-sized oysters sampled during February surveys in 2012 (filled grey circles) and in 2009 (open black circles).

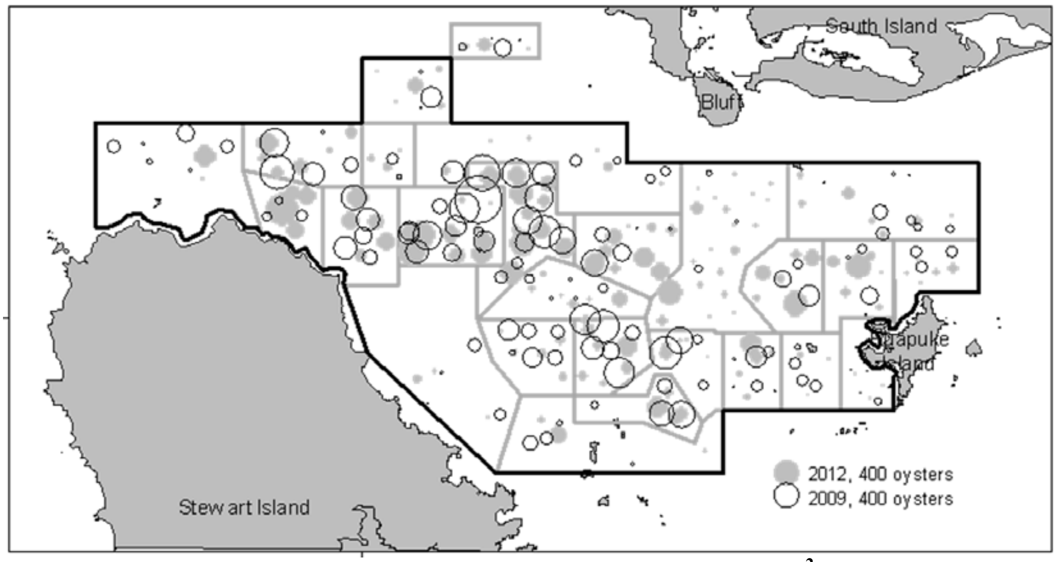

Figure 22: The densities (numbers of oysters per standard tow, 1221 m^2) of pre-recruit oysters sampled during February surveys in 2012 (filled grey circles) and in 2009 (open black circles).

The distributions of small oyster densities in 2012 (Figure 23) are more variable than for recruit and pre-recruit oysters, both within fishery areas and across the entire fishery. Some sites in western and central fishery areas have increased markedly, especially between 2009 and 2012 (Figure 23) while other sites in central and southern areas have declined. 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 compared to eastern and southern areas.

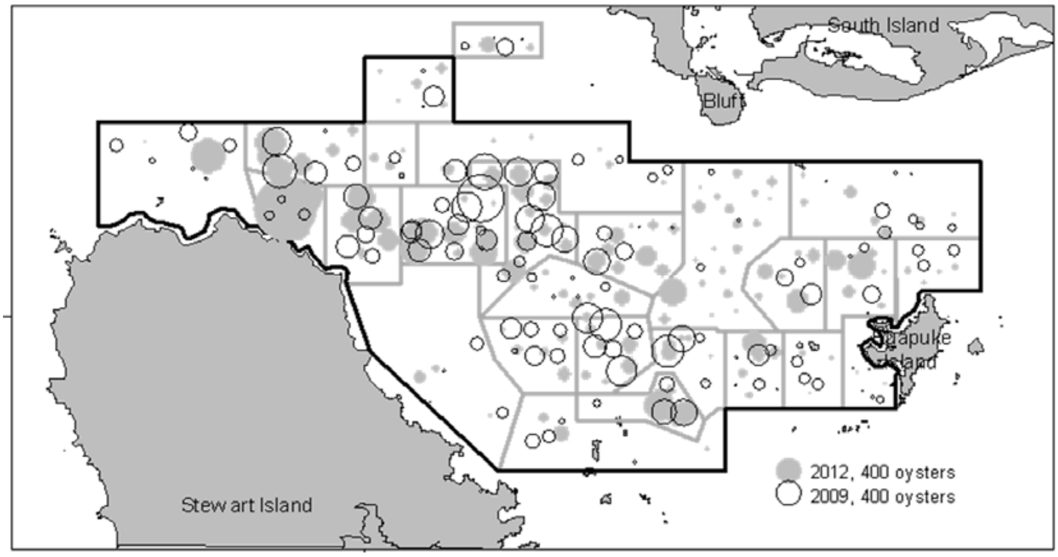

Figure 23: The densities (numbers of oysters per standard tow, 1221 m^2) of small oysters sampled during February surveys in 2012 (filled grey circles) and in 2009 (open black circles).

4.6 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 recruit have slightly declined since 2009 (Figure 24), suggesting that 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, 2010, and 2011, on spat plates during spat monitoring, and the static numbers of small oysters from surveys (889 million in 2009 and 607 million in 2012, Table 7).

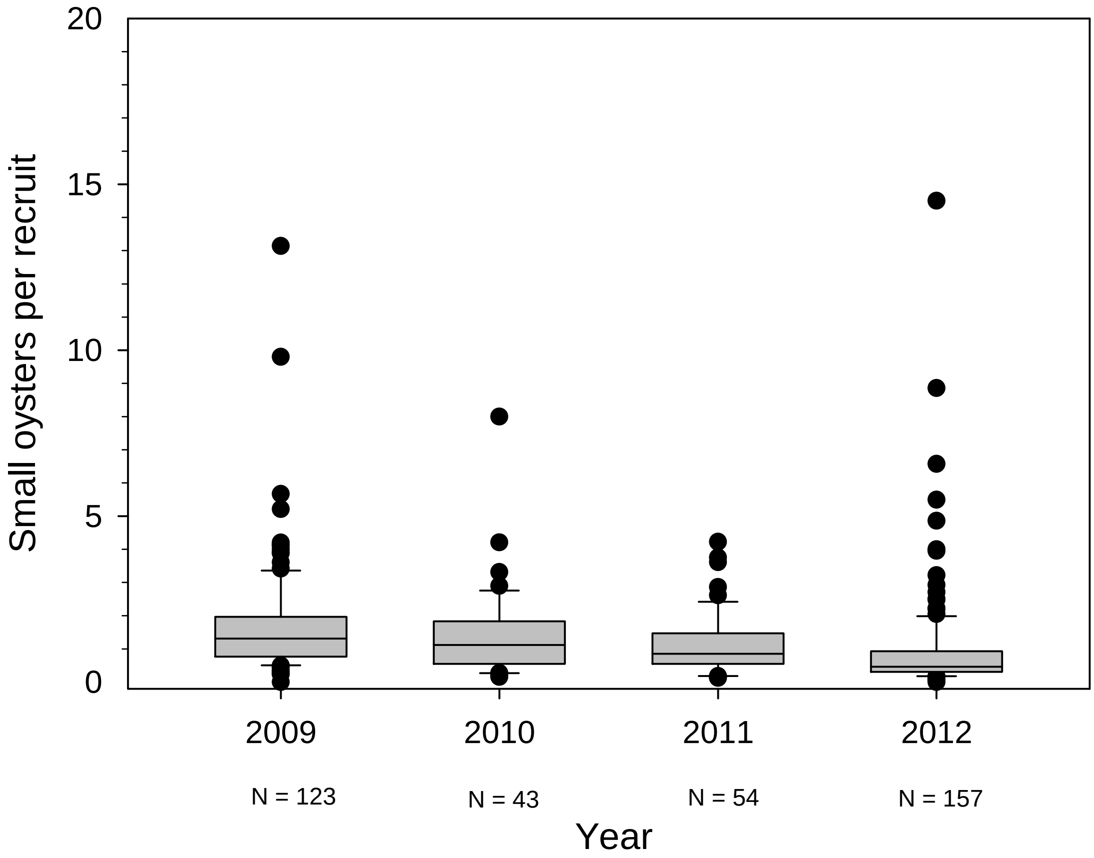

Figure 24: The numbers of small oysters per recruit-sized oyster sampled at stations between 2009 and 2012. The numbers of stations sampled each year varies. Medians shown as solid lines, boxes represent 50 percentiles, whiskers 75 percentiles, and outliers as filled circles.

4.7 Mortality in oysters before the February 2012 survey

Median numbers of recruit-sized new clocks and gapers sampled at 156 of the 158 stations in 2012 were higher than in surveys in 2009 and 2010, but lower than in February 2011 when pre-survey oyster mortality was 3% (Table 11). The percentages of survey stations with no detectable mortality (no recruit-sized clocks or gapers) was lower than in 2009, but higher than in 2010 and 2011 and the 95% percentiles suggest that the variance in infection was similar to previous years, except in 2010 when it was lower (Table 11). Moderate mortality (less than 5%) was similar to previous years, and heightened mortality (greater than 5%) was less than in 2010 and 2011, but greater than in 2009.

Table 11: Changes in the percentages of survey stations with no detectable mortality (no clocks or gapers), low (less than 5%), moderate (5%–10%), and heightened mortality (more than 10%) at stations sampled between 2009, 2010, and 2011.

Year	2009	2010	2011	2012
Number of stations	124	43	54	156
Median mortality	1	0.8	3.0	2.3
Lower 95% CI	0	0	0.7	0
Upper 95% CI	10.3	3.7	11.0	11.1
Range of mortality	0–100.0	0–73	0–33.3	0–29
%. stations no mortality	31.1	16.3	3.7	17.9
% stations <5% mortality	54.6	81.4	66.7	62.8
% stations 5.0–10.0% mortality	8.4	2.3	24	12.8
% stations more than 10% mortality	5.9	0	5.6	6.5

The distribution of oyster mortality before the February 2012 survey, as indicated by the numbers of recruit-sized new clocks and gapers, was widespread (Figure 25). Generally, pre-survey mortality was low (near background levels) in fishery areas where oyster densities were relatively high, and absent in background fishery areas with low oyster densities. Pre-survey mortality was highest in western and central west fishery areas in 2012, but there was heightened mortality in other fishery areas, especially eastern fishery areas.

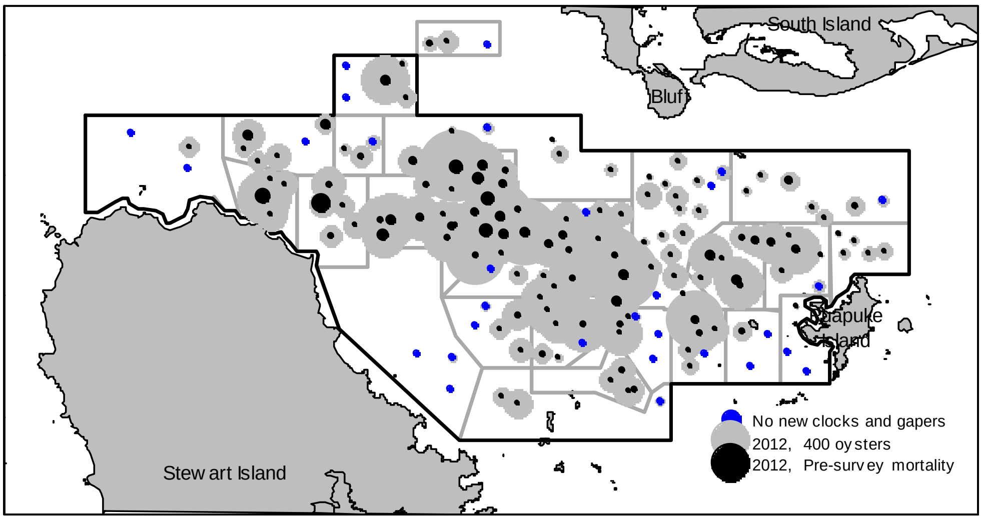

Figure 25: The distribution of recruit-sized oysters, new clock, and gaper densities combined (filled grey circles) and the densities of recruit-sized new clocks and gapers combined (black circles) showing the pre-survey mortality in February 2012. Stations with no recruit-sized new clocks and gapers are shown as filled blue circles.

Estimates of recruit-sized new clocks sampled at randomly selected stations in 2012 are shown in Table 12. Estimates assume that mean dredge efficiency is the same as for live oysters (17%) and that new clocks sampled are equally representative of oyster deaths in each stratum.

Pre-survey mortality was estimated to be higher in 2012, 30.0 million new clocks (c.v. of 14%, 95% CI 18.4–46.8) than in 2011 (bonamia survey) 22.5 million new clocks (c.v. of 10%, 95% CI 13.5–35.1); and in 2009, 10.5 million new clocks (c.v. of 40%, 95% CI 2.6–20.5).

The mean density of recruit-sized new clocks was 0.03 clocks/m^2 and ranged from 0−0.11 new clocks per m^2 in 2012. Strata B3 and C7 had the highest densities of recruit-sized new clocks (0.11 clocks/m^2, c.v. 0.20, and 0.10 clocks/m^2, c.v. 0.72 respectively), and the remaining strata ranged from 0.1–0.8 m^2, but were highly variable with c.v.s of between 0.14 and 1.00.

In order of decreasing abundance, recruit-sized new clocks were highest in strata B3, B1, C7, E2, C6a, C7a, C3, and B7 in 2012 (Table 12).

Table 12: Recruit-sized new clocks estimated from randomly selected stations in 2012: the number of stations sampled (No. stations), the mean new clock 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 in millions of new clocks (Mean population), upper and lower 95% confidence intervals (CI), and the area of each stratum (Area), by stratum for the February 2012 Foveaux Strait oyster survey.

Stratum	No. stations	Mean density	Density s.d.	c.v.	Mean population	Lower 95% CI	Upper 95% CI	Area (km^2)
B1	5	0.05	0.02	0.50	3.9	0.1	8.6	78.2
B1a	3	0.02	0.01	0.64	0.3	0.0	0.7	16.0
B1b	3	0.01	0.01	1.00	0.2	0.0	0.7	36.2
B2	3	0.01	0.01	0.84	0.3	0.0	0.8	17.9
B2a	5	0.02	0.02	0.94	0.6	0.0	1.9	29.8
B2b	6	0.02	0.01	0.53	1.5	0.0	3.3	83.3
B3	13	0.11	0.02	0.20	4.7	2.5	7.8	44.7
B4	3	0.00	0.00	0.00	0.0	0.0	0.0	98.7
B5	3	0.01	0.01	0.76	0.6	0.0	1.7	63.6
B6	6	0.03	0.01	0.45	0.9	0.1	1.9	30.0
B6b	3	0.00	0.00	1.00	0.1	0.0	0.2	19.8
B7	20	0.02	0.01	0.41	1.5	0.3	3.1	86.1
C1a	5	0.01	0.01	0.63	0.4	0.0	0.9	31.3
C2	3	0.02	0.01	0.21	0.5	0.3	0.9	21.9
C3	6	0.05	0.01	0.31	1.6	0.6	2.9	32.7
C4	5	0.01	0.00	0.41	0.2	0.0	0.5	26.3
C5	8	0.02	0.01	0.27	0.8	0.4	1.5	37.7
C5a	5	0.02	0.01	0.51	0.5	0.0	1.0	23.5
C6	3	0.01	0.01	1.00	0.2	0.0	0.8	23.5
C6a	5	0.03	0.01	0.46	2.0	0.2	4.3	77.1
C7	5	0.10	0.07	0.72	3.5	0.0	9.1	36.1
C7a	4	0.08	0.07	0.81	2.0	0.0	5.6	23.6
C8	6	0.02	0.01	0.45	0.4	0.0	0.9	26.8
C9	6	0.02	0.01	0.31	0.7	0.2	1.2	34.5
E2	8	0.06	0.02	0.31	2.4	0.9	4.4	42.8
E4	4	0.01	0.01	1.00	0.2	0.0	0.8	28.0
All	146	0.03	0.00	0.14	30.0	18.4	46.8	1070.3

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

The 2012 survey sampled background strata with low oyster densities not normally sampled in dedicated bonamia surveys, in the year between stock assessments. Of the 71 stations sampled for bonamia (59 first-phase and 12 target stations), samples of 25 oysters were collected from all but 5 stations (stations 1, N=4; 20, N=16; 13, N=20; 82 and 63, N=21). A total of 1733 oysters were sampled for bonamia; and the size composition of oysters at stations where pre-recruit and small sized oysters were included in the samples shown in Table 13. The estimates of prevalence may have been underestimated at stations with smaller sample sizes, and stations with pre-recruit and small sized oysters in the samples.

The bonamia scores between the two readers scoring slides was mostly in agreement. Estimates of prevalence of infection were similar, as were estimates of intensity of infection. When estimates of intensity of infection differed, both readers re-examined the slides, and together scored the slides, and recorded a consensus score.

Table 13: The numbers of small, pre-recruit, and recruit-sized oysters in bonamia samples, N denotes the total sample size.

Station	Number small	Number pre-recruit	Number recruit-sized	N
63	8	4	10	22
76	7	11	7	25
156	4	2	19	25
13	2	3	15	20
20	2	2	12	16
18		6	19	25
221		4	21	25
64		3	22	25
102		3	22	25
71		1	24	25

4.9 Prevalence and intensity of infection in oysters by bonamia

The number of oysters taken for bonamia sampling, and the scaled numbers of oysters with category 1−5 infections found at each station are summarised in Appendix 3, Table 3.1.

Percentages of oysters infected in 2012 were similar to 2010 and 2011; and of the 1733 oysters examined for bonamia in 2012, 89% had no detectable infection, similar to the 90% and 88% in 2010 and 2011 respectively. Of the remaining 11% of oysters with detectable infections in 2012, 3% had light category 1 and 2 infections (3% in 2012 and 4% in 2010), and 8% had category 3 and higher infections (7% in 2011 and 8% in 2010) that are normally fatal.

The prevalence of infection ranged from 4% to 44%, with peak prevalence lower than 2011 (52%). The mean prevalence of infection across all stations in 2012 was the same as for 2011 (10%), and lower than in 2010 (12%), however the median in 2012 (5%) was lower than in 2011 (8%). Fewer stations had high prevalence in 2012 compared with 2011. The number of uninfected stations was similar to previous years, 20% in 2012, 31% in 2011, 28% in 2010, and 29% in 2009. The percentage of stations with prevalence less than 10% was higher in 2012, 58% compared with 28%, 30%, and 37% in 2011, 2010, and 2009 respectively; and for 10–20% prevalence, 29% in 2012 compared with 14%, 26%, 27% in 2011, 2010, and 2009 respectively, and for more than 20 % prevalence, 26% in 2012 compared with 15%, 16%, and 8% in 2011, 2010, and 2009 respectively.

The mean intensity of infection (3.2) was similar for the years 2009–2012. The proportion of stations with category 3 and higher infections increased from 74% in 2009 to 94% in 2010, decreased to 86% in 2011, and decreased further to 67% in 2012. The intensity of infection was highly variable within stations, and patterns of variation were similar across the fishery area, and in all years.

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

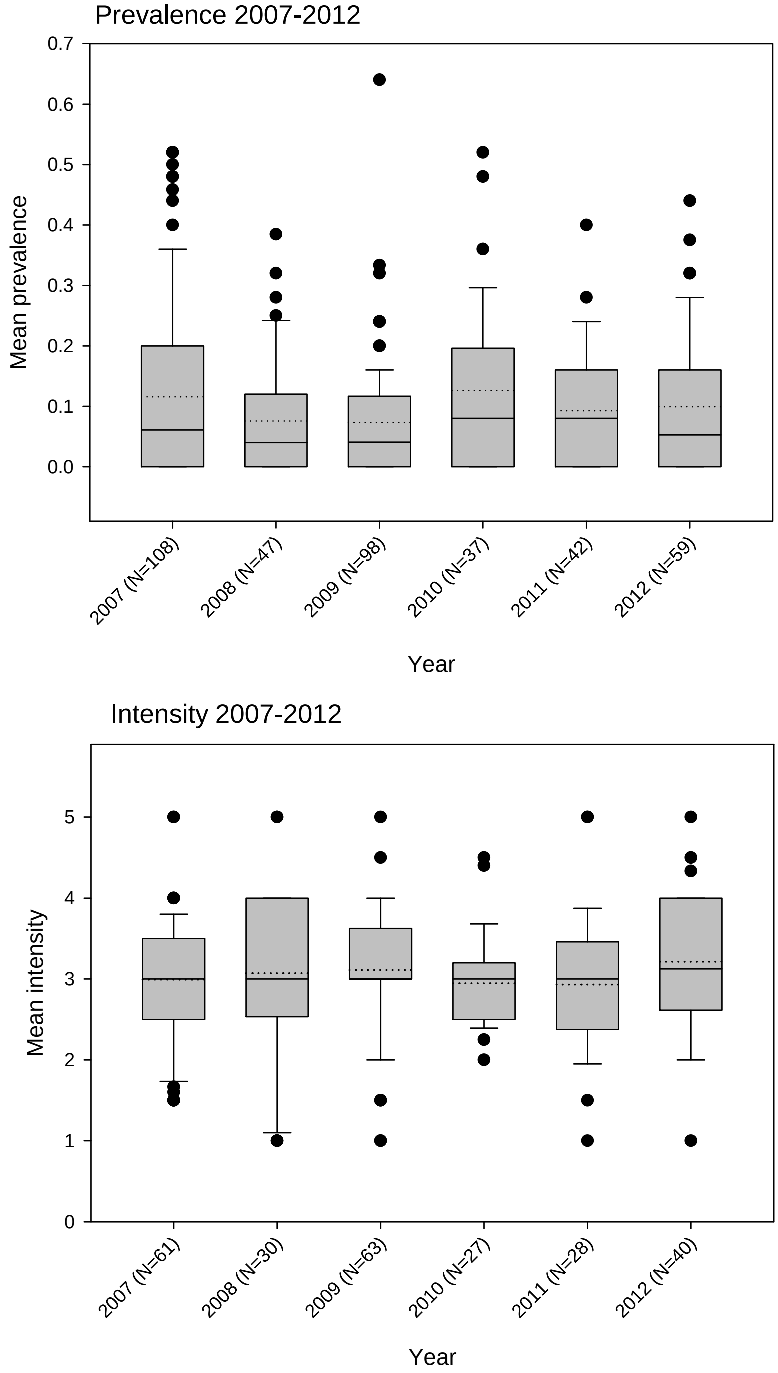

Figure 26: Boxplots of the mean prevalence of infection at all stations (top), and the mean intensity of infection from those stations that had some infection (bottom). Medians shown as solid lines, means as dotted lines, boxes represent 50 percentiles and whiskers 75 percentiles, and outliers as filled circles.

The prevalence of infection at all sample stations is similar and consistently variable between 2007 and 2012. The median of prevalence is generally low (4−8%), but the upper 50% percentiles have a higher spread of infection, with a mean prevalence between about 7 and 13%. There were fewer stations with higher prevalence between 2007 and 2009, and an increase in 2010 that has remained constant in 2011 and 2012 (Figure 26). The range of mean intensity of infection (stations with bonamia infection only) is also similar, showing no inter-annual trends. The mean and median intensity of infection is 3, showing that half the stations each year have some fatal infections. The numbers of stations with a mean intensity of infection of 3 and greater increased between 2007 and 2009, dropped in 2010 and has since increased in 2012 (Figure 26).

The trend in the percentage of stations with no infection decreased between 2007 and 2010, and slightly increased in 2011, and remained at a similar level in 2012 (Figure 27). The mean percentage prevalence of infection by station has been generally low between 2007 and 2012. The percentage of stations with a mean prevalence greater than 20% was high in 2007, declined in 2008 and 2009, increased in 2010, declined in 2011, and increased in 2012 (Figure 27). The pattern of percentage mean prevalence of infection across all stations in February 2012 is similar to that in February 2007 and 2010. Even at higher percentage prevalence in recent years, the fishery has continued to rebuild.

Mean intensity of infection at stations with infection has been generally high since February 2007 (Figure 28), and in 2012 there were more stations with high mean intensity of infection. The differences in mean intensity between February 2007 and 2012 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.

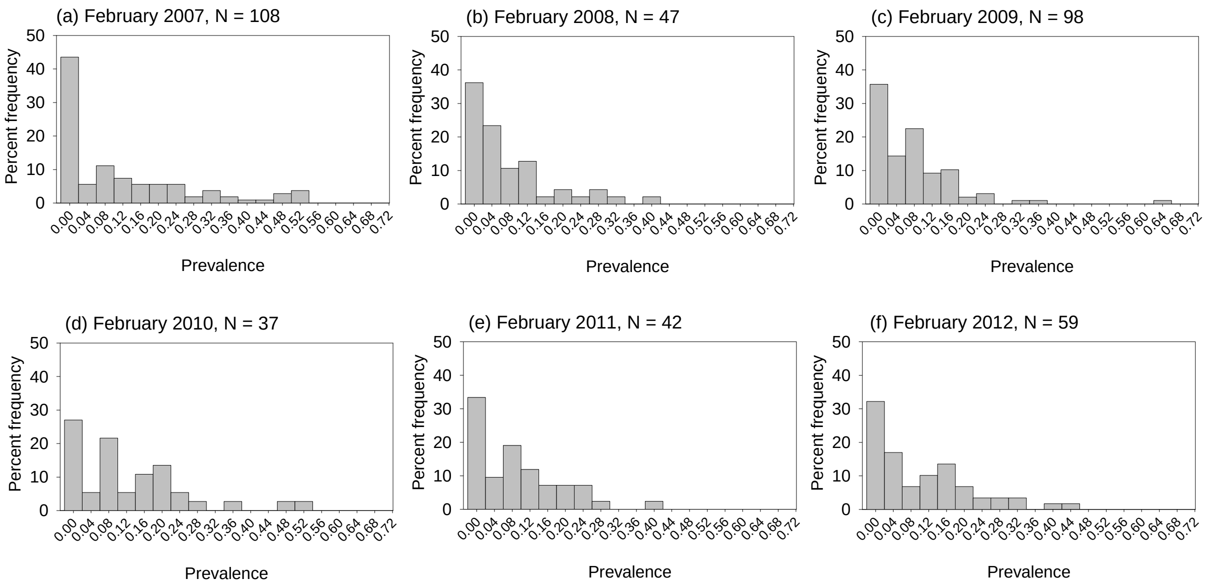

Figure 27: Percentage prevalence of bonamia infection at sites sampled in (a) February 2007, (b) February 2008, (c) February 2009, (d) February 2010, (e) February 2011 (f) February 2012.

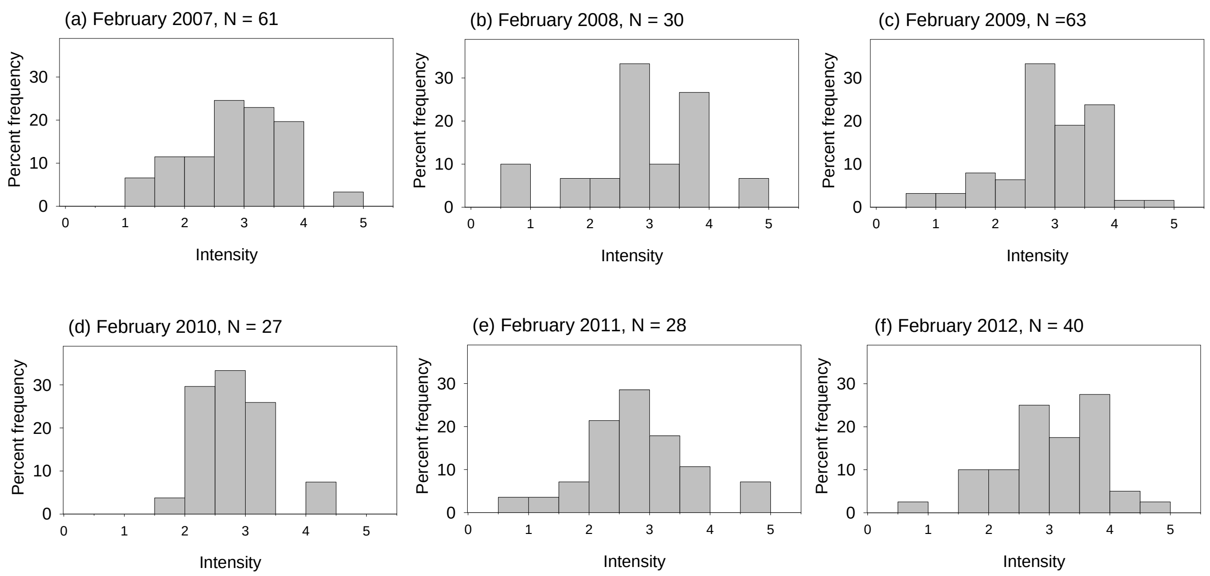

Figure 28: Percentage mean intensity of bonamia infection at infected stations only by station sampled in (a) February 2007, (b) February 2008, (c) February 2009, (d) February 2010, (e) February 2011, and (f) February 2012.

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

During the two stock assessment surveys in 2009 and 2012, sampling was widespread throughout the fishery area, and in the years between stock assessments (2010 and 2011), sampling was more limited to commercial fishery areas. The distribution of the prevalence and intensity of bonamia infection from February 2009 to February 2012 is shown in Figures 29–32. Bonamia infection in oysters was widespread and variable in February 2012; 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 and 2011, with increasing prevalence and intensity at some central fishery sites where it was low in 2009 (Figures 29–32).

In February 2009 (Figure 29), the 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 30) where oyster density had 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 31). In February 2012, the distribution of infection was more similar to previous years with increasing prevalence and likely mortality in western and eastern fishery areas, but decreased infection in the central and southern areas that support most of the commercial fishery (Figure 32).

Patterns in the distribution of prevalence and intensity of infection were not consistent with dredging or oyster density; oyster densities are increasing in the eastern fishery, but infection there is similar to that in western fishery areas where oyster density has been high.

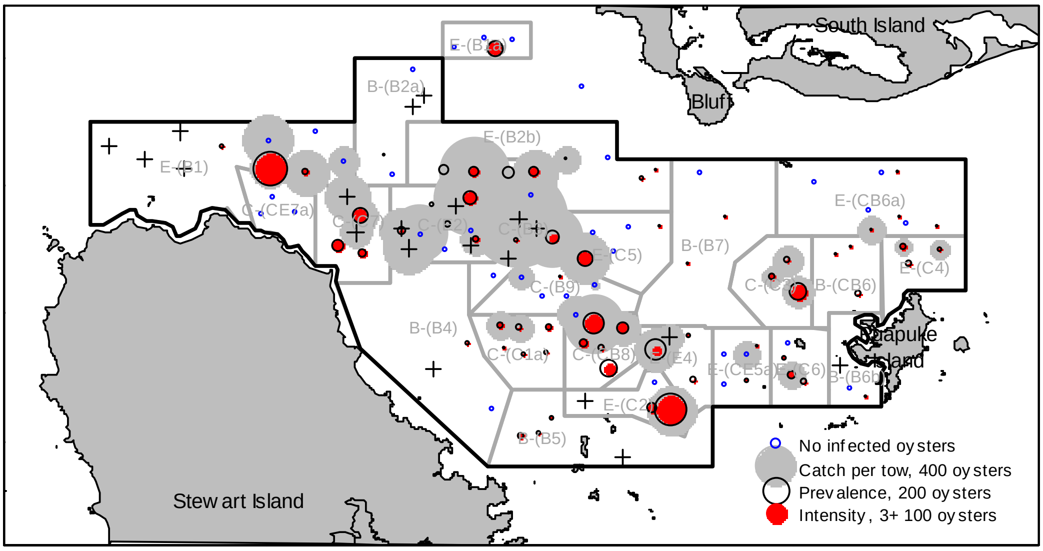

Figure 29: The distributions of oysters and bonamia infection in February 2009 survey. Numbers of oysters (filled grey circles), numbers of oysters with bonamia infection (intensity categories 1–5 combined, open black circles); and fatal infections (intensity categories 3–5 combined, filled red circles). 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".

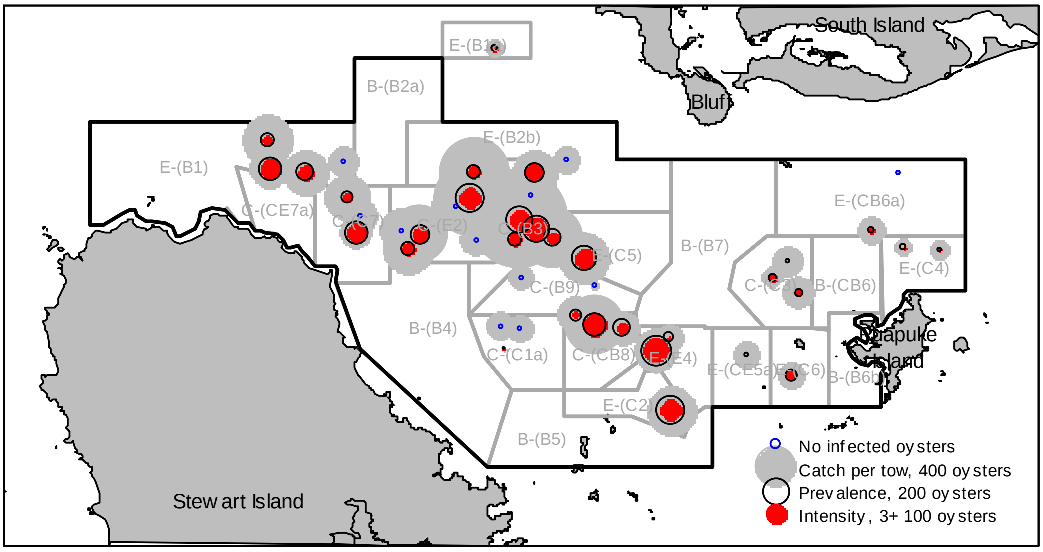

Figure 30: The distributions of oysters and bonamia infection in February 2010 survey. Numbers of oysters (filled grey circles), numbers of oysters with bonamia infection (intensity categories 1–5 combined, open black circles); and fatal infections (intensity categories 3–5 combined, filled red circles). 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".

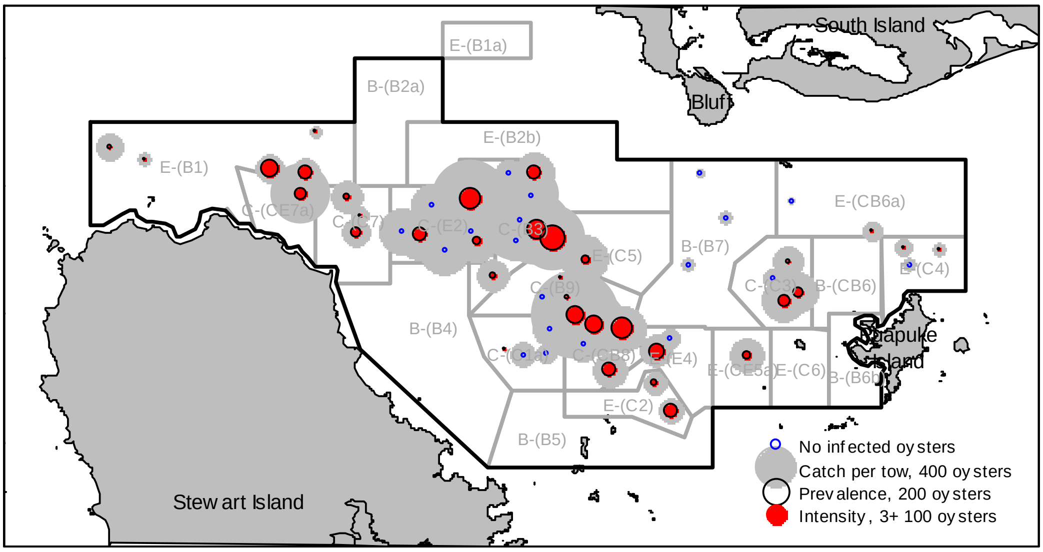

Figure 31: The distributions of oysters and bonamia infection in February 2011 survey. Numbers of oysters (filled grey circles), numbers of oysters with bonamia infection (intensity categories 1–5 combined, open black circles); and fatal infections (intensity categories 3–5 combined, filled red circles). 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".

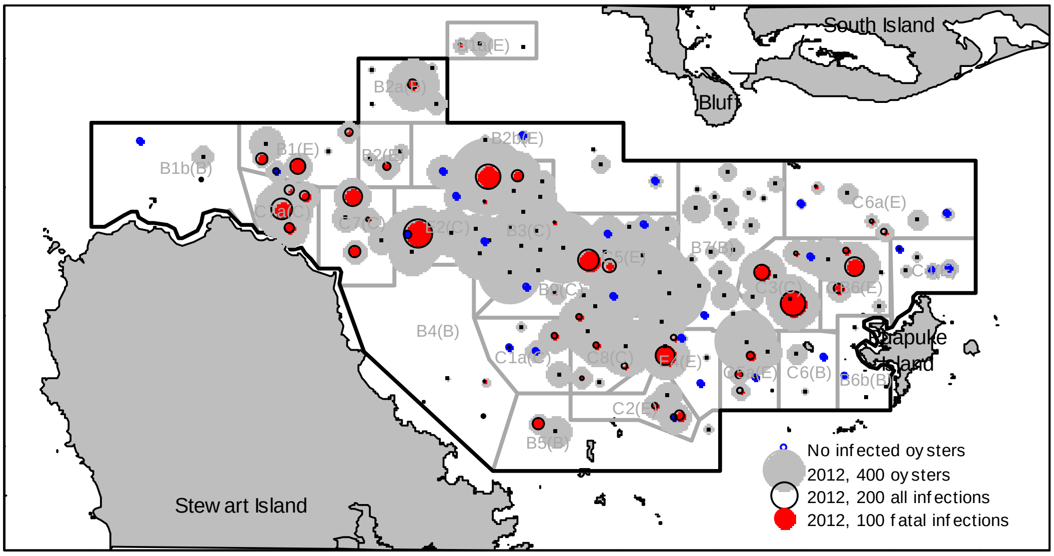

Figure 32: The distributions of oysters and bonamia infection in February 2012 survey. Numbers of oysters (filled grey circles), numbers of oysters with bonamia infection (intensity categories 1–5 combined, open black circles); and fatal infections (intensity categories 3–5 combined, filled red circles). Stations with no bonamia (open blue circles). The 2005 survey area (black outer line) and the February 2012 survey strata (grey lines); the 2012 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".

4.9.3 Changes in the numbers of oysters infected with bonamia

Estimates of the numbers of recruit-sized oysters in each stratum infected with bonamia were scaled up from the catches at the sixty first-phase stations where bonamia was sampled and compared with estimates from the last stock assessment survey in 2009 when 90 stations were sampled for bonamia. The total numbers of infected oysters increased from 51.9 million in 2009 (c.v. 0.16) to 83.2 million in 2012 (c.v. 0.26) (Table 14). The total numbers of infected oysters with fatal infections (category 3−5 intensity of infections) increased from 33.8 million in 2009 (c.v. 0.15) to 56.9 million in 2012 (c.v. 0.27), Table 15.

The percentage of the total recruit-sized oyster population infected with bonamia increased from 7.2% in 2009 to 9.1% in 2012 (Table 16). The percentage of fatal infections followed a similar trend increasing from 4.7% to 6.2% over the same period (Table 16).

Table 14: Absolute population estimates for recruit-sized oysters infected with bonamia (categories 1−5) from tows sampled for bonamia only: the number of randomly selected stations sampled (No. stations), the mean oyster density per m^2 (Mean density), standard deviation (s.d.) of the density estimate, coefficient of variation (c.v.) of the density estimate, mean population size in millions of oysters (Mean population), upper and lower 95% confidence intervals (CI), and the area of each stratum (Area), by stratum for the February 2012 survey.

Stratum	No. Stations	Mean density	s.d.	Density c.v.	Mean population	Lower 95% CI	Upper 95% CI	Area (km^2)
B1	3	0.21	0.06	0.28	16.1	6.6	28.8	78.2
B2b	3	0.00	0.00	0.00	0.0	0.0	0.0	83.3
B3	3	0.37	0.26	0.70	16.4	0.0	42.1	44.7
B6	3	0.24	0.13	0.57	7.1	0.0	16.4	30.0
C1a	3	0.02	0.02	0.88	0.6	0.0	1.8	31.3
C3	3	0.11	0.10	0.85	3.7	0.0	10.5	32.7
C4	3	0.00	0.00	1.00	0.1	0.0	0.2	26.3
C5	3	0.10	0.10	1.00	3.7	0.0	11.7	37.7
C5a	3	0.06	0.03	0.53	1.5	0.0	3.3	23.5
C6a	3	0.02	0.01	0.72	1.3	0.0	3.3	77.1
C7	3	0.24	0.13	0.53	8.8	0.0	19.7	36.1
C7a	4	0.27	0.12	0.45	6.4	0.7	13.5	23.6
C8	3	0.07	0.01	0.13	1.8	1.1	2.8	26.8
C9	3	0.01	0.01	1.00	0.2	0.0	0.7	34.5
E2	3	0.37	0.36	0.98	15.8	0.0	50.3	42.8
All	46	0.13	0.03	0.26	83.2	37.3	147.6	628.6

Table 15: Absolute population estimates for recruit-sized oysters with fatal bonamia infections (categories 3−5) from tows sampled for bonamia only: the number of randomly selected stations sampled (No. stations), the mean oyster density per m^2 (Mean density), standard deviation (s.d.) of the density estimate, coefficient of variation (c.v.) of the density estimate, mean population size in millions of oysters (Mean population), upper and lower 95% confidence intervals (CI), and the area of each stratum (Area), by stratum for the February 2012 survey.

Stratum	No. Stations	Mean density	s.d.	Density c.v.	Mean population	Lower 95% CI	Upper 95% CI	Area (km^2)
B1	3	0.14	0.06	0.41	10.6	2.0	21.3	78.2
B2b	3	0.00	0.00	0.00	0.0	0.0	0.0	83.3
B3	3	0.23	0.17	0.75	10.4	0.0	27.8	44.7
B6	3	0.19	0.09	0.48	5.8	0.3	12.4	30.0
C1a	3	0.02	0.02	1.00	0.6	0.0	1.8	31.3
C3	3	0.11	0.10	0.85	3.7	0.0	10.5	32.7
C4	3	0.00	0.00	0.00	0.0	0.0	0.0	26.3
C5	3	0.02	0.02	1.00	0.9	0.0	2.9	37.7
C5a	3	0.04	0.02	0.53	1.0	0.0	2.2	23.5
C6a	3	0.01	0.01	0.66	1.0	0.0	2.5	77.1
C7	3	0.18	0.09	0.50	6.5	0.2	14.3	36.1
C7a	4	0.16	0.06	0.38	3.7	0.9	7.3	23.6
C8	3	0.05	0.01	0.29	1.3	0.5	2.3	26.8
C9	3	0.01	0.01	1.00	0.2	0.0	0.7	34.5
E2	3	0.27	0.26	0.97	11.4	0.0	36.2	42.8
All	46	0.09	0.02	0.27	56.9	24.4	102.2	628.6

Table 16: Mean and 95% confidence intervals (95%CI) for the numbers of all infected recruit-sized oysters (millions) in the survey population (Prev.all) from all survey strata sampled each year, where three or more random stations were sampled in February 2009 and 2012. 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 and higher category infections (Prev3+), and the numbers (millions), and percentage of infected oysters that have fatal infections are also given for the same data (% fatal infections).

Survey	Prev.all			Population size			Percent of population infected			
	Mean	Lower 95%CI	Upper 95%CI	Mean	Lower 95%CI	Upper 95%CI	Mean	Lower 95%CI	Upper 95%CI	
2009	51.9	30.5	84.2	724.8	475.6	1081.2	7.2	6.4	7.8	
2012	83.2	37.3	147.6	918.4	600.1	1383.7	9.1	6.2	10.7	
Survey	Prev.3+									% fatal
2009	33.8	20.3	54.4	724.8	475.6	1081.2	4.7	4.3	5.0	65.1
2012	56.9	24.4	102.2	918.4	600.1	1383.7	6.2	4.1	7.4	68.4

4.9.4 Projected short-term mortality from bonamia infections

Post-survey mortality of recruit-sized oysters was estimated in strata with three or more randomly selected stations. The mean proportion of oysters infected with category 3 and higher infections in the catch were used to calculate a correction factor for each stratum (1 - mean proportion of oysters infected with bonamia, Table 17) and this correction factor was applied to the mean density estimated from all random tows (first and second phase sampling). The post-survey mortality of oysters was projected to reduce the recruit-sized oyster population from 918.4 million oysters (95% CI 600.1−1383.7) at the time of the survey (February 2012) to 837.3 million oysters (95% CI 546.3−1262.6), a loss of 81 million oysters (8.8%) by early in the new oyster season, (Table 17).

Table 17: Absolute population estimates for recruit-sized oysters after projected mortality from bonamia based on category 3 and higher 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 oyster density, mean population size in millions of oysters (Mean population), 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 population	Lower 95% CI	Upper 95% CI	Area (km^2)
B1	5	0.78	0.54	0.18	0.34	42.4	13.4	80.2	78.2
B1a	3	0.96	0.35	0.20	0.58	5.6	0.0	13.2	16.0
B1b	3	1.00	0.21	0.21	0.99	7.7	0.0	24.3	36.2
B2	3	0.88	0.38	0.13	0.33	6.8	2.3	12.8	17.9
B2a	5	0.96	0.78	0.58	0.75	23.2	0.0	61.8	29.8
B2b	6	1.00	0.40	0.20	0.49	33.7	1.5	73.0	83.3
B3	13	0.94	3.34	0.66	0.20	149.3	80.1	247.7	44.7
B4	3	0.86	0.04	0.03	0.67	3.8	0.0	9.7	98.7
B5	3	0.67	0.42	0.20	0.49	26.6	1.3	57.7	63.6
B6	6	0.85	0.97	0.42	0.44	29.1	3.8	60.1	30.0
B6b	3	1.00	0.04	0.02	0.45	0.8	0.1	1.7	19.8
B7	20	1.00	0.81	0.36	0.44	69.9	8.9	146.4	86.1
C1a	5	0.99	0.58	0.23	0.39	18.0	3.9	36.3	31.3
C2	3	0.95	0.92	0.15	0.17	20.2	11.7	32.5	21.9
C3	6	0.96	1.38	0.39	0.29	45.3	18.7	81.9	32.7
C4	5	1.00	0.24	0.06	0.23	6.3	3.1	10.7	26.3
C5	8	0.98	1.93	0.52	0.27	72.7	31.2	128.1	37.7
C5a	5	0.91	1.22	0.78	0.64	28.7	0.0	72.4	23.5
C6	3	1.00	0.22	0.15	0.69	5.3	0.0	13.5	23.5
C6a	5	0.90	0.29	0.06	0.20	22.1	12.0	36.3	77.1
C7	5	0.80	0.81	0.14	0.18	29.0	16.2	47.2	36.1
C7a	4	0.91	1.63	0.69	0.43	38.4	6.3	79.3	23.6
C8	6	0.95	1.57	0.61	0.39	42.1	9.2	83.6	26.8
C9	6	0.97	1.00	0.48	0.47	34.6	2.0	74.2	34.5
E2	8	0.84	1.57	0.41	0.26	67.1	29.6	118.7	42.8
E4	4	1.00	0.31	0.22	0.70	8.8	0.0	22.7	28.0
All	146		0.78	0.07	0.09	837.3	546.3	1262.6	1070.3

4.9.5 Projected medium-term mortality from bonamia infections

How quickly low level, category 1 and 2 infections progress to category 3 and higher infections, and the variance of progression 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 33), 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 low intensity infections is relatively low compared to recruit-sized oyster density (Figure 33).

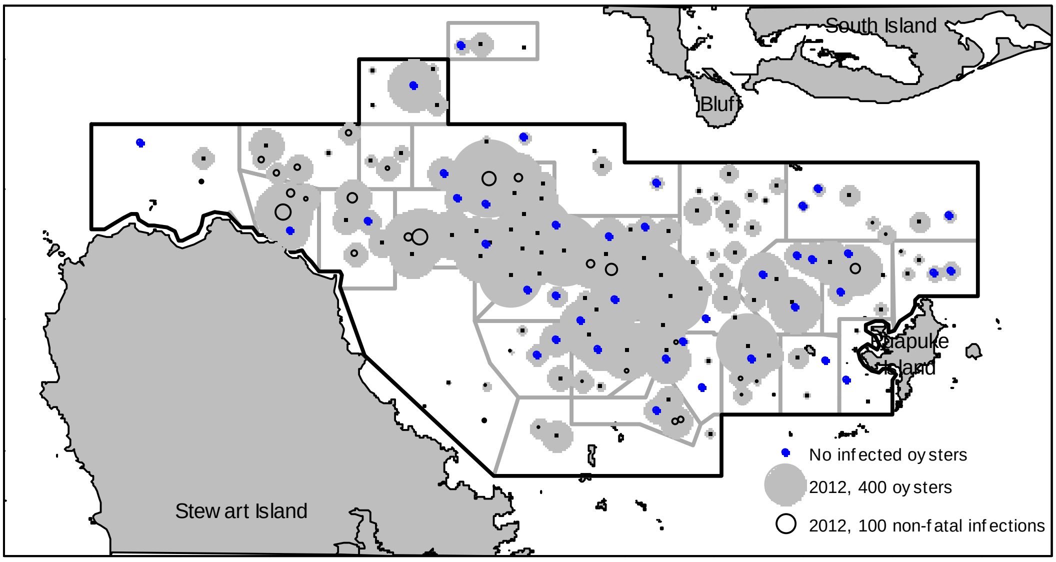

Figure 33: The distribution of recruit-sized oysters (filled grey circles showing numbers per standard tow) and oysters with non-fatal infections (open black circles, the numbers of oysters scaled to the size of the catch with intensity of infection category 1 and 2) in February 2012. Sites with no bonamia infection are shown by filled blue circles, and sample stations as black dots.

5. DISCUSSION

5.1 The February 2012 survey

The sampling performance of the February 2012 survey is consistent with previous years. The data are comparable and are a valuable addition to the OYU 5 survey time series. Fishers' logbook data (2006−2011) showed slightly higher catch rates during periods when the sea conditions were calm. Sea conditions were calmer than for recent surveys and dredge efficiency may have increased slightly. This is unlikely to have had a significant effect on estimates of oyster density; observations of straight line dredge tows used on these surveys show that the dredges are likely to saturate in commercial fishery areas after 0.1 nautical miles of towing. Survey tows are 0.2 nautical miles long and any increase in dredge efficiency is likely to have caused saturation earlier than otherwise during the tow. The effects of better sea conditions, differences in shell bycatch, and seabed characteristic in different fishery areas are not known. There is the potential for these factors to produce slightly biased estimates of dredge efficiency. Biased estimates of oyster density cannot therefore be ruled out, but if they occur, they are likely to have minimal effect on the management of the fishery while the exploitation rate is low.

The vessel, skipper, and crew used on the survey were the same as for surveys since 2010. The survey dredge was the same dredge used since 2000, but had the ring-bag replaced with one built to the same specifications as the original. It is not known whether the new vessel or refurbished dredge has any influence on the time-series 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). Tow length and dredge fullness were all within the ranges assumed for effective sampling, and not likely to increase variance in dredge efficiency. Sea conditions did not deteriorate to levels likely 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 19991). Although the duration and timing of mortality may vary seasonally during epizootics, late January–early February has proved to be the most reliable period for detecting bonamia infections. Estimates of new clocks in February 2012 showed heightened pre-survey mortality similar to 2009−2011; and oysters with category 3 and higher infections were higher, 81 million recruit-sized oysters compared to 40 million and 53 million oysters in 2010 and 2011 respectively from smaller bonamia surveys.

5.2 Estimates of population size, density, and distribution

The population of recruit-sized oysters for all the survey area (including stratum B1a) has increased from 724.8 million oysters (95% CI 475.6−1081.2) in 2009 to 918.4 million oysters (95% CI 6000.1−1383.7) in 2012. The coefficients of variation (c.v.s) for 2009 and 2012 stock assessment surveys were low, 8% for recruit-sized oyster for both surveys, 10% for pre-recruits for both surveys, and 10% and 14% for small oysters in 2009 and 2012 respectively.

Mean oyster densities were slightly higher for recruit-sized oysters in 2012 compared to 2009 (0.86 oysters/m^2, compared with 0.68 oysters/m^2), were similar for pre-recruits (0.39 oysters/m^2, compared with 0.33 oysters/m^2), and for small oysters were lower in 2012 than in 2009 (0.57 oysters/m^2, compared with 0.85 oysters/m^2). The lower population sizes of pre-recruit and small oysters may limit future increases in recruit-sized oyster density, and the speed of rebuilding of the fishery.

Commercial fishery areas (strata E2, C9, C8, 7a, C7, C5, C3, C1a, and B3) accounted for 58.5% of the recruit-sized population in 28.1% of the survey area. Most tows in commercial strata have higher oyster densities than those in non-commercial strata (Figure 34), corroborating the designation of stratum categories. Catches in commercial strata varied suggesting the patchy distribution of high density patches of oysters within commercial strata. A few relatively high oyster densities were sampled in tows from background strata close to the boundaries of commercial strata, influencing the overall mean density in non-commercial strata.

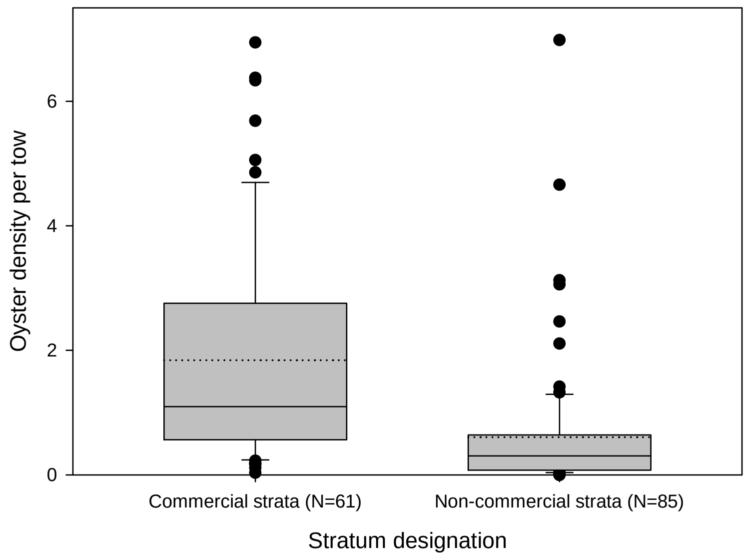

Figure 34: Boxplots of absolute recruit-sized oyster density (oysters/m^2) corrected for dredge efficiency, 0.17, by tow for designated commercial and non-commercial strata from the February 2012 survey. Medians shown as solid lines, means as dotted lines, boxes represent 50 percentiles and whiskers 75 percentiles, and outliers shown as filled circles.

The stratified random survey design focused on commercial fishery areas, and this survey design does not estimate oyster distribution well. Oyster density is rebuilding most quickly and extensively in central and southern fishery areas. Eastern areas are rebuilding more slowly as they are subjected to higher levels of bonamia mortality, and some western fishery areas are contracting as a result of persistent heightened mortality from bonamia. The distributions of pre-recruit and small oysters are similar to recruit-sized oysters, and there are some localised areas of high densities of small oysters in the western fishery area.

5.3 Status of infection

The total summer mortality is the pre-survey mortality estimated from new clocks and gapers and the proportion of the population likely to die shortly after the survey based on category 3 and higher bonamia infections. Although these estimates are summed to give an indicative total mortality, recruit-sized new clocks, gapers, and live oysters are likely to have different catchabilities (q), and q is also likely to vary regionally in the fishery for each of these components. Although the two estimates are not directly comparable, their combined totals are presented as an indicative estimate of total summer mortality from bonamia. These estimates are used in years between stock assessments to assess the effects of bonamia mortality on projections of stock size from the last assessment.

Two methods are used to calculate post-survey mortality. Method 1 estimates the population size of oysters in each stratum and all strata combined using a correction factor to reduce the mean density of oysters by the mean proportion of fatally infected oysters with category 3 and higher infections. This method uses information from all random tows. Method 2 scales up the proportion of oysters sampled with category 1−5 infection to the catch at each station and uses scaled numbers of infected oysters to estimate the population size of all infected and fatally infected oysters in each stratum and combines them to get estimates of the total numbers of infected oysters. Fewer stations are sampled for bonamia compared with those to estimate oyster density, and this difference in sample size may affect mean estimates of infection.

Post-survey mortality using method 1 was estimated to be 8.8% in February 2012, higher than for 2007–2011 when mortality was 6.9%, 3.3%, 6.3%, 6.6%, and 6.7% respectively. The oyster population has shown the capacity to rebuild at levels of post-survey mortality of about 10%.

Since 2005, indicative estimates of total summer mortality from bonamia have been low, generally about 10%. The indicative level of disease mortality in 2012 is higher than for 2007–2011, and was 8.5%, 8.2%, and 12.0% respectively for the 2007, 2009, and 2012 stock assessment surveys. Total mortality estimated in 2012 was up to 111 million oysters, of which about 30 million died before the survey (new clocks and gapers) and about 81 million oysters are expected to die post-survey. Fishers observed high localised mortality of recruit-sized oysters (up to 70%) early in the 2012 oyster season that began 1 March 2012, confirming that the projected higher mortality in 2012 occurred. The total bonamia mortality estimated 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.

The total numbers of infected oysters estimated using method 2 increased from 51.9 million in 2009 (c.v. 0.16) to 83.2 million in 2012 (c.v. 0.26); lower than the total number of fatally infected oysters using method 1. The total numbers of infected oysters with fatal infections increased from 33.8 million in 2009 (c.v. 0.15) to 56.9 million in 2012 (c.v. 0.27). The percentage of the total recruit-sized oyster population infected with bonamia has ranged from 7.2−11.8% from 2009 to 2012, and was 9.1% in 2012. The percentage of fatal infections followed a similar trend ranging from 4.7−6.9% from 2009 to 2012, and was 6.2% in 2012. Although the numbers of all infected and fatally infected oysters are increasing as the population size of oysters' increases, the percentages of infected oysters are similar between 2009 and 2012.

The prevalence and intensity of infection can by highly variable, even over small spatial scales and estimates of projected mortality are sensitive to sampling effort. The absolute population of fatally infected oysters was lower using method 2 (56.9 million oysters) than method 1 (81.1 million oysters).

5.4 Status of the OYU 5 fishery

The Foveaux Strait oyster stock assessment shows that at the currently low levels of exploitation (less than the TACC of 15 million oysters), harvest levels have little effect on the future status of the oyster population. If recruitment remains near the long-tern 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 decline 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 indicates 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. Modifications to the ring-bags of commercial dredges as they are replaced on some vessels will increase dredge efficiency and CPUE.

Projections from the 2009 stock assessment based on a TACC of 15 million oysters and with no mortality of oysters from bonamia, predicted an increase in recruit-sized stock abundance of 29% by 2012; however with a bonamia mortality of 10%, the population size would only increase by 11% over the same period (Fu & Dunn 2009). Bonamia mortality has been about 10% between 2009 and 2012; and the estimated numbers of recruit-sized oysters killed between the 2009 survey and the 2012 survey was about 198 million oysters. The population size of recruit-sized oysters has increased by 21.1% between the 2009 and 2012 surveys. If the estimated post-survey mortality in 2012 (81 million oysters) is taken into account, the population size of recruit-sized oysters increased by 13.5%, which is consistent with the 2009 stock assessment.

Although the trend in the population size of pre-recruit oysters is flat, and slowly declining for small oysters, and the mortality of recruit-sized oysters is about 10%, the fishery is continuing to increase. Fishery indicators suggest an improvement in the fishery, commercial catches between 2009 and 2012 have increased (8.23, 9.54, 10.5 million oysters (including RWC) respectively), as has unstandardised CPUE for over the same period (3.12 s/h, 4.16 s/h, and 4.24 s/h).

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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 ___

Recorder

....

Comments

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

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: Scaled estimates of prevalence and intensity of infection by bonamia, February 2012, by stratum and station. For each station, where r is the number of recruit-sized oysters infected with bonamia and N the number of recruit-sized oysters in the sample, 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), The number of live recruit-sized oysters per tow standardised to 0.2 nautical miles (Std_l.rec), and the scaled numbers of oysters with no infection (No. infect) and numbers of category 1–5 infections (Num.cat.1−5). Total numbers infected (Num.all), lightly infected (category 1 and 2 infections, Num.light), and with fatal infections (category 3–5 infections, Num.fatal).

Stratum	Station	r	N	Prevalence	Std_l.rec	No. infect	Num.cat.1	Num.cat.2	Num.cat.3	Num.cat.4	Num.cat.5	Num.all	Num.light	Num.fatal
B1b	1	0	1	0.00	1	1	0	0	0	0	0	0	0	0
B2a	6	1	25	0.04	648	623	0	0	0	26	0	26	0	26
B5	10	9	24	0.38	109	68	5	0	5	23	9	41	5	36
B6b	13	0	15	0.00	15	15	0	0	0	0	0	0	0	0
B7	18	0	19	0.00	13	13	0	0	0	0	0	0	0	0
C6	20	0	12	0.00	12	12	0	0	0	0	0	0	0	0
B1a	24	1	25	0.04	69	66	0	0	3	0	0	3	0	3
B1	25	11	25	0.44	86	48	0	14	10	14	0	38	14	24
B1	26	5	25	0.20	118	94	14	0	5	5	0	24	14	9
B1	28	8	25	0.32	200	136	8	8	16	32	0	64	16	48
B2	32	4	25	0.16	143	120	0	6	6	6	6	23	6	17
B2b	33	0	25	0.00	275	275	0	0	0	0	0	0	0	0
B2b	34	0	25	0.00	40	40	0	0	0	0	0	0	0	0
B2b	38	0	24	0.00	57	57	0	0	0	0	0	0	0	0
B6	40	4	25	0.16	634	533	0	25	0	25	51	102	25	76
B6	42	4	25	0.16	173	145	0	0	14	0	14	28	0	28
C6a	46	4	25	0.16	49	41	2	0	0	4	2	8	2	6
C6a	47	0	25	0.00	37	37	0	0	0	0	0	0	0	0
C2	51	2	25	0.08	150	138	0	0	6	6	0	12	0	12
C2	52	1	25	0.04	265	254	11	0	0	0	0	11	11	0
C4	54	0	25	0.00	66	66	0	0	0	0	0	0	0	0
C4	56	0	25	0.00	83	83	0	0	0	0	0	0	0	0
C5a	59	5	25	0.20	121	97	0	10	10	5	0	24	10	14
C5a	62	4	25	0.16	81	68	0	3	3	3	3	13	3	10
C5a	63	1	10	0.10	14	12	0	1	0	0	0	1	1	0
E4	64	0	22	0.00	12	12	0	0	0	0	0	0	0	0

Table 3.1 continued.

Stratum	Station	r	N	Prevalence	Std_l.rec	No. infect	Num.cat.1	Num.cat.2	Num.cat.3	Num.cat.4	Num.cat.5	Num.all	Num.light	Num.fatal
E4	66	0	25	0.00	34	34	0	0	0	0	0	0	0	0
B3	70	2	25	0.08	570	525	0	23	0	23	0	46	23	23
B3	71	3	24	0.08	37	34	0	0	0	2	2	3	0	3
B3	72	3	25	0.12	1441	1268	0	58	58	58	0	173	58	115
C1a	76	1	7	0.14	7	6	0	1	0	0	0	1	1	0
C1a	77	1	25	0.04	262	251	0	0	0	10	0	10	0	10
C1a	78	0	25	0.00	113	113	0	0	0	0	0	0	0	0
C3	81	3	25	0.12	509	448	0	0	0	61	0	61	0	61
C3	82	0	21	0.00	274	274	0	0	0	0	0	0	0	0
C3	83	1	25	0.04	175	168	0	0	0	0	7	7	0	7
C5	86	0	25	0.00	129	129	0	0	0	0	0	0	0	0
C5	87	4	24	0.17	355	296	15	30	0	15	0	59	44	15
C5	88	0	25	0.00	324	324	0	0	0	0	0	0	0	0
C7	90	7	25	0.28	350	252	14	14	70	0	0	98	28	70
C7	91	1	25	0.04	154	148	0	0	0	6	0	6	0	6
C7	92	8	25	0.32	144	98	0	12	17	17	0	46	12	35
C7a	95	4	25	0.16	821	689	33	33	0	66	0	131	66	66
C7a	96	3	25	0.12	219	193	0	9	0	18	0	26	9	18
C7a	97	3	25	0.12	293	258	0	0	0	23	12	35	0	35
C7a	98	6	25	0.24	121	92	0	19	10	0	0	29	19	10
C8	99	2	25	0.08	124	115	0	5	5	0	0	10	5	5
C8	100	1	25	0.04	376	361	0	0	15	0	0	15	0	15
C8	102	5	22	0.23	70	54	3	3	10	0	0	16	6	10
C9	105	0	25	0.00	89	89	0	0	0	0	0	0	0	0
C9	107	0	25	0.00	697	697	0	0	0	0	0	0	0	0
C9	108	1	25	0.04	112	107	0	0	0	4	0	4	0	4
E2	112	7	25	0.28	802	577	32	32	0	0	160	224	64	160
E2	114	0	25	0.00	182	182	0	0	0	0	0	0	0	0
E2	115	1	25	0.04	78	75	0	0	3	0	0	3	0	3
C6a	151	1	25	0.04	49	47	0	0	0	2	0	2	0	2
C4	156	1	19	0.05	21	20	0	1	0	0	0	1	1	0
B6	170	4	25	0.16	90	75	0	0	4	7	4	14	0	14
B4	221	4	21	0.19	21	17	0	1	3	0	0	4	1	3