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A survey of the Foveaux Strait oyster (*Ostrea chilensis*) population (OYU 5) in commercial fishery areas and the status of bonamia (*Bonamia exitiosa*) in February 2016.

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Michael, K.P.; Forman, J.; Hulston, D; Sutherland, J. (2017). A survey of the Foveaux Strait oyster (*Ostrea chilensis*) population (OYU 5) in commercial fishery areas and the status of bonamia (*Bonamia exitiosa*) in February 2016.

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The February 2016 Foveaux Strait oyster and bonamia survey was the third in a new time-series of surveys that incorporated a fully randomised, two-phase sampling design and a standard bonamia survey area to make surveys comparable from year to year. Fourteen core strata of the twenty six 2012 stock assessment survey strata were surveyed as the Bonamia survey area. There was also some limited sampling in a single background stratum (all the remaining stock assessment strata combined) to allow these data to be incorporated into assessments.

This survey was undertaken in collaboration with the Bluff Oyster Management Company who provided a vessel, the survey dredge, and crews for the survey. We sampled 55 first phase and 5 second phase random stations, and 12 target stations in February 2016. Sampling began on the 8th of February and was completed on the 15th of February. Sea conditions were good for sampling and the survey was comparable to previous surveys. The abundance of kaeos (*Pyura pachydermatina*) may have greatly reduced dredge efficiency of some tows in strata C5a and E4, as was suspected in 2015, and oyster densities in these strata are likely to be grossly underestimated.

Density and population size of all three size groups of oysters increased in 2016. The density of recruit-sized oysters in core strata was 0.78 oysters m^{-2} in 2016, slightly higher than in 2015, and was 56% of the density in 2012. The population size of recruit-sized oysters in core strata increased from 351.4 million oysters in 2015 (CV 8%) to 385.2 million oysters in 2016 (CV 11%), and was also 56% of the population size in 2012. Recruit-sized oysters increased by similar levels in the background stratum, 158.5 million oysters in 2015 (CV 23.4%) to 176.0 million oysters in 2016 (CV 35.3%). Population size in the background stratum is not well estimated by the five stations sampled in each survey. Pre-recruit (smaller than 58 mm in diameter and larger than 50 mm) oyster densities increased 35.1% from 0.18 oysters m^{-2} in 2015 to 0.25 oysters m^{-2} in 2016. The pre-recruit population size increased from 89.2 million oysters in 2015 to 120.5 million oysters in 2016. The population size of small oysters also increased from 249.0 million oysters in 2015 to 364.3 million oysters in 2016.

Bonamia infection levels decreased markedly in 2016. Stations with no detectable infection were spread across the fishery. The highest and most extensive patterns of infection were in the eastern fishery area (strata C3 and B6), but these were relatively low. The mean prevalence from heart imprints in 2016 (7.5%) was lower than in 2015 (15.3%). The prevalence of infection ranged from 0% to 28% in 2016; with no detectable infection at 13 of the 55 stations, a marked increase from three stations with no detectable infection in 2015. The median prevalence in 2016 was 4.0%, less than in 2015 (12%). The numbers of infected oysters declined from 49.8 million in 2015 to 25.3 million recruit-sized oysters in 2016.

Pre-survey mortality was low in core strata in 2016. Recruit-sized new clocks decreased markedly from 13.5 million in 2015 to 1.4 million in 2016. A similar decline was observed in the numbers of pre-recruit new clocks, 2.2 million in 2015 to 0.2 million in 2016. Post-survey mortality estimated from fatal infections declined from 34.4 million oysters in 2015 to 14.8 million oysters in 2016, 3.8% of the recruit-sized population. Summer mortality was 16.2 million oysters, 4.2% of the recruit-sized population. Summer mortality was much lower in 2016 than in 2015 (12.4–13.1%).

The 2016 Bonamia survey showed some promising signs for the fishery: Bonamia infection and summer mortality were down, and there was an upward trend in the population sizes of all three size groups of

oysters. The declining trend in the fishery from 2012 to 2015 has levelled off in 2016. Because of the relatively low numbers of pre-recruit and small sized oysters, any rebuilding of the recruit-sized population is likely to be slow.

1. INTRODUCTION

The Foveaux Strait oyster fishery (OYU 5) is a high value, iconic fishery that has been fished for over 140 years. Oysters (*Ostrea chilensis*) are an important customary (taonga), recreational, and commercial species, and are important to the socioeconomics of Bluff and Invercargill. The OYU 5 stock is part of the Group 1 stocks in the Ministry for Primary Industries (MPI) draft National Fisheries Plan for Inshore Shellfish which recognises the relatively high biological vulnerability of Group 1 stocks (including OYU 5) and prescribes a close monitoring approach. Achieving maximum value from Group 1 stocks is considered to be best achieved through accurate and frequent monitoring to support responsive management (see MPI research specifications for OYS2013). Additionally, there is an approved collaborative fisheries plan for the management of the fishery, the Foveaux Strait Oyster Fisheries Plan (Ministry of Fisheries 2009). This plan was collaboratively developed by the Foveaux Strait Oyster Fisheries Plan Management Committee (FSOFPMC) which included representatives from the Bluff Oyster Management Company (BOMC), customary and recreational fishers, and the then Ministry of Fisheries, now Ministry for Primary Industries (MPI).

The haplosporidian parasite of flat oysters *Bonamia exitiosa* (bonamia) is thought to be an endemic disease of Foveaux Strait oysters. Two recent bonamia epizootics in 1985–92 and from 2000 to the present (2016) have shown that bonamia mortality is a recurrent feature of the oyster population, and this mortality is the principal driver of oyster population abundance during epizootics. These recurrent events suggest that bonamia epizootics can be expected in the future. Management of the fishery recognises that recruit-sized stock abundance and future benefits from the fishery (harvest levels) are mainly determined by the levels of bonamia mortality, and that the current harvest levels and any effects of fishing on either oyster production or on exacerbating bonamia mortality are not detectable. A summary of bonamia and its effects on the fishery are given in Michael et al. (2015b).

Since 2000, research for the fishery has been directed by strategic research plans (Andrew et al. 2000, Michael & Dunn 2005, Michael 2010). In 2010, a strategic research plan (SRP) for OYU 5 was revised for five years from 2010 to 2015 (Michael 2010). This plan was collaboratively developed with the FSOFPMC and the then Ministry of Fisheries. The 2010 SRP provides a broad range of research programmes aimed at maximising production from the oyster fishery and meeting the Foveaux Strait Oyster Fisheries Plan (Ministry of Fisheries 2009) goals and objectives (see Michael 2010 for details). Developing a better understanding of bonamia and monitoring its effect in the fishery are rated as the highest priorities in the Foveaux Strait Oyster Fisheries Plan and SRP.

Since 1999 the status of the Foveaux Strait oyster population have been assessed by way of a length based Bayesian stock assessment model informed by regular biomass surveys. In the years between stock assessments, annual surveys are undertaken to estimate the status of bonamia in the fishery and to estimate changes in abundance (see Michael et al. 2015b for details). Surveys of the oyster population have sampled a consistent survey area: the 1999 survey area (1054 km^2) and stratum B1a, an additional stratum (16 km^2) that was introduced by oyster skippers for the survey in 2007. Since 2007, the size of the Foveaux Strait oyster survey area has remained at 1070 km^2. The original stratum boundaries have also remained similar since 1999, however some of the 1999 strata were subdivided at different times to better define the areas with commercial densities of oysters. In 2012, 26 strata were sampled.

In years between stock assessments, smaller focused surveys of bonamia prevalence and intensity (bonamia surveys) have been used to monitor the status of bonamia infection. These surveys also estimated short-term (summer) mortality from bonamia in designated commercial areas that were likely to be important to fishers in the following oyster season (see Michael et al. 2015b for details). The combinations of strata surveyed during bonamia surveys differed as the distribution of oyster density

changed with changing patterns of disease mortality. The information required from these surveys has also changed since 2000 (see Michael et al. 2015b for details).

The introduction of five-yearly stock assessments in 2012 has placed greater onus on the annual bonamia surveys to monitor changes in the oyster population in commercial fishery areas as well as the status of bonamia. These changes constitute a new time series of surveys with emphasis on both the status of the oyster population and bonamia mortality. The first of this new time series of bonamia surveys was undertaken in February 2014 (Michael et al. 2015b).

This new time-series of surveys incorporated a fully randomised, two-phase sampling design aimed at better estimating oyster densities and population sizes of oysters and new clocks. To make these surveys comparable from year to year, a standard bonamia survey area was established primarily using fishery independent survey data and fishers' logbook data. This area represents the core commercial fishery that has been consistent through the fluctuations in relative oyster abundance driven by bonamia mortality. Core strata made up 14 of the 26 stock assessment survey strata from 2012 which represented 75% of the recruit-sized oyster population and 46% of the stock assessment survey area. Some limited sampling in background strata was also undertaken to allow these data to be incorporated into stock assessments. This survey design and sampling effort predicts a coefficient of variation (CV) for survey estimates of about 11%. The 2014 survey achieved a CV of 11.2% for recruit-sized oysters in the bonamia survey area, and a CV of 11.7% for the whole population (2007 survey area) from an additional 5 stations in the background stratum (Michael et al. 2015b). The 2015 survey achieved a CV of 8.0% for recruit-sized oysters in the bonamia survey area, and a CV of 9.0% for the whole population (Michael et al. 2015a).

This report provides a summary of information from the third of the new series of Foveaux Strait oyster surveys in the bonamia survey area undertaken in February 2016. This survey estimated the oyster population size and the status of infection by bonamia, and outlines the implications for the future stock status. This survey was undertaken as part of the research for MPI project OYS2013/01.

2. OBJECTIVES

1. To evaluate the current abundance and biomass of oysters in the OYU 5 fishery and to evaluate current and expected oyster mortality from bonamia infection for the 2014, 2015 and 2016 fishing years.

2. To evaluate the current status of the prevalence and intensity of bonamia in the OYU 5 fishery for the 2014, 2015 and 2016 years.

Specific Objective 3 (2015/16)

Using a stratified random sampling design estimate the current recruited abundance and biomass in the area of the commercial Foveaux Strait oyster fishery (for the 2016 fishing year), with a target CV of ≤20%.

Specific Objective 4 (2015/16)

Using a stratified random sampling design estimate the annual mortality from bonamia in the area of the commercial Foveaux Strait oyster fishery for the 2016 fishing year.

Specific Objective 5 (2015/16)

Using a stratified random sampling design estimate the prevalence and intensity of bonamia in the area covering the commercial Foveaux Strait oyster fishery for the 2016 fishing year.

Specific Objective 6 (2015/16)

Evaluate which of the biomass projections, as assessed by the stock assessment model, is the most likely reflection of the current status of the OYU 5 fishery, for the 2016 fishing year.

Specific Objective 7 (2015/16)

Review all qPCR procedures prior to undertaking any analysis of tissue samples for the 2016 fishing year.

3. METHODS

Detailed methods for annual oyster surveys are given in Michael et al. (2015b). A brief summary and any variation to these standard methods is given below.

3.1 Methods for Objective 3

Survey strata for the February 2016 survey were the same as for the February 2014 and February 2015 surveys (Figure 1). The inclusion of a single large background stratum (Figure 1) ensures that the entire 2007 stock assessment survey area is sampled, and data from these annual surveys can be included in stock assessments for OYU 5.

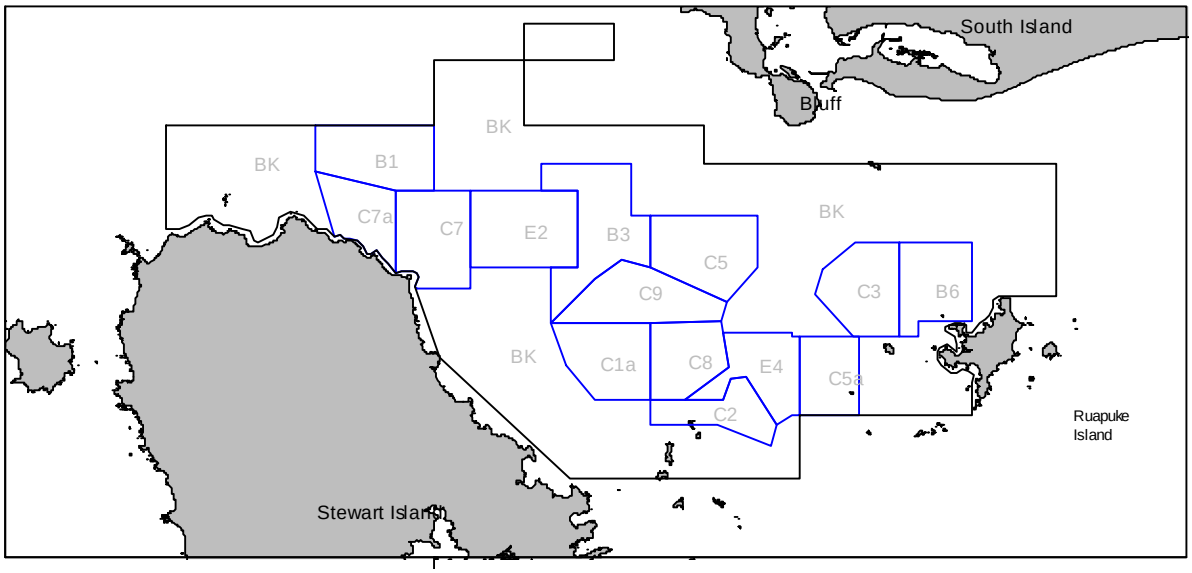

Figure 1: The 2016 survey area with the 2007 survey boundary shown as a heavy, black outer line, and the 2016 survey strata representing the core commercial fishery area shown as blue lines. Strata are labelled with grey text. The remaining stock assessment survey strata which do not represent the core commercial fishery area were merged into a single, large background stratum (BK).

Simulations were undertaken in 2014 to determine the optimal stratification and the numbers of stations required to give a survey coefficient of variation (CV) for the recruit-sized population estimate in the range of 8–12% (see Michael et al. 2015b, objective 2 of OYS2013/01). Simulations predicted that 55 stations in the core strata would produce a CV of about 11%. ALLOCATE (Francis 2006), was used to allocate the numbers of stations to strata in 2016 (Table 1). Rand_Stn (Doonan & Rasmussen 2012) was used to generate the location of 50 random first-phase stations (Figure 2) and sufficient stations in each stratum to sample 5 second-phase stations from core strata, and 5 stations from the background stratum (Figure 2). Stations were generated with an exclusion zone of 0.75 nautical miles to spread stations within strata to ensure good spatial coverage and to prevent the overlap of sample tows. The 12 fixed stations were also sampled in February 2016 (Table 1, Figure 2) to provide a time series of changes in oyster density and bonamia status in localised areas. The Ministry for Primary Industries Shellfish Working Group agreed that they add value to the information obtained from these surveys.

Table 1: The numbers of first-phase stations allocated to each stratum for the February 2016 bonamia survey, the numbers of targeted sample stations in each stratum, total number of stations in each stratum, and the area of each stratum. A single, large background stratum (BK) represents the merged stock assessment survey strata outside the bonamia survey area.

Stratum	First-phase	Target	Area (km^2)
B1	3	1	78.2
B3	3		44.7
B6	5		30.0
B6a		2	*
BK	5		578.3
C1a	3		31.3
C2	3	1	21.9
C3	3	1	32.7
C5	3	1	37.7
C5a	3	1	23.5
C7	3		36.1
C7a	3		23.6
C8	4	1	26.8
C9	8		34.5
E2	3	2	42.8
E4	3	2	28.0
Totals	**55**	**12**	**1070.3**

* The allocation of random stations in the background stratum (BK) included stratum B6a. Two of the target stations are located within BK.

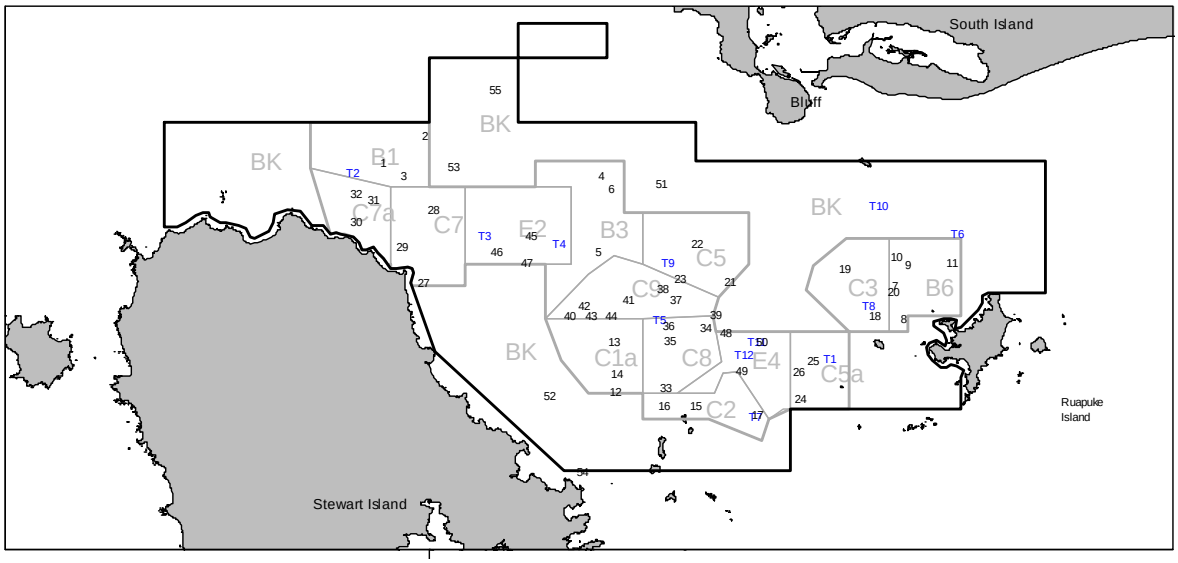

Figure 2: The 2016 survey area with the 2007 survey boundary shown as a heavy, black outer line, and the 2016 survey strata shown as grey lines and the core commercial fishery area shown by heavy grey lines. Strata are labelled with grey text. The remaining stock assessment survey strata which do not represent the core commercial fishery area were merged into a single, large background stratum (BK). First-phase station numbers shown in black text and fixed station numbers in blue text.

Catch sampling

Dredge sampling followed standard procedures for stock assessment and bonamia surveys between October 2002 and February 2014 (Michael et al. 2015b). The commercial oyster vessel used for these surveys (F.V. *Golden Quest*) was not available for the 2016 survey and was replaced with a commercial oyster vessel, F.V. *Golden Lea*, used previously for surveys. The same skipper (Stephen Hawke) that has run these surveys since 2011 skippered the survey vessel. Survey stations were sampled with the standard survey dredge (commercial dredge 3.35 m wide and weighing 430 kg) used since 1993 and rebuilt in 2014 to the same specifications. In February 2016, dredges were deployed using a hydraulic winch system that replaced the traditional friction winch used for surveys before 2014. Standard dredge sampling methods, standard methods for sorting the catch and recording data (data forms are shown in Appendix 1), and standard methods for sampling oysters to determine the status of bonamia were used (see Michael et al. 2015b for details).

In 2016, 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. The catch was further sorted into two size groups: recruit-sized (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). The station data form is shown in Appendix 1 (see Michael et al. 2015b for details).

Estimates of oyster densities and population size

Oyster densities and population sizes for the three size groups of live oysters were estimated for the Bonamia survey area (14 core strata), the single background stratum (combining the 12 non-core strata), and all 26 survey strata combined, which comprise the whole stock assessment survey area. Estimates are presented by core survey strata where three or more randomly selected stations were sampled in

February 2016 and these were compared with the estimates from strata sampled in the 2012 (Michael et al. 2013), 2014 (Michael et al. 2015b), and 2015 (Michael et al. 2015a) surveys. Estimates for the three size groups of live oysters and recruit-sized new clocks are presented separately. The absolute population size of each size group of oysters was estimated using the combined population sizes in each stratum. Estimates of the commercial population size (Michael et al. 2015b) are given for comparison.

Estimates of absolute abundance and variance were calculated using standard stratified random sampling theory (Francis 1984, Jolly & Hampton 1990). We used an estimate of dredge efficiency from Dunn (2005), 0.17 (95% confidence intervals 0.13–0.22) re-estimated from the 1990 data of Doonan et al. (1992) as a single scalar, and hence calculated the absolute population size of recruit, pre-recruit, and small oysters, and clocks using the combined population sizes in each stratum as,

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

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

The coefficient of variation (CV) 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 for each stratum and the total population are estimated by resampling a normal distribution whose variance is based on a CV and the error of the estimated dredge efficiency. The total error of the estimates of the population mean has two sources: One is the sampling error from the survey, where the survey estimate of population size follows a normal distribution and this is based on standard survey sampling theory. The other source is error associated with dredge efficiency, which is assumed to be normally distributed (there are only three data points). If the two sources of error are independent, then the error can be estimated by simply adding the two variance components.

Recruitment to the fishery was summarized using plots of 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 2012, February 2014, February 2015, and February 2016 surveys.

3.2 Methods for Objective 4: estimate the annual mortality from bonamia

Although significant winter mortality from bonamia has occurred previously (Hine 1991), we estimated summer mortality from bonamia only, and for recruit-sized oysters only. Summer mortality comprises the aggregate of two different estimates: 1. Pre-survey mortality estimated from the population size of recruit-sized new clocks and gapers that had died after the last summer, and 2. projections of future (within about two months) disease mortality from the proportion of oysters with categories three and higher (fatal) bonamia infections scaled-up to the size of the total recruit-sized oyster population (Objective 5). Although pre- and post- survey mortality measure different variables and pre-survey mortality may include heightened natural (non-disease related) mortality, the sum of pre- and post-survey totals gives the best estimate of summer mortality.

Pre-survey mortality, the absolute population size of recruit-sized new clocks and gapers, was estimated using the same methods as for live oysters (see Section 3.3 and Michael et al. 2015b for details). Post-survey mortality used the mean proportion of oysters with fatal infections (category 3−5 infections, from Diggles et al. 2003) in each stratum as a correction factor, i.e. 1 - mean proportion of category 3−5 infections. Population estimates for each stratum and the total survey area were recalculated to account for the projected mortality. Total projected mortality is the difference between the total population size at the time of the survey and the population corrected for projected bonamia mortality (at the end of summer). A second estimate of post-survey mortality uses the prevalence of oysters with fatal infections as a scalar to the prevalence in the dredge catch. Stratum and population estimates of fatally infected oysters were made using the method in Section 3.3 and the scaled up numbers of fatally infected oysters in each station sample.

3.3 Methods for Objective 5: estimate the prevalence and intensity of bonamia infection

Definitions and details of the methods used to estimate the prevalence and intensity of bonamia infection are given in Michael et al. (2015c). The numbers of infected recruit-sized oysters were estimated from heart imprints and the quantitative polymerase chain reaction (qPCR) assays. Estimates of prevalence from heart imprints assumed that oysters that tested negative for bonamia using qPCR for heart tissue analysis were also negative for heart imprints. The numbers of non-fatally and fatally infected oysters were estimated from bonamia intensity scores derived from histology and scaled up to the size of the recruit-sized oyster population by strata and for the commercial fishery area.

Histology and quantitative polymerase chain reaction sampling methods

Station 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 station was taken for heart imprints and qPCR. Each oyster in the sample was assigned a unique number from 1 to 25, a size category using oyster size rings, and measured for length and height (see Michael et al. 2015c for details). In 2016, small oysters were denoted with an S (small oysters were denoted with an O in previous surveys). Gaping oysters were marked with an asterisk alongside the corresponding oyster number. Oysters were recorded as either incubating white larvae (early-stage), grey larvae (late-stage), yellow larvae (almost ready to settle); or with no larvae present.

Heart imprints were made using standard methods. Histological samples were taken from the first five oysters processed for heart imprints (see Michael et al. 2015b for details) as for previous surveys. Oysters sampled for heart imprints were also sampled for qPCR. Laboratory work sheets recorded sampling data including: date, name of sampler, plate number and station number and the date and time the sample was collected. The prevalence of infection was first determined by qPCR methods and then heart imprints. Samples of oysters to be scored for intensity of infection were determined from the results of the qPCR testing using standard methods (Michael et al. 2015c).

A detailed account of the qPCR method and testing is given in Maas et al. (2013) and Michael et al. (2015c). This method includes a duplex qPCR assay (the co-amplification of the bonamia target (ITS region of the ribosomal genes) and *Ostrea chilensis* β-actin gene as an internal control), a new master mix that is able to cope with inhibitors often found in crude extracts, and a system to delay the amplification of the internal control to prevent a low level bonamia ITS amplification being outcompeted by the stronger internal control (β-actin) reaction. This method uses a 96 well-plate format, and analysis undertaken with a BIORAD-CFX96 qPCR instrument.

qPCR quality control

Quality control of reagents and methods was undertaken before the samples from the 2016 survey were analysed. A synthetic standard for bonamia was designed (dnature LTD) incorporating the primer and probe sequences and was serially diluted in an oyster lysate diluent (oyster DNA extracted using the same method as used for testing free of bonamia) down to 1 copy per µl. These dilutions (2 µl) were tested with the bonamia duplex assay and two copies could be reliably detected.

Aliquots of the 10^3 copies/ µl dilution were used as inter-plate calibrators to permit collation of data among multiple runs. 20X bonamia qPCR primer/probe mix incorporated primers and probes for the bonamia target and internal control as well as the BLOCK system to prevent the high level endogenous internal control outcompeting a low level bonamia target. Resulting lots of this mix were tested on the synthetic template standard dilutions to ensure that the same sensitivity was maintained (i.e. detection of the 1 copy/ µl dilution).

The qPCR data were analysed using BioRad CFX Manager™ software (Version 3.0), and if needed, qPCR assays were repeated based on the criteria given in Mass et al. (2013). The cycle of quantification (Cq) cut-off to determine positives from false positives was derived from a standard curve analysis of serial dilutions of the standard to extinction, and maintained at Cq 35.

Previously, both heart and gill were analysed for *B. exitiosa* infection using qPCR. In 2016, only heart tissues were analysed, gill tissue samples were archived for future reference. All heart imprint slides for those samples that tested positive for bonamia infection were examined. In addition, at least three samples that were qPCR negative were also randomly selected from the remaining samples from each station. Repeated samples that gave anomalous results such as flat-liners where no reaction was detected or those samples that showed early amplification (very low Cq values) were also scored from heart imprints.

Heart imprints were examined based on the methods of Michael et al. (2015b), and imprints scored based on a categorical scale (Diggles et al. 2003). In 2016, heart imprints were examined by a single experienced reader, and a review of scoring protocols was undertaken before screening samples. 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.

Changes to the qPCR sampling method for the detection of bonamia in oyster tissues

The oyster samples were tested for the presence of bonamia infection using the qPCR method established in 2013 (Maas et al. 2013). Previous surveys tested heart and gill samples. In 2016, only heart tissues ($N \leq 25$ per station) were tested. Samples were tested on a 96 well plate format. All plates were run with serial dilutions of the synthetic standard as positive controls and a single well of deionised distilled water as a negative control. Samples that showed anomalies in the qPCR data were rerun. The repeat scores were used in the analysis for presence/absence.

After the initial qPCR screening for prevalence of bonamia infection a random subset of heart imprint slides were selected to estimate prevalence from heart imprints, and the intensity of infection. These slides included:

1. All corresponding heart imprint slides for those qPCR samples that tested positive for bonamia infection (heart samples only in 2016).
2. At least three heart imprint samples randomly selected from each station that were qPCR negative.
3. All corresponding heart imprint slides for heart qPCR samples that did not amplify both fluorophores (flatliners): FAM (6-carboxyfluorescein) used to detect bonamia, and TR (Texas-red, sulforhodamine 101 acid chloride) used as a cross check to ensure that the qPCR reaction occurred by detecting DNA from oyster tissue in the sample.
4. All corresponding heart imprint slides for heart qPCR samples that were "early ampers" , i.e., the samples where either or both fluorophores amplified very early in the cycling (Cq less than 10 cycles).

The standard methods of Michael et al. (2015b) were used to make estimates of prevalence and intensity of bonamia infection, and scaled population estimates of bonamia infection.

3.4 Methods for Objective 6: evaluate the best future stock projection from the 2012 OYU 5 assessment

Under the new management plan for OYU 5, stock assessments will be carried out five-yearly with annual population and bonamia surveys between assessments. The last assessment was completed in 2012 (Fu 2013) updating the stock assessment models with data on recruitment, harvest, catch rates, population size, and mortality (mostly mortality from bonamia during epizootics). Three projections of future stock status were based on 0%, 10%, and 20% disease mortality. The MPI Shellfish Working Group recommended that no "turn handle" updates of these stock assessment models are required for annual surveys. Selection of the most appropriate projection for future stock status is determined by expert opinion based on the level of summer mortality from bonamia and trends in the population sizes of small and pre-recruit oysters. When these simplistic indicators were used previously to select the most appropriate projection, the population estimates predicted were similar to the estimates of population size estimated from subsequent surveys.

Estimates of summer mortality 2010–2012 ranged from 7.3–12.0%. Using summer mortality to predict future stock abundance was reliable between the 2009 and 2012 stock assessments. 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 was 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 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%, consistent with projections from 2009 stock assessment.

3.5 Methods for Objective 7: review qPCR procedures prior to testing

The qPCR method requires strict adherence to aseptic and molecular biology techniques due to the sensitivity of the method. Quality control of reagents and methods is undertaken before the samples from each survey are analysed.

In 2016, new reagents were tested at NIWA Greta Point to ensure consistency of reaction and Cq values. Reagents were checked using both positive and negative controls and Cq values were checked to ensure that they were within an acceptable range. Further testing was carried out to ensure that serial dilution of the positive control produced the standard cut off value for negatives (Cq35).

In addition to the pre-analysis testing, positive and negative controls were included on every 96 well qPCR plate to ensure the validity of data from each run.

4. RESULTS

4.1 Survey operational detail

The oyster vessel F.V. *Golden Lea* successfully sampled 55 first phase and 5 second phase random stations, and 12 target stations in February 2016. Several allocated stations couldn't be sampled because of rough ground, stations 11, 12, 24, 27, 40, and 54 were replaced by stations 64, 68, 84, 88, 99, and 56 respectively. Sampling began on the 8th of February 2016 and was completed on the 15th of February, sampling on 6 days (8th and 11th–15th) over this period. Survey tows completed are shown in Figure 3, and the numbers of stations sampled in each stratum are shown in Table 2.

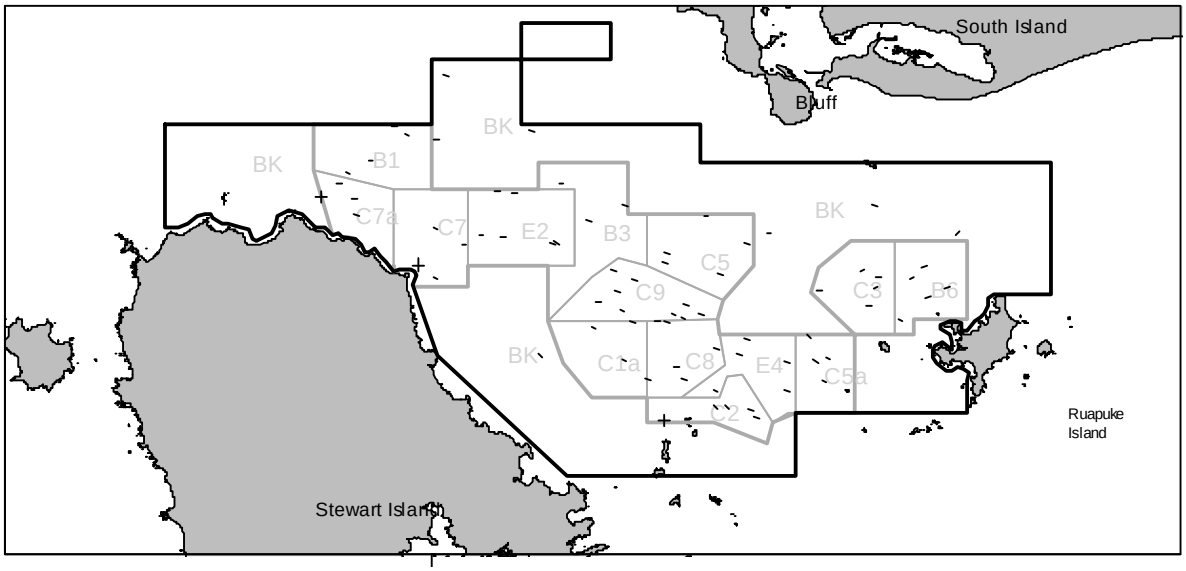

Figure 3: The survey tows (black lines) sampled in February 2016 to determine the status of bonamia infection and oyster density. The stations that could not be dredged because of foul ground are shown as crosses. The 2007 survey area is bound by the outer black line and the February 2016 survey strata are bound by the grey lines. The 2016 survey stratum labels are shown in grey text. Stock assessment survey strata outside the bonamia survey area are merged into a single stratum (BK). Bonamia survey stratum labels have been retained from previous surveys for consistency.

We aimed to collect 30 recruit-sized oysters from each station, to provide tissue samples for qPCR and heart imprints (N=25), and histology (N=5). Target sample size was achieved from 65 of the 72 stations. At sites where fewer than 30 recruit-sized oysters were caught, samples included pre-recruit and small oysters. At stations 64 (N=21), 26 (N=20), 52 (N=13), 50 (N=10), 84 (N=9), and 25 (N=8) fewer than 30 oysters were caught. No oysters were caught at station 108. Oyster samples were couriered to NIWA, Greta Point (Wellington) where they were processed for heart imprints and qPCR. Oyster tissues were also taken for histology and these were archived for future research.

Table 2: The numbers of first-phase, second-phase, and target stations sampled in February 2016 by stratum.

Stratum	First-phase	Second-phase	Target	Total
B1	3		1	4
B3	3			3
B6	5			5
Bk	5		2	7
C1a	3			3
C2	3		1	4
C3	3		1	5
C5	3		1	5
C5a	3		1	4
C7	3	3		3
C7a	3			3
C8	4		1	6
C9	8			9
E2	3		2	6
E4	3	2	2	5
Total	55	5	12	72

Survey comparability

Dredge tow lengths were almost all about 0.2 nautical miles (371 m) in length (Figure 4). 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 wind conditions less than 10 knots (Figure 5). 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 4 (11−15 knots) respectively. Maximum wind speed during sampling was about 15 knots. Dredge sampling during the February 2016 survey was undertaken in calmer conditions than the February 2015 survey which had a median of 3 Beaufort scale (7−10 knots), and 5 and 95 percentiles of Beaufort scale 0 (i.e. less than 1 knot) and 5 (16−20 knots) respectively; and in similar wind conditions to 2014. This wind range and the resulting sea conditions were below the level likely to affect dredge efficiency, but any gains in efficiency may have been moderated by the high tidal flows (spring tides) thought to reduce dredge efficiency (Stephen Hawke, oyster vessel skipper, pers. comm.) over the 2016 sampling period.

Oyster dredges are considered saturated and cease fishing before the end of tow when they are more than 80% full on landing (Cranfield pers. comm.). Dredge saturation may lead to an underestimate of oyster density. No dredge was landed more than 80% full. Dredge fullness ranged from 1% to 80% with a median fullness of 40%, the same as in 2015, but lower than in 2014 (50%) and higher than in 2013 (30%). Differences in dredge fullness are in part related to levels of pre-survey mortality from bonamia that increases the quantities of dead shell. Dredge saturation is not likely to have had a large effect on sampling effectiveness in the 2016 survey (Figure 6). Observations and anecdotal evidence from video data recorded during dredge trials suggest that dredge saturation may occur in dredges landed less than 80% full, however, when this occurs, the dredge contents were unevenly, but symmetrically, spread with contents lower in the middle of the dredge than at the edges of the dredge ring bag. This was not recorded in the 2016 survey data; future surveys will identify stations with this pattern in the distribution of catch. Five stations were landed over 70% full in 2016 with catches of 13, 122, 182, 311, and 758 recruit-sized oysters. Oyster densities may have been underestimated at these stations.

Dredge efficiency is thought to be greatly reduced in areas densely populated with kaeos (*Pyura pachydermatina*) as the dredge skims above the seabed with little or no contact (personal observation, 2015 and 2016 bonamia surveys). Large numbers of kaeos and very few oysters were caught in stratum E4 (station 108) and, stratum C5a (stations 25, 26, and 84). Oyster density was most likely underestimated at these stations.

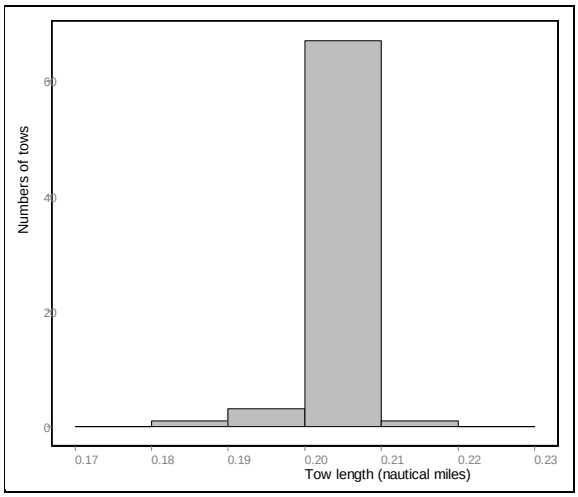

Figure 4: Distribution of dredge tow lengths from the February 2016 survey. The standard tow length was 0.2 nautical mile (371 m).

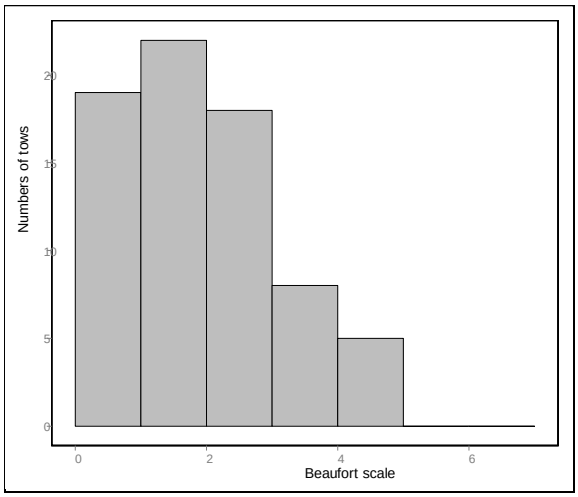

Figure 5: Distribution of sea state (Beaufort scale) recorded during survey tows in February 2016. Beaufort scale: 0, < 1 knot; 1, 1−2 knots; 2, 3−6 knots; 3, 7−10 knots; 4, 11−15 knots; 5, 16−20 knots; and 6, 21−26 knots. Sea states over a Beaufort scale of 5 may reduce dredge efficiency.

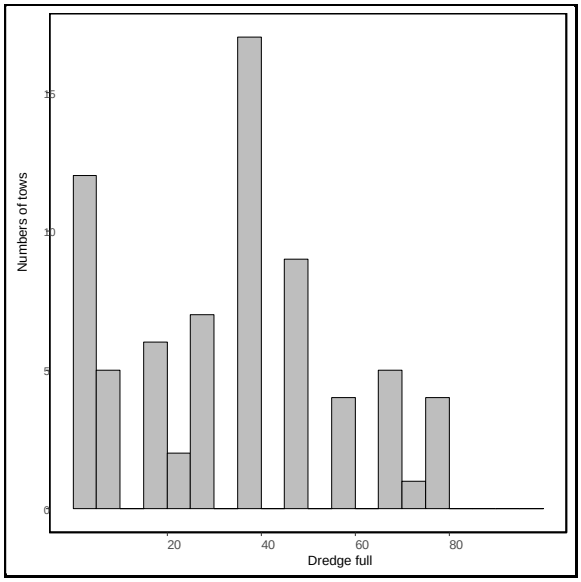

Figure 6: Distribution of dredge fullness recorded for survey tows in February 2016. No tows were landed with a dredge fullness of greater than 80%. Unpublished video data suggests that dredge saturation may occur below 80% full.

4.2 Oyster abundance (Objective 3)

Changes in oyster densities between 2015 and 2016

Plots of catches adjusted to the standard tow length (0.2 nautical miles) during the 2015 and 2016 surveys for recruit-sized, pre-recruit and small oysters, their means and 95% confidence intervals by stratum are shown in Figures 7–9 respectively. Strata are arranged west to east with northern strata at similar longitudes shown before those to the south.

There were high individual catches of recruit-sized oysters in 2016, however, catches were generally similar at stratum level between 2015 and 2016. There were comparatively large declines in catches from stratum C7a in the west, suggesting high localised bonamia mortality (Figure 7), and in E4 in the south, potentially because of reduced dredge efficiency from kaeos.

Pre-recruit-sized oysters also showed a number of relatively high individual catches in 2016 (Figure 8), and generally similar catches at stratum level between 2015 and 2016. Strata B3 and C5 had higher catches in 2016 than in 2015 suggesting some localised recruitment. Catches of small oysters were generally similar or higher across the fishery in 2016 compared with 2015, with a number of high individual catches, and higher catches at stratum level in strata C9, C5, and C5a (Figure 9).

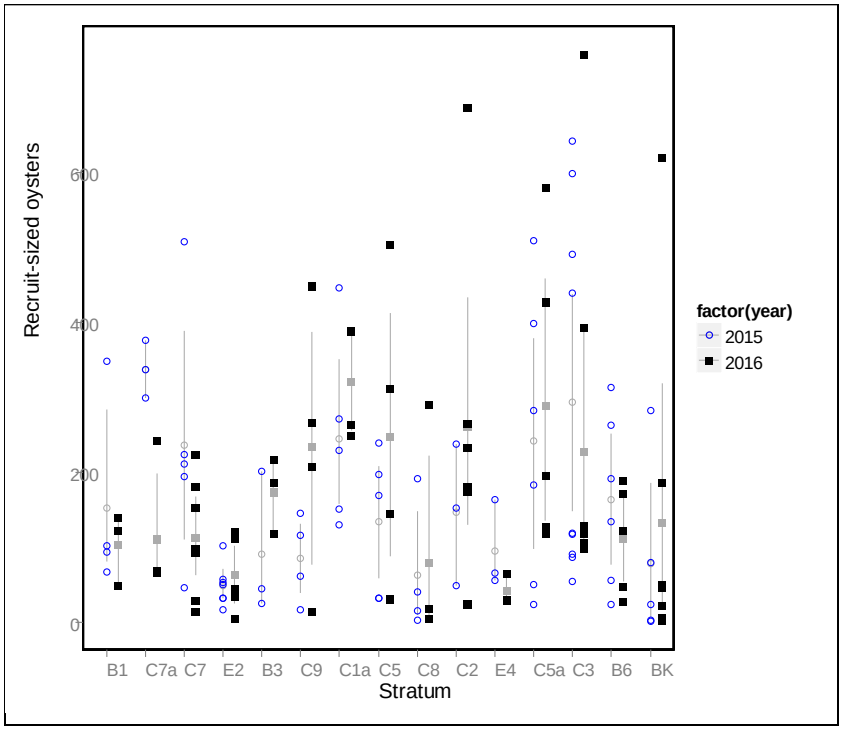

Figure 7: Plots of catches adjusted to the standard tow length (0.2 nautical miles) for recruit-sized oysters, their means and 95% confidence intervals (grey line) by stratum sampled during the 2015 (blue open circles) and 2016 (black closed squares) surveys. Grey open circles (2015) and closed squares (2016) represent annual strata means. Strata are arranged west to east with northern strata at similar longitudes shown first.

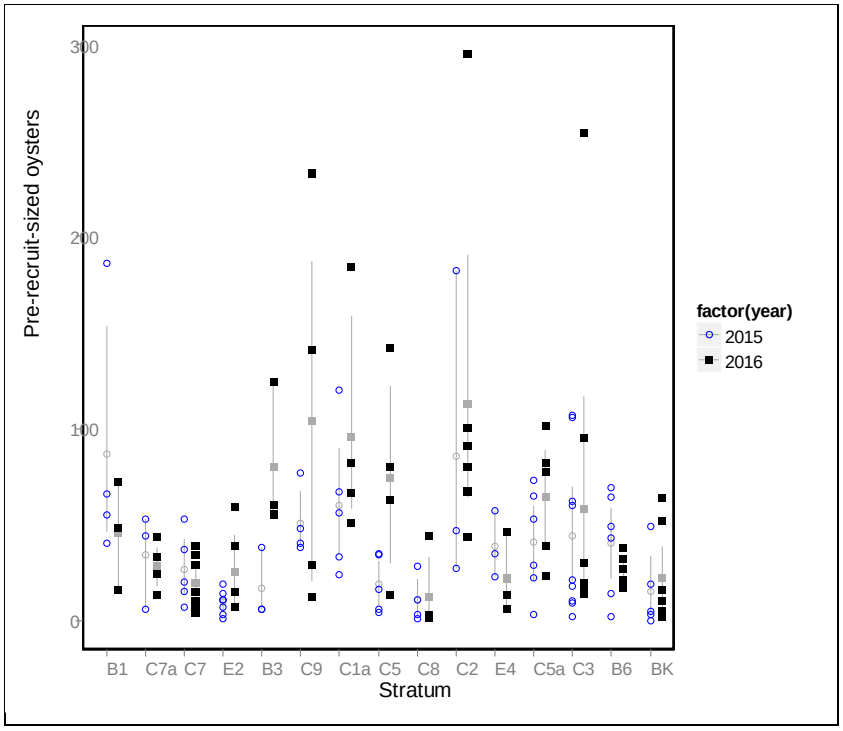

Figure 8: Plots of catches adjusted to the standard tow length (0.2 nautical miles) for pre-recruit-sized oysters, their means and 95% confidence intervals (grey line) by stratum sampled during the 2015 (blue open circles) and 2016 (black closed squares) surveys. Grey open circles (2015) and closed squares (2016) represent annual strata mean. Strata are arranged west to east with northern strata at similar longitudes shown first.

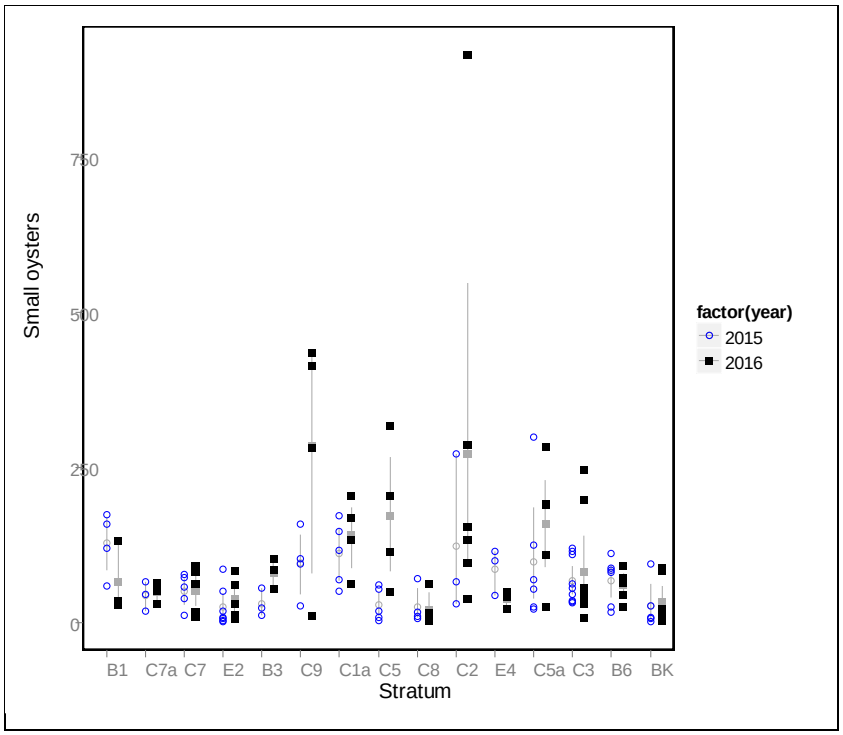

Figure 9: Plots of catches adjusted to the standard tow length (0.2 nautical miles) for small oysters, their means and 95% confidence intervals (grey line) by stratum sampled during the 2015 (blue open circles) and 2016 (black closed squares) surveys. Grey open circles (2015) and closed squares (2016) represent annual strata means. Strata are arranged west to east with northern strata at similar longitudes shown first.

Survey estimates of population size

Estimates of absolute population size for recruit-sized, pre-recruit, and small oysters from the February 2016 survey are shown in Tables 3–5. These tables show population estimates for the core strata (N = 14: B1, B3, B6, C1a, C2, C3, C5, C5a, C7, C7a, C8, C9, E2, and E4), all core strata combined, the background stratum (all background strata combined, N = 12: B1a, B1b, B2, B2a, B2b, B4, B5, B6b, B7, C4, C6, and C6a), and the whole 2007 stock assessment survey area. Two 95% confidence intervals are given: S.lower and S.upper being the sampling confidence limits calculated from the mean, standard deviation and sample size alone, and bootstrapped estimates (B.lower and B.upper) from resampling a normal distribution whose variance is based on a CV and the error of the estimated dredge efficiency. We refer to bootstrapped estimates in the text as they are likely to better represent the true range of possible population size .

The population estimates for recruit-sized, pre-recruit, and small oysters from the 2012, 2014, and 2015 surveys are shown in Appendix 3 (Tables A3.1–A3.9) for comparison. Comparisons between the population estimates for the background stratum in 2012, 2014, and 2015 should be made with caution as there were only 5 stations sampled in total in 2014, 2015, and 2016.

The density and population size of recruit-sized oysters in core strata (commercial fishery areas) increased between 2015 and 2016 (Table 3). The mean density in core strata declined from 1.40 oysters m^{-2} in 2012 to 1.09 oysters m^{-2} in 2014, further declined to 0.71 oysters m^{-2} in 2015, and increased in 2016 (0.78 oysters m^{-2}). Mean density has declined by 50% since 2012 and 35% since 2014. The population size of recruit-sized oysters in core strata declined from 688.1 million oysters in 2012 to 538.0 million oysters in 2014, further declined to 351.4 million oysters in 2015, and increased to 385.2 million oysters in 2016. The population size of recruit-sized oysters declined 49% between 2012 and 2015, declined 35% between 2014 and 2015, but increased 10% between 2015 and 2016. Some of this increase may represent survey variation inherent in random surveys. The coefficients of variation (CV) for all core strata combined was lowest in 2015, 8.0% from 55 stations, compared with 9.2% CV (N = 84) in 2012, 11.2% CV (N = 55) in 2014, and 11.0% CV (N = 55) in 2016. The CV predicted for all core strata combined before the survey using the 2014 and 2015 survey data was less than 11.0%.

The density and population size of recruit-sized oysters in the background stratum are not likely to be well estimated by the surveys since 2012 due to the low numbers of stations sampled (N=5) over a large area (578.4 km^2). Population size is estimated to have increased from 230.3 million oysters in 2012 to 482.9 million oysters in 2014, declined to 158.5 million oysters in 2015, and increased to 176.0 million oysters in 2016. The CVs have increased from 19.7% in 2012 (stations sampled, N=62), to 21.3% (N=5) in 2014, 23.4% (N=5) in 2015, and 35.3% (N=5) in 2016. It is not known how well the nominal five stations represent the size of the oyster population in the background stratum.

The coefficients of variation for estimates between 2012 and 2016 are relatively low: 8.5% in 2012 (N = 146), 11.7% in 2014 (N = 60), 9.1% in 2015 (N = 60), and 13.4% in 2016 (N = 60). The overall decline in population size of 45% between 2012 (Table A3.3) and 2015 (Table A3.1) is consistent with the decline in all core strata combined, however, recruit-sized oysters increased by 10.1% between 2015 and 2016. In retrospect, it is likely that the estimate of population size in the background stratum in 2014 (482.9 million oysters) was by chance high; a result of low sample numbers and random sampling, and this high estimate clearly contributed to the increase in total population size for the 2007 stock assessment survey area between 2012 and 2014, 918.4 million oysters to 1020.9 million oysters respectively.

Recruit-sized oyster population sizes (and mean densities) decreased in five (B3, B6, C5a, C7a, and C9) of the fourteen core strata (Table 3). Declines ranged from 33.0% (C9) to 63.0% (B3) of the 2015 estimates. In both 2015 and 2016, estimates of population size for stratum C5a may have been affected by the abundance of kaeos (which reduced the efficiency of sampling); kaeos were not present in 2014.

Pre-recruit mean oyster densities in all core strata combined declined from 0.60 m^{-2} in 2012, to 0.30 oysters m^{-2} in 2014, to 0.18 oysters m^{-2} in 2015, but increased to 0.25 oysters m^{-2} in 2016 (Table 4). The population size declined from 297.4 million oysters in 2012 to 148.4 million oysters in 2014 and 89.2 million oysters in 2015, and increased to 120.5 million oysters in 2016. Population size declined 70% between 2012 and 2015, and 40% between 2014 and 2015, but increased 35.1% between 2015 and 2016 (Table 4). The population size in the background stratum, and for the 2007 stock assessment survey area showed relatively large increases between 2015 and 2016 (Table 4). The population size of pre-recruits for the 2007 stock assessment area declined from 414.3 million oysters in 2012 to 226.2 million oysters in 2014 and 122.1 million oysters in 2015, but increased to 191.2 million oysters in 2016. The population size declined in six (B1, B3, B6, C5a, C7a, and E2) of the fourteen core strata. A number of strata recorded relatively high increases of up to 380.9% (Table 4).

The mean densities and population sizes of small oysters for all the core strata combined declined markedly (65%) from 451.3 million oysters in 2012 to 156.3 million oysters in 2014, remained similar in 2015 with 158.5 million oysters, and increased to 256.1 million oysters in 2016 (Table 5). The population in the background stratum remained similar between 2012 (160.9 million oysters) and 2014 (156.3 million oysters), but declined 38% in 2015 to 90.5 million oysters, and increased slightly to 108.2 million oysters in 2016 (Table 5). Overall, the population size of small oysters in the 2007 survey area declined by about 50% from 612.2 million oysters in 2012 to 302.6 million oysters in 2014, and further declined 19% to 249.0 million oysters in 2015, but increased by 46.3% to 364.3 million oysters in 2016 (Table 5). Mean small oyster density in all the core strata combined was relatively low (0.52 oysters.m^{-2}), ranging from 0.04 oysters.m^{-2} (C5a) to 1.32 oysters.m^{-2} (C7), but higher than in 2015 (0.32 oysters.m^{-2}). Mean small oyster density in the background stratum was 0.19 oysters.m^{-2} and for the stock assessment survey area was 0.34 oysters.m^{-2} (Table 5).

Table 6 compares survey estimates for recruit-sized, pre-recruit, and small oysters from all core strata combined and for the 2007 stock assessment survey area from 2012, 2014, 2015 and 2016, and gives the percentage change in population size between 2012 and 2014, 2014 and 2015, 2012 and 2015, 2015 and 2016, and 2012 and 2016.

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

Table 7 shows estimates of commercial population size, using the catch of recruit-sized oysters at each station minus 400 oysters, for the 2015 core strata (N = 14), all core strata combined, all background strata combined (N = 12), and for the whole 2007 stock assessment survey area sampled in 2016. Estimates for the 2015, 2014, and 2012 surveys are shown in Appendix 3 (Tables A3.10–12 respectively).

Ten core strata supported commercial densities in 2012, six in 2014, only two in 2015, and six in 2016. The mean commercial density in the background stratum was 0.11 oysters.m^{-2} in 2012, and zero in 2014, 2015, and 2016 (Tables 7, A3.10–12). The commercial population size declined from 473.9 million oysters in 2012 to 211.3 million oysters in 2014, further declined to 55.4 million oysters in 2015, and increased to 88.8 million oysters in 2016. The declines in the oyster populations are consistent with the levels of bonamia mortality observed in the fishery and the prolonged period of relatively low recruitment.

Table 3: **Absolute population estimates from randomly allocated stations only for recruit-sized oysters in the core strata (Stratum), background stratum (BK), and for the whole 2007 stock assessment survey area (Survey total) sampled in 2016. The number of stations sampled (No. stns), the mean oyster density per m^2 (Mean density), the standard deviation of the mean density estimate (Density s.d.), the coefficient of variation (CV) of the density estimate, the mean population size in millions of oysters (Pop.n, shaded grey), upper and lower 95% confidence intervals (95% CI) in millions of oysters where an S prefix denotes the sampling CI calculated from the mean, standard deviation and sample size alone, and a B prefix denotes the bootstrapped estimates, and the area of each stratum (Area. km^2) in square kilometres, by stratum for the February 2016 Foveaux Strait oyster survey. The percentage of the 2015 estimate (% of 2015) is shaded green for increases in population size and red for decreases.**

2016 Stratum	No. stns	Mean density	Density s.d.	CV	2016 Pop.n	S.lower 95%CI	S.upper 95%CI	B.lower 95%CI	B.upper 95%CI	Area.km^2	% of 2015 pop.n
B1	3	0.50	0.13	0.26	39.2	27.5	51.0	17.3	69.0	78.2	117.2
B3	3	0.61	0.29	0.47	27.2	12.7	41.8	2.3	57.8	44.7	37.0
B6	5	0.65	0.18	0.27	19.6	15.0	24.2	8.4	34.4	30.0	56.8
C1a	3	0.84	0.14	0.17	26.2	21.3	31.2	15.2	41.9	31.3	194.1
C2	3	1.08	0.62	0.57	23.7	8.4	39.0	0.0	55.1	21.9	296.4
C3	3	1.46	0.21	0.15	47.9	40.0	55.8	28.6	75.8	32.7	154.0
C5	3	0.79	0.40	0.50	29.8	12.9	46.7	0.8	65.5	37.7	151.5
C5a	3	0.05	0.02	0.46	1.1	0.5	1.6	0.1	2.3	23.5	46.7
C7	6	1.26	0.45	0.36	45.6	32.6	58.7	12.9	87.5	36.1	176.9
C7a	3	0.19	0.05	0.26	4.5	3.2	5.9	2.0	8.0	23.6	41.7
C8	4	1.24	0.54	0.44	33.3	19.1	47.4	4.8	69.1	26.8	138.0
C9	8	1.10	0.41	0.37	37.9	28.2	47.7	9.8	74.5	34.5	77.0
E2	3	0.58	0.19	0.32	24.9	15.8	34.0	9.0	46.6	42.8	118.6
E4	5	0.86	0.59	0.68	24.1	9.7	38.6	0.0	62.5	28.0	618.3
Core	55	0.78	0.09	0.11	385.2	374.0	396.3	246.9	593.8	491.8	109.6
BK	5	0.30	0.11	0.35	176.0	121.4	230.5	51.2	339.6	578.4	111.0
Survey total	60	0.52	0.07	0.13	561.1	542.1	580.2	341.6	866.7	1070.2	110.1

Table 4: **Absolute population estimates from randomly allocated stations only for pre-recruit-sized oysters in the core strata (Stratum), background stratum (BK), and for the whole 2007 stock assessment survey area (Survey total) sampled in 2016. The number of stations sampled (No. stns), the mean oyster density per m^2 (Mean density), the standard deviation of the mean density estimate (Density s.d.), the coefficient of variation (CV) of the density estimate, the mean population size in millions of oysters (Pop.n, shaded grey), upper and lower 95% confidence intervals (95%CI) in millions of oysters where an S prefix denotes the sampling CI calculated from the mean, standard deviation and sample size alone, and a B prefix denotes the bootstrapped estimates, and the area of each stratum (Area. km^2) in square kilometres, by stratum for the February 2016 Foveaux Strait oyster survey. The percentage of the 2015 estimate (% of 2015) is shaded green for increases in population size and red for decreases.**

2016 Stratum	No. stns	Mean density	Density s.d.	CV	Pop.n	S.lower 95%CI	S.upper 95%CI	B.lower 95%CI	B.upper 95%CI	Area.km^2	% of 2015 pop.n
B1	3	0.22	0.08	0.35	17.2	10.3	24.0	4.9	33.0	78.2	84.2
B3	3	0.11	0.03	0.25	5.1	3.6	6.5	2.4	8.7	44.7	67.5
B6	5	0.12	0.03	0.27	3.5	2.7	4.3	1.5	6.2	30.0	92.7
C1a	3	0.38	0.11	0.28	12.0	8.2	15.8	5.1	21.6	31.3	480.9
C2	3	0.60	0.29	0.49	13.2	5.9	20.5	0.5	28.6	21.9	239.3
C3	3	0.32	0.04	0.14	10.6	9.0	12.2	6.5	16.6	32.7	147.3
C5	3	0.25	0.10	0.39	9.6	5.4	13.7	2.2	18.9	37.7	354.0
C5a	3	0.01	0.00	0.40	0.2	0.1	0.3	0.0	0.4	23.5	32.0
C7	6	0.55	0.18	0.34	19.7	14.4	25.0	6.2	37.0	36.1	130.5
C7a	3	0.10	0.05	0.55	2.4	0.9	3.8	0.0	5.4	23.6	53.5
C8	4	0.29	0.09	0.30	7.8	5.5	10.1	3.0	14.2	26.8	176.9
C9	8	0.28	0.14	0.51	9.7	6.2	13.1	0.0	21.9	34.5	130.8
E2	3	0.14	0.02	0.15	6.1	5.1	7.1	3.7	9.5	42.8	90.4
E4	5	0.13	0.07	0.50	3.7	2.1	5.3	0.1	8.2	28.0	366.3
Core	55	0.25	0.03	0.11	120.5	116.9	124.2	76.8	186.7	491.8	135.1
BK	5	0.12	0.05	0.40	70.7	45.7	95.7	14.1	143.0	578.4	214.9
Survey total	60	0.18	0.03	0.17	191.2	183.2	199.3	109.9	304.8	1070.2	156.6

Table 5: **Absolute population estimates from randomly allocated stations only for small oysters in the core strata (Stratum), background stratum (BK), and for the whole 2007 stock assessment survey area (Survey total) sampled in 2016. The number of stations sampled (No. stns), the mean oyster density per m^2 (Mean density), the standard deviation of the mean density estimate (Density s.d.), the coefficient of variation (CV) of the density estimate, the mean population size in millions of oysters (Pop.n, shaded grey), upper and lower 95% confidence intervals (95%CI) in millions of oysters where an S prefix denotes the sampling CI calculated from the mean, standard deviation and sample size alone, and a B prefix denotes the bootstrapped estimates, and the area of each stratum (Area. km^2) in square kilometres, by stratum for the February 2016 Foveaux Strait oyster survey. The percentage of the 2015 estimate (% of 2015) is shaded green for increases in population size and red for decreases.**

2016 Stratum	No. stns	Mean density	Density s.d.	CV	Pop.n	S.lower 95%CI	S.upper 95%CI	B.lower 95%CI	B.upper 95%CI	Area.km^2	% of 2015 pop.n
B1	3	0.62	0.25	0.41	48.9	30.6	55.4	9.5	98.3	78.2	113.6
B3	3	0.24	0.05	0.21	10.6	6.2	13.2	5.7	17.5	44.7	109.6
B6	5	0.32	0.07	0.22	9.7	6.0	9.2	4.9	16.3	30.0	127.5
C1a	3	0.39	0.07	0.17	12.3	2.5	6.7	7.0	19.7	31.3	266.7
C2	3	1.18	0.60	0.51	25.8	5.1	11.1	0.0	57.1	21.9	318.4
C3	3	0.59	0.15	0.26	19.4	12.2	20.6	8.6	34.2	32.7	118.4
C5	3	0.60	0.22	0.36	22.7	1.9	6.1	6.4	43.7	37.7	566.6
C5a	3	0.04	0.02	0.50	0.9	1.1	1.5	0.0	2.0	23.5	71.0
C7	6	1.32	0.65	0.50	47.5	6.6	37.0	0.6	103.7	36.1	218.0
C7a	3	0.18	0.04	0.20	4.3	7.3	12.7	2.3	7.1	23.6	43.2
C8	4	0.74	0.27	0.37	19.8	5.5	9.7	5.4	38.6	26.8	260.4
C9	8	0.40	0.15	0.38	13.8	10.3	12.9	3.3	27.4	34.5	118.6
E2	3	0.35	0.06	0.17	14.9	7.2	14.6	8.5	24.0	42.8	136.3
E4	5	0.20	0.09	0.47	5.6	0.6	3.0	0.5	12.2	28.0	312.3
Core	55	0.52	0.07	0.14	256.1	153.3	163.7	155.0	407.3	491.8	161.6
BK	5	0.19	0.07	0.38	108.2	50.8	130.2	27.3	213.0	578.4	119.6
Survey total	60	0.34	0.05	0.15	364.3	235.3	262.7	215.9	570.6	1070.2	146.3

Table 6: Percentage changes in the absolute population estimates from randomly allocated stations only for recruit-sized, pre-recruit, and small oysters in the core strata, and for the whole 2007 stock assessment survey area (26 strata) sampled in 2012, 2014, 2015, and 2016. The mean oyster density per m^2 (Mean density), coefficient of variation (CV) of the density estimate, mean population size in millions of oysters (Pop.n, shaded grey), bootstrapped upper and lower 95% confidence intervals (95%CI) in millions of oysters, and the percentage change in population size.

2012

Core Strata	Mean density	CV	Pop.n	B.lower 95%CI	B.upper 95%CI
Recruit	1.40	0.09	688.1	449.2	1046.7
Pre-recruit	0.60	0.10	297.4	192.6	454.4
Small	0.92	0.16	451.3	261.5	731.7
Survey total					
Recruit	0.86	0.08	918.4	600.1	1383.7
Pre-recruit	0.39	0.10	414.3	267.8	629.0
Small	0.57	0.14	612.2	370.3	967.9

2014

Core Strata	Mean density	CV	Pop.n	B.lower 95%CI	B.upper 95%CI	% change 2012-2014
Recruit	1.09	0.11	538.0	343.6	832.2	-21.8
Pre-recruit	0.30	0.12	148.4	93.7	230.7	-50.1
Small	0.32	0.10	156.3	101.1	239.4	-65.4
Survey total						
Recruit	0.95	0.12	1020.9	635.1	1554.2	11.2
Pre-recruit	0.21	0.14	226.2	135.1	352.1	-45.4
Small	0.28	0.11	302.6	189.2	459.2	-50.6

2015

Core Strata	Mean density	CV	Pop.n	B.lower 95%CI	B.upper 95%CI	% change 2014-2015	% change 2012-2015
Recruit	0.71	0.08	351.4	232.1	528.8	-34.7	-48.9
Pre-recruit	0.18	0.12	89.2	55.8	139.2	-39.9	-70.0
Small	0.32	0.12	158.5	99.6	247.1	1.4	-64.9
Survey total							
Recruit	0.48	0.09	509.9	327.4	761.8	-50.0	-44.5
Pre-recruit	0.11	0.11	122.1	76.7	184.7	-46.0	-70.5
Small	0.23	0.20	249.0	130.8	412.4	-17.7	-59.3

2016

Core Strata	Mean density	CV	Pop.n	B.lower 95%CI	B.upper 95%CI	% change 2015-2016	% change 2012-2016
Recruit	0.78	0.09	385.2	246.9	593.8	9.6	-44.0
Pre-recruit	0.25	0.03	120.5	186.7	491.8	35.1	-59.5
Small	0.52	0.07	256.1	155.0	407.3	61.6	-43.3
Survey total							
Recruit	0.52	0.07	561.1	341.6	866.7	10.1	-38.9
Pre-recruit	0.18	0.03	191.2	109.9	304.8	56.1	-53.8
Small	0.34	0.05	364.3	215.9	570.6	46.3	-40.5

Table 7: **Absolute population estimates from randomly allocated stations only for the size 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 the 2015 core strata, the background stratum (BK), and for the whole 2007 stock assessment survey area (Survey total) sampled in 2016. The number of stations sampled (No. stns), the mean oyster density per m^2 (Mean density), the standard deviation of the mean density estimate (Density s.d.), the coefficient of variation (CV) of the density estimate, the mean population size in millions of oysters (Pop.n, shaded grey), upper and lower 95% confidence intervals (95%CI) in millions of oysters where an S prefix denotes the sampling CI calculated from the mean, standard deviation and sample size alone, and a B prefix denotes the bootstrapped estimates, and the area of each stratum (Area. km^2) in square kilometres, by stratum for the February 2016 Foveaux Strait oyster survey. The percentage of the 2015 estimate (% of 2015) is shaded red for decreases in population size and NC for no change.**

2016 Stratum	No. stns	Mean density	Density s.d.	CV	Pop.n	S.lower 95%CI	S.upper 95%CI	B.lower 95%CI	B.upper 95%CI	Area.km^2	% Change since 2015
B1	3	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	78.2	0.0
B3	3	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	44.7	0.0
B6	5	0.00	0.00	0.00	0.0	1.8	27.8	0.0	0.0	30.0	-14.8
C1a	3	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	31.3	0.0
C2	3	0.73	0.73	1.00	16.0	0.0	0.0	0.0	51.4	21.9	16.0
C3	3	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	32.7	0.0
C5	3	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	37.7	0.0
C5a	3	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	23.5	0.0
C7	6	0.56	0.56	1.00	20.3	0.0	0.0	0.0	63.9	36.1	20.3
C7a	3	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	23.6	0.0
C8	4	0.71	0.71	1.00	19.1	0.0	0.0	0.0	60.8	26.8	19.1
C9	8	0.46	0.46	1.00	15.9	30.0	51.2	0.0	51.1	34.5	-24.7
E2	3	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	42.8	0.0
E4	5	0.62	0.62	1.00	17.5	0.0	0.0	0.0	55.4	28.0	17.5
Core	55	0.18	0.08	0.45	88.8	50.1	60.7	11.4	187.1	491.8	33.4
BK	5	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	578.4	578.4
Survey total	60	0.08	0.04	0.45	88.8	49.8	61.0	11.4	187.1	1070.2	33.4

Changes in the distribution of live oysters

Stratified random surveys are generally not as good as grid design surveys at estimating the distribution of oysters in Foveaux Strait, especially because of their patchy distribution. The February 2016 survey sampled 60 first and second-phase random stations generated with a 0.75 nautical mile exclusion zone to spread sampling effort, and 12 fixed stations. All 72 stations were used to describe oyster distribution. Sampling effort was focused in core strata with background strata receiving only 5 stations for 51.4% of the survey area. The sampling was therefore insufficient to provide a consistent or complete coverage of the fishery area in 2016, and hence the survey is not likely to have estimated the distributions of oyster density well for live recruit, pre-recruit, and small oysters outside of core strata. These distributions of oysters are compared with the last stock assessment survey in 2012 which sampled 158 stations in total and provided more complete coverage of the fishery. Only 71 and 72 stations were sampled in 2014 and 2015 respectively.

Comparisons of the distributions of recruit-sized, pre-recruit, and small oyster density for 2012 and 2016, and 2015 and 2016 are shown in Figures 10–15. The distribution of oyster densities of all sizes is widespread, covering most of the fishery area with the highest densities in core fishery strata (Figures 10, 12, and 14). Densities of all three size groups of oysters were lower in 2016 than in 2012, and generally higher than in 2015. The numbers and sizes of localised areas of relatively high density of recruit-sized oysters decreased between 2012 and 2016, but were higher than in 2015 (Figures 10 and 11). The decrease since 2012 is most likely the result of ongoing, low to moderate level bonamia mortality and reduced recruitment to the fishery. Densities of recruit-sized oysters decreased in western areas (B1 and C7a) between 2012 and 2016 where there was virtually no fishing. They also decreased in northern and central areas, and were generally static in southern and eastern areas (Figure 10).

The density estimates of pre-recruit oysters decreased markedly between 2012 and 2016 (Figure 12), to become very low and patchy in 2016 (Figure 12). Pre-recruit-sized oysters are as vulnerable to bonamia mortality as recruit-sized oysters, and the low densities also reflect the low settlement of oyster spat and low survival of juveniles (small oysters) in recent years. The numbers and sizes of pre-recruit sized oysters increased in 2016 from the few, low density, isolated patches in 2015 (Figure 13).

The distributions of small oyster densities (Figures 14 and 15) showed similar patterns to pre-recruit sized oyster densities. Relatively high densities of small oysters were widespread throughout the fishery in 2012, except for in the central fishery area (Figure 14). Densities decreased markedly across the entire fishery by 2015 (Figure 15), but increased markedly in 2016, especially in western areas. Small oysters are not vulnerable to bonamia mortality. The low densities reflect low recruitment to the oyster population which is consistent with low spat settlement since 2009.

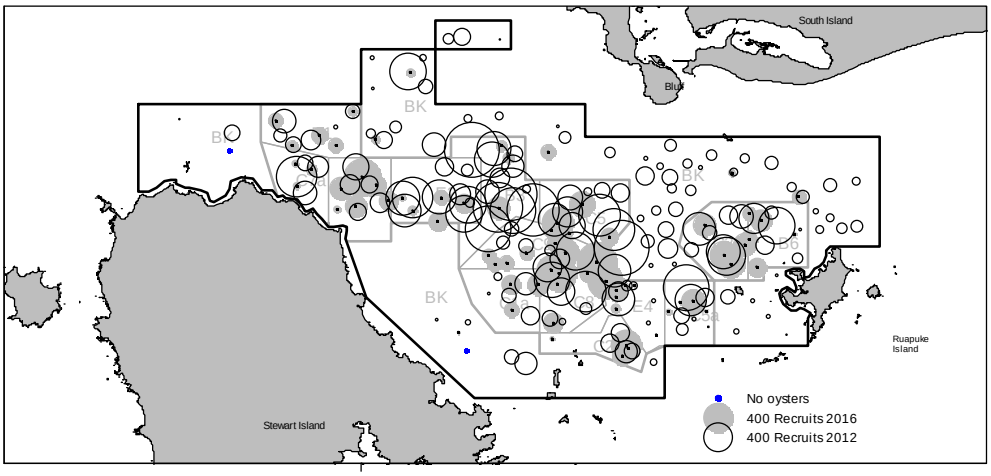

Figure 10: The densities (numbers of oysters per standard tow, 1221 m^2) of recruit-sized oysters sampled during the February surveys in 2016 (filled grey circles) and in 2012 (open black circles). Blue filled circles denote no oysters caught.

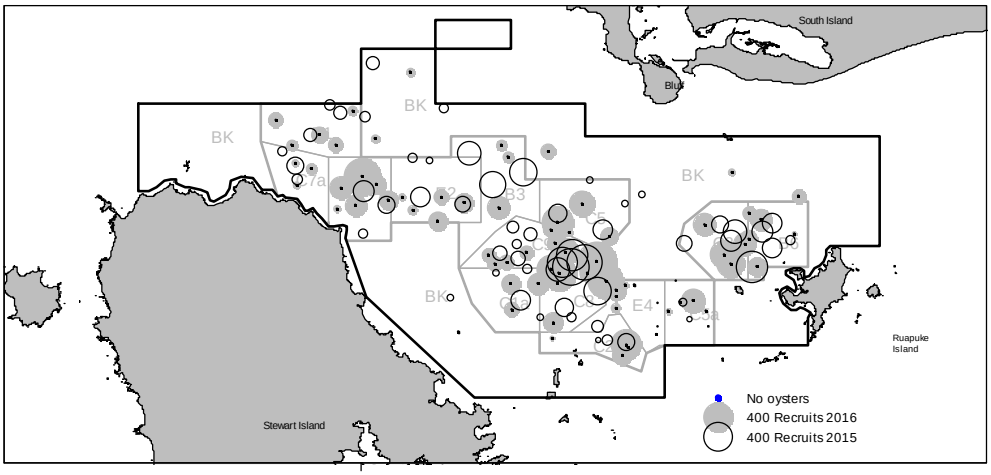

Figure 11: The densities (numbers of oysters per standard tow, 1221 m^2) of recruit-sized oysters sampled during the February surveys in 2016 (filled grey circles) and in 2015 (open black circles). Blue filled circles denote no oysters caught.

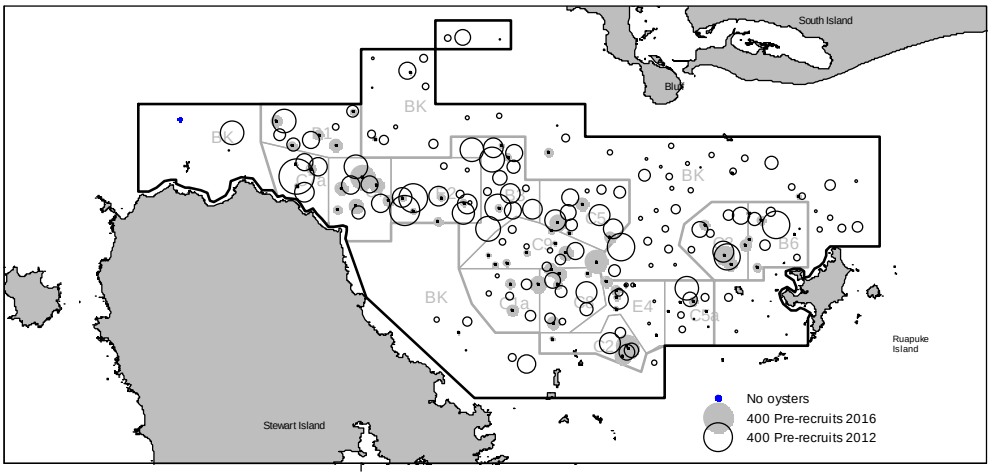

Figure 12: The densities (numbers of oysters per standard tow, 1221 m^2) of pre-recruit-sized oysters sampled during the February surveys in 2016 (filled grey circles) and in 2012 (open black circles). Blue filled circles denote no oysters caught.

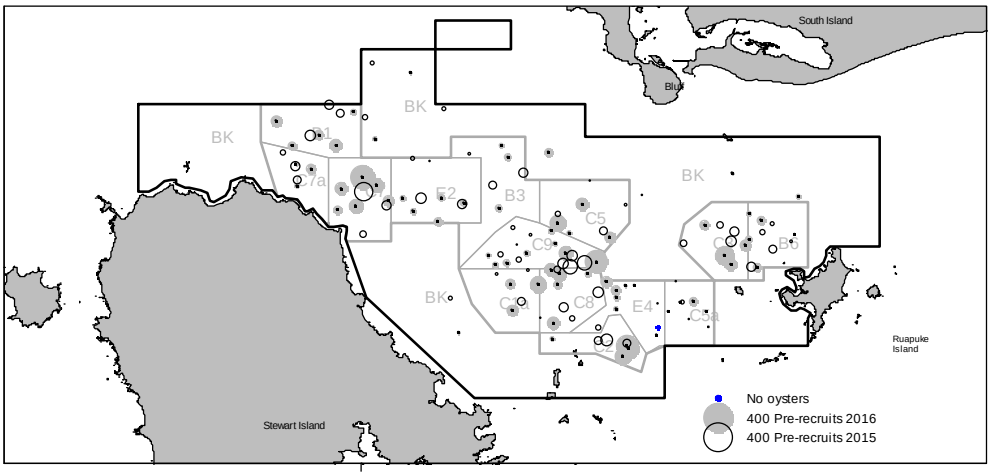

Figure 13: The densities (numbers of oysters per standard tow, 1221 m^2) of pre-recruit-sized oysters sampled during the February surveys in 2016 (filled grey circles) and in 2015 (open black circles). Blue filled circles denote no oysters caught.

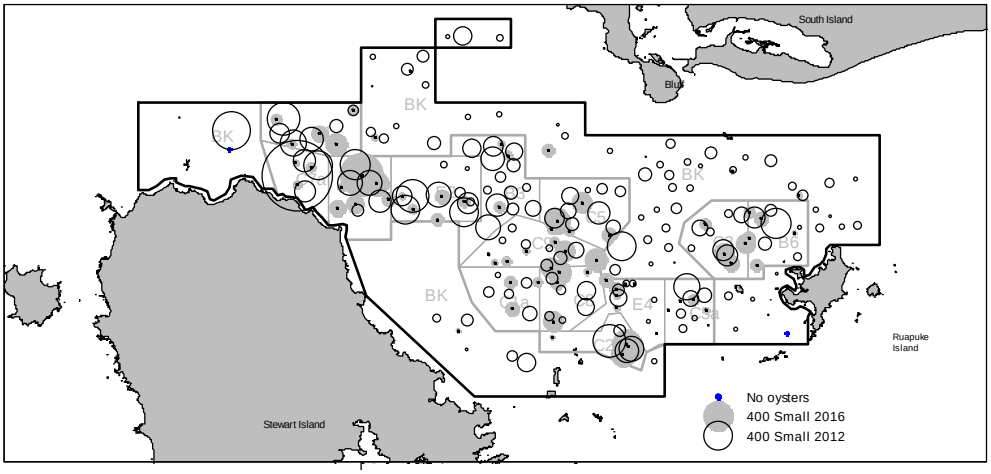

Figure 14: The densities (numbers of oysters per standard tow, 1221 m^2) of small oysters sampled during the February surveys in 2016 (filled grey circles) and in 2012 (open black circles). Blue filled circles denote no oysters caught.

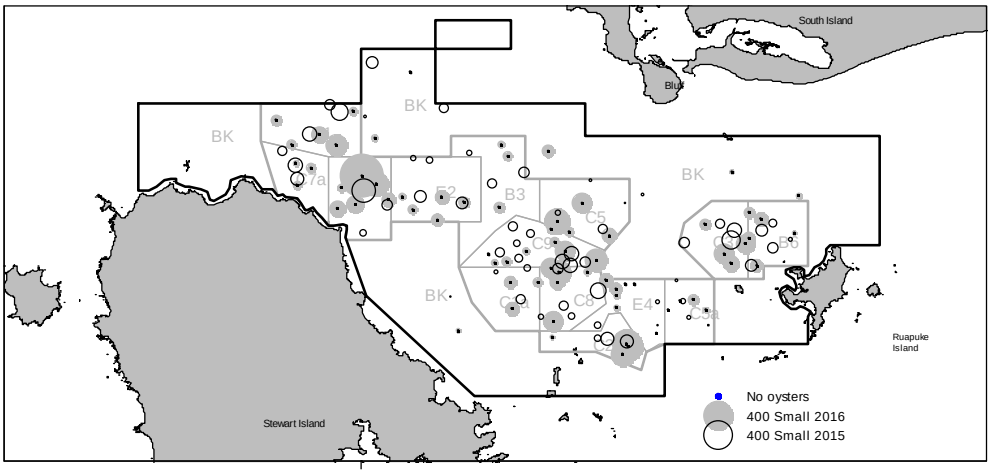

Figure 15: The densities (numbers of oysters per standard tow, 1221 m^2) of small oysters sampled during the February surveys in 2016 (filled grey circles) and in 2015 (open black circles). Blue filled circles denote no oysters caught.

Recruitment

Small oysters settle and remain attached to settlement surfaces up to a size of about 40 mm in length. Although oyster spat readily settle on clean shell surfaces, most small oysters are found on live oysters, possibly because survival of juveniles is better on large live oysters. Relatively few small oysters are found on other settlement surfaces. The median numbers of small oysters per recruited oyster is used as a relative index of replenishment to the population, but not an absolute estimate of recruitment.

The numbers of small oysters per recruit shows large fluctuations in a broadly cyclic trend between 1993 and 2016 (Figure 16). The numbers of small oysters per recruit were generally low between 1995 and 2001, suggesting reduced recruitment to the population at a time when the numbers of recruit-sized oysters were increasing and relatively high compared to 1993 (and earlier) (Figure 16). Small oysters per recruit were relatively high between 2002 and 2005 when the recruit-sized oyster population was declining rapidly from bonamia mortality. From 2009, the numbers of small oysters per recruit declined to low levels and have remained low (Figure 16). This is consistent with the trend of declining numbers of small oysters sampled from the commercial catch between 2009 and 2012 (Fu et al. 2013), and the decreasing numbers of small oysters from stock assessment surveys (889 million oysters (574–1351) in 2009 and 607 million oysters (369–952) in 2012 (Michael et al. 2013).

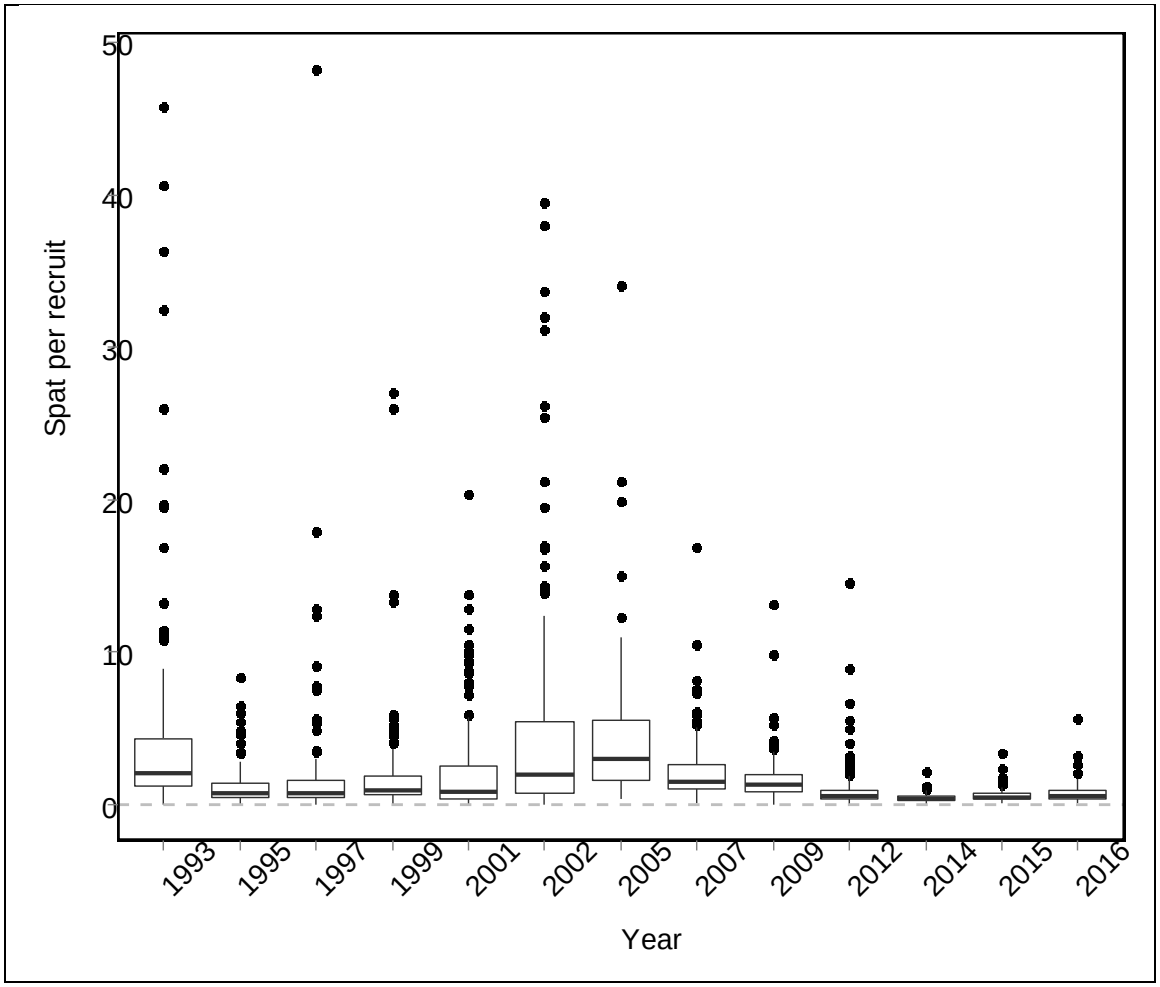

Figure 16: The numbers of small oysters per recruited oyster sampled between 1993 and 2016. The numbers of stations sampled each year varies. Medians shown as solid lines, boxes represent 50 percentiles (25–75%) and whiskers 90 percentiles (5–95%), and outliers smaller than 5% and greater than 95% as filled circles.

4.3 Estimates of oyster mortality before and during the February 2016 survey (Objective 4)

Descriptive statistics for the percentages of recruit-sized and pre-recruit new clocks and gapers sampled in 2016 are given in Table 8 along with statistics for the 2012, 2014 and 2015 surveys for comparison. Decreases in these statistics for recruit sized new clocks and gapers suggest that pre-survey mortality was markedly lower in 2016 than in the previous two years. Pre-survey mortality for pre-recruits showed a similar trend, but the percentages are in part influenced by the low population size compared to that in 2012.

Table 8: Descriptive statistics for the percentages of new clocks and gapers for two size groups, recruit and pre-recruit. Percentages are new clocks and gapers to new clocks, gapers and oysters combined, sampled from survey tows with more than 50 live recruit-sized or pre-recruit oysters in 2012, 2014, 2015, and 2016.

Percentage new clocks and gapers	Recruit sized				Pre-recruits			
Year	**2012**	**2014**	**2015**	**2016**	**2012**	**2014**	**2015**	**2016**
No. stations	112	50	54	52	78	30	20	26
Median	3.3	7.8	4	0.4	2.6	2.5	1.6	0
Minimum	0	1.7	0	0	0	0	0	0
Maximum	28.9	15.1	14.3	3	12.5	8.1	5.2	1.2
Lower 5th percentile	0.3	2.5	0	0.2	0	0	0	0
Upper 95th percentile	7.2	14	11.4	0.6	10.1	7.8	4.3	0.1
No. stations with no new clocks	5	0	5	22	11	8	9	22

There were very few gapers observed during the February 2016 survey, three stations (4.2%) had one or more recruit-sized gaper. Only one station (1.4%) had a single pre-recruit-sized gaper in 2016. Fewer stations recorded gapers than in previous surveys; 26% in 2012, 14% in 2014, and 6.9% in 2015.

Markedly fewer new clocks were sampled from survey tows with more than 50 live oysters in 2016 than in 2015. In 2016, pre-survey mortality for recruit-sized oysters was lower in most strata (Figure 17).

The distributions of recruit-sized oysters, new clocks and gapers combined, and recruit-sized new clocks and gaper densities showing levels of pre-survey mortality for the 2012, 2014, 2015, and 2016 surveys are shown in Figures 18–21 respectively. Pre-survey mortality increased between 2012 and 2014, then declined markedly to become very low in 2016.

Pre-survey mortality was widespread and variable in 2012, and higher at stations where recruit-sized oyster densities were high, mostly in strata designated as commercial (E2, B3, C3, CB6, C7, and C7a) (Figure 18). Recruit-sized oyster densities were generally low in western strata; as was pre-survey mortality, except for a couple of stations where oyster density was high.

In 2014, the distribution of pre-survey mortality was similar to 2012. However, the densities of recruit-sized new clocks and gapers were generally much higher in 2014, and the densities of recruit-sized oysters were lower than in 2012 (Figure 19). Bonamia mortality had greatly reduced the numbers and sizes of areas with relatively high oyster density by 2015, especially west of a line from Bluff Hill to Port William. The pre-survey mortality had greatly declined across the fishery by 2015 (Figure 20), and declined further in 2016 to very low levels, while oyster densities increased slightly (Figure 21).

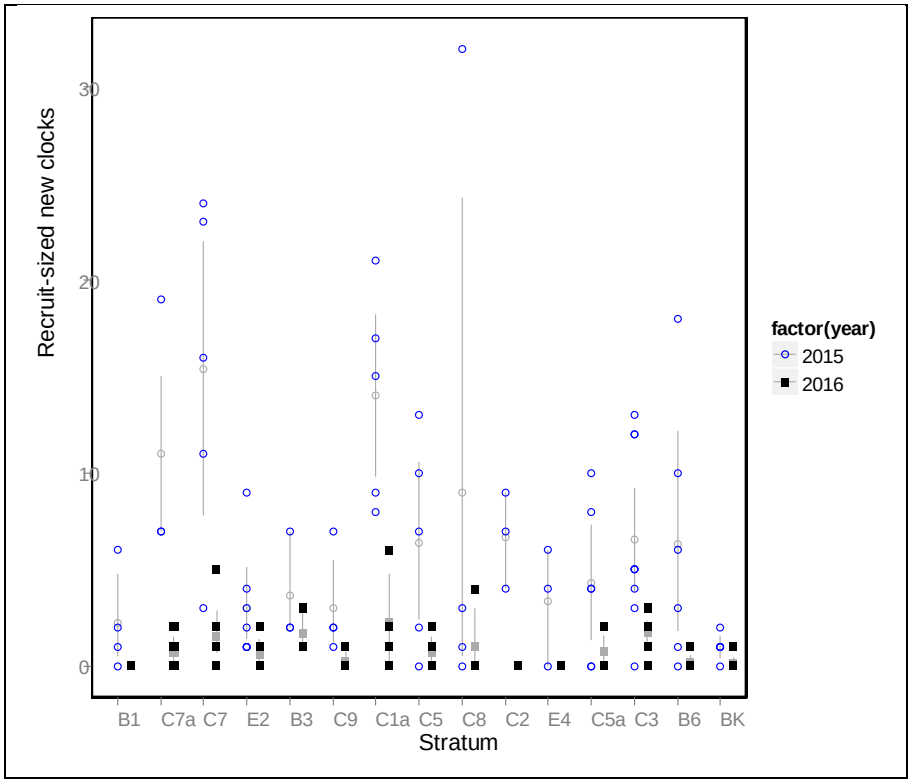

Figure 17: Plots of catches adjusted to the standard tow length (0.2 nautical miles) for recruit-sized new clocks, their means and 95% confidence intervals (grey) by stratum sampled during the 2015 (blue) and 2016 (black) surveys. Strata are arranged west to east with northern strata at similar longitudes shown first.

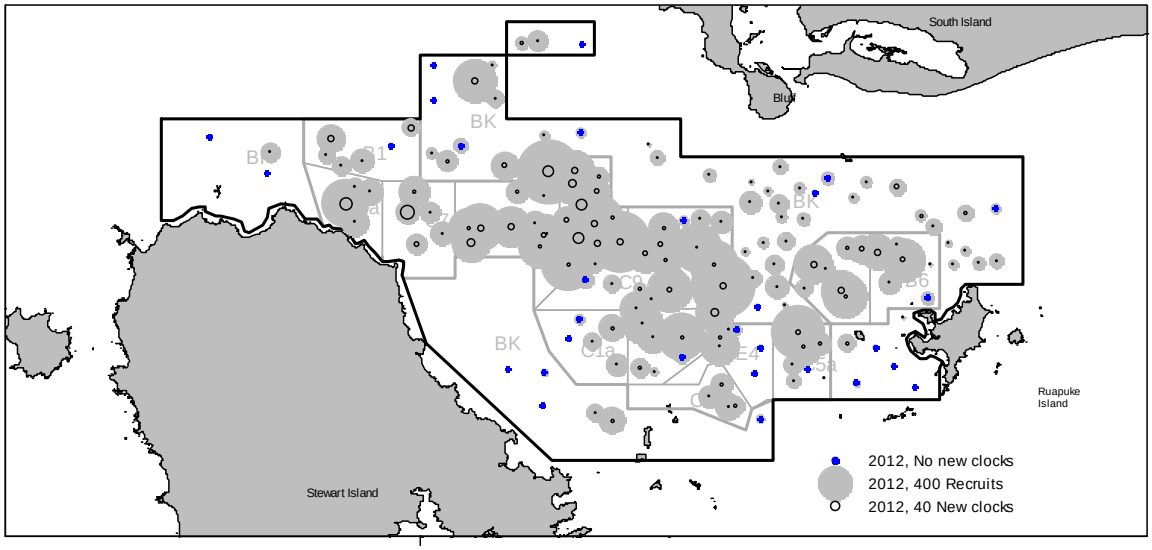

Figure 18: The distribution of recruit-sized oysters, new clocks and gaper densities combined ("Recruits", filled grey circles) and the densities of recruit-sized new clocks and gapers combined ("New clocks", open black circles) showing the pre-survey mortality in February 2012. Stations with no recruit-sized new clocks and gapers are shown as filled blue circles.

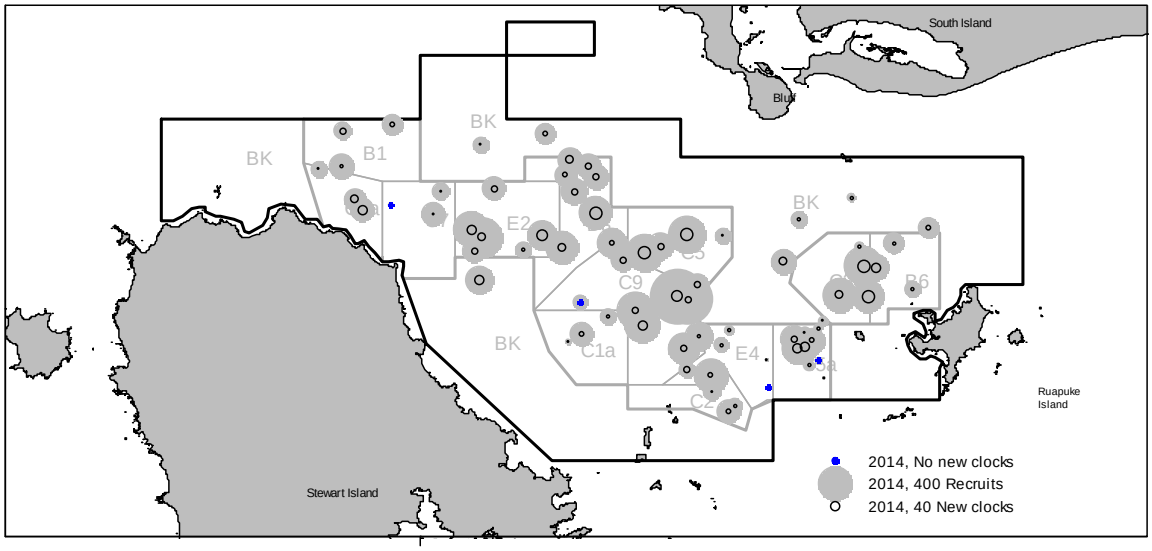

Figure 19: The distribution of recruit-sized oysters, new clocks and gaper densities combined ("Recruits", filled grey circles) and the densities of recruit-sized new clocks and gapers combined ("New clocks", black circles) showing the pre-survey mortality in February 2014. Stations with no recruit-sized new clocks and gapers are shown as filled blue circles.

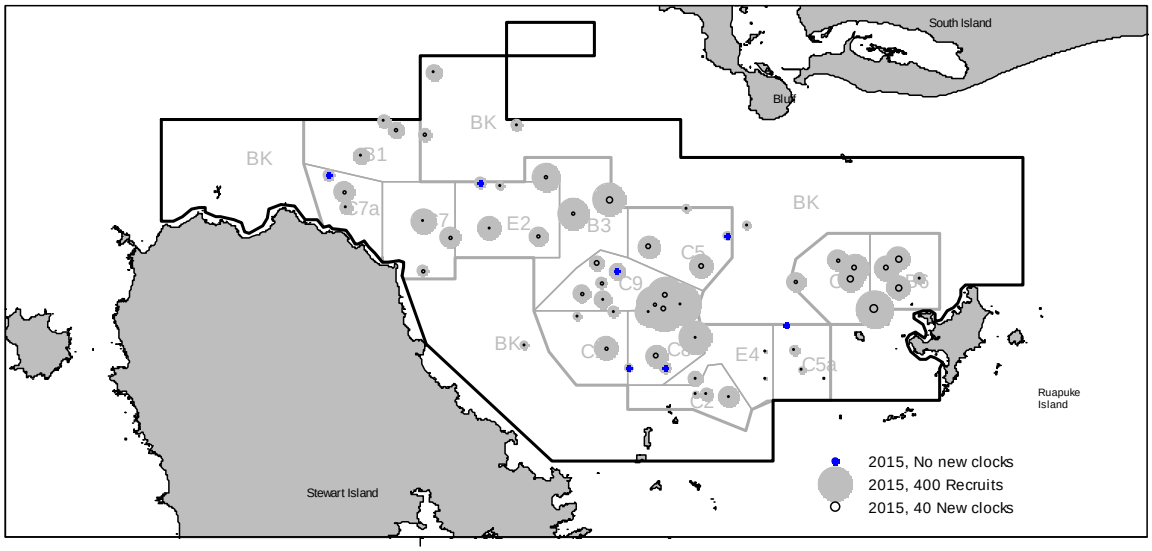

Figure 20: The distribution of recruit-sized oysters, new clocks and gaper densities combined ("Recruits", filled grey circles) and the densities of recruit-sized new clocks and gapers combined ("New clocks", black circles) showing the pre-survey mortality in February 2015. Stations with no recruit-sized new clocks and gapers are shown as filled blue circles.

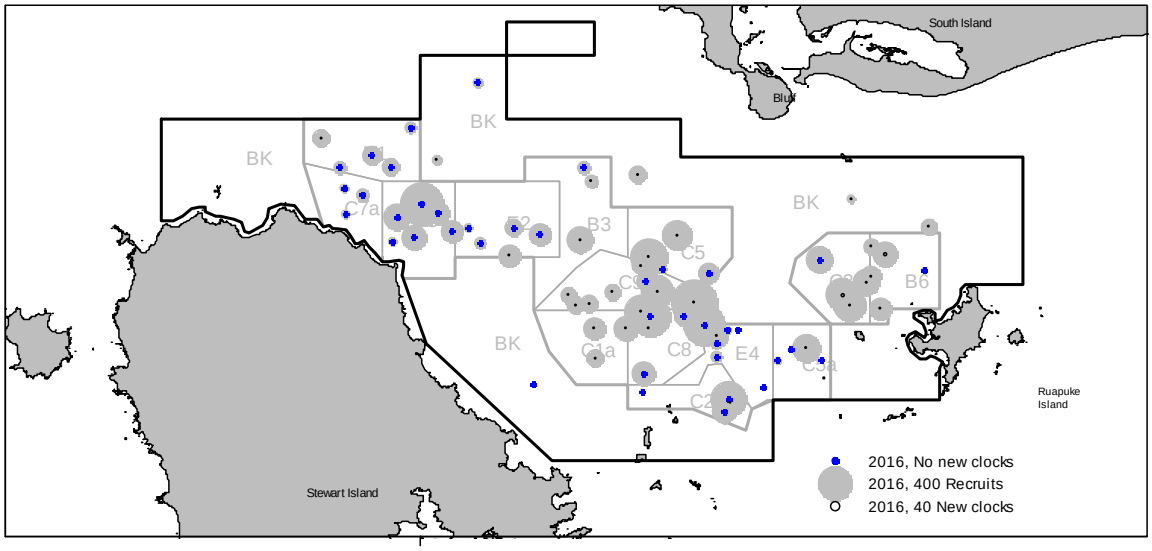

Figure 21: The distribution of recruit-sized oysters, new clocks and gaper densities combined ("Recruits", filled grey circles) and the densities of recruit-sized new clocks and gapers combined ("New clocks", black circles) showing the pre-survey mortality in February 2016. Stations with no recruit-sized new clocks and gapers are shown as filled blue circles.

New clock densities allow pre-survey mortality to be estimated. Estimates of the population sizes for recruit-sized and pre-recruit new clocks in core strata, the background stratum, and for the whole 2007 stock assessment survey area sampled at random stations in 2016 are shown in Tables 9 and 10 respectively; and for 2015, 2014 and 2012 in Appendix 3 (Tables A3.13–A3.18).

Table 9: Recruit-sized new clocks estimated from randomly selected stations in the core strata (Stratum), background stratum (BK), and for the whole 2007 stock assessment survey area (Survey total) sampled in 2016. The number of stations sampled (No. stns), the mean oyster density per m^2 (Mean density), the standard deviation of the mean density estimate (Density s.d.), coefficient of variation (CV) of the density estimate, mean population size in millions of oysters (Pop.n, shaded grey), upper and lower 95% confidence intervals (95%CI) in millions of oysters where a S prefix denotes the sampling CI calculated from the mean, standard deviation and sample size alone, and a B prefix denotes the bootstrapped estimate, and the area of each stratum (Area. km^2) in square kilometres, by stratum for the February 2016 Foveaux Strait oyster survey. The percentage of the 2015 estimate (% of 2015) shaded green for decreases in new clock population size and red for increases.

2016 Stratum	No. stns	Mean density	Density s.d.	CV	Pop.n	S.lower 95%CI	S.upper 95%CI	B.lower 95%CI	B.upper 95%CI	Area.km^2	% of 2015 pop.n
B1	3	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	78.2	0.0
B3	3	0.00	0.00	0.57	0.2	0.1	0.4	0.0	0.5	44.7	9.0
B6	5	0.01	0.00	0.48	0.3	0.2	0.4	0.0	0.6	30.0	11.9
C1a	3	0.01	0.00	0.40	0.3	0.1	0.4	0.1	0.5	31.3	50.3
C2	3	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	21.9	0.0
C3	3	0.00	0.00	0.58	0.2	0.1	0.3	0.0	0.4	32.7	8.4
C5	3	0.00	0.00	1.00	0.1	0.0	0.1	0.0	0.2	37.7	5.6
C5a	3	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	23.5	0.0
C7	6	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	36.1	0.0
C7a	3	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	23.6	0.0
C8	4	0.00	0.00	1.00	0.1	0.0	0.1	0.0	0.2	26.8	13.0
C9	8	0.01	0.00	0.21	0.3	0.2	0.3	0.2	0.5	34.5	26.5
E2	3	0.00	0.00	1.00	0.1	0.0	0.1	0.0	0.2	42.8	13.6
E4	5	0.00	0.00	1.00	0.0	0.0	0.1	0.0	0.1	28.0	27.3
Core	55	0.00	0.00	0.18	1.4	1.3	1.5	0.8	2.3	491.8	10.4
BK	5	0.00	0.00	0.46	2.2	1.3	3.1	0.2	4.7	578.4	21.7
Survey total	60	0.00	0.00	0.29	3.6	3.4	3.9	1.4	6.5	1070.2	15.3

Table 10: Pre-recruit-sized new clocks estimated from randomly selected stations in the core strata (Stratum), background stratum (BK), and for the whole 2007 stock assessment survey area (Survey total) sampled in 2016. The number of stations sampled (No. stns), the mean oyster density per m^2 (Mean density), the standard deviation of the mean density estimate (Density s.d.), coefficient of variation (CV) of the density estimate, mean population size in millions of oysters (Pop.n, shaded grey), upper and lower 95% confidence intervals (95%CI) in millions of oysters where a S prefix denotes the sampling CI calculated from the mean, standard deviation and sample size alone, and a B prefix denotes the bootstrapped estimate, and the area of each stratum (Area. km^2) in square kilometres, by stratum for the February 2016 Foveaux Strait oyster survey. The percentage of the 2015 estimate (% of 2015) shaded green for decreases in new clock population size and red for increases.

2016 Stratum	No. stns	Mean density	Density s.d.	CV	Pop.n	S.lower 95%CI	S.upper 95%CI	B.lower 95%CI	B.upper 95%CI	Area.km^2	% of 2015 pop.n
B1	3	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	78.2	0.0
B3	3	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	44.7	0.0
B6	5	0.00	0.00	1.00	0.1	0.0	0.1	0.0	0.2	30.0	58.0
C1a	3	0.00	0.00	1.00	0.1	0.0	0.1	0.0	0.2	31.3	NA
C2	3	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	21.9	0.0
C3	3	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	32.7	0.0
C5	3	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	37.7	0.0
C5a	3	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	23.5	NA
C7	6	0.00	0.00	1.00	0.0	0.0	0.1	0.0	0.1	36.1	3.6
C7a	3	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	23.6	0.0
C8	4	0.00	0.00	0.58	0.1	0.0	0.1	0.0	0.2	26.8	65.5
C9	8	0.00	0.00	1.00	0.0	0.0	0.0	0.0	0.1	34.5	21.0
E2	3	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	42.8	0.0
E4	5	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	28.0	NA
Core	55	0.00	0.00	0.41	0.2	0.2	0.2	0.0	0.5	491.8	10.1
BK	5	0.00	0.00	1.00	0.6	0.1	1.0	0.0	1.7	578.4	24.1
Survey total	60	0.00	0.00	0.72	0.8	4.1	4.9	0.0	2.0	1070.2	17.3

The population size of recruit-sized new clocks in core strata was lower in 2016 (1.4 million, 95% CI 2.0–20.7, Table 9) than in 2015 (13.5 million, 95% CI 2.0–20.7), 2014 (39.4 million, 95% CI 24.7–61.4) and in 2012 (22.4 million, 95% CI 12.8–36.6). Pre-survey mortality of recruit-sized oysters in core strata (Table 10) was low (0.2%) in 2016, much lower than in 2015 (3.7%), 2014 (6.8%), and in 2012 (3.2%). Estimates of new clock population size from background strata show the same overall pattern as core strata, and because of its large stratum area, BK has a large influence on the population size for the entire 2007 stock assessment survey area. The trend in pre-survey mortality for the entire 2007 stock assessment survey area is similar to that of core strata (Table 11).

Recruit-sized new clock densities in core strata were low in 2016. There were no strata with recruit-sized new clock densities above 0.01 m^{-2} in 2016 (Table 9). Recruit-sized new clock densities declined markedly from 2012 highs (B3 and C7), decreasing in 2014 (B3, C3, C5, C7a, C8, and C9), and in 2015 (Appendix 3). This decline also reflects the approximate 50% reduction in the recruit-sized oyster population since 2012, and decreased pre-survey mortality (Table 11). The proportion of the total summer mortality occurring before and during the survey is likely to change from year to year, hence the levels of pre-survey mortality may, in part, reflect the timing of mortality events and not increases or decreases in total mortality.

The population size of pre-recruit new clocks in core strata in 2016 (0.2 million, 95% CI 0.2–0.2) is lower than in 2015 (2.2 million, 95% CI 1.0–3.9), 2014 (3.6 million, 95% CI 2.2–5.7) and in 2012 (8.9 million, 95% CI 5.1–14.4). Pre-survey mortality of pre-recruit oysters in core strata was much lower in 2016 (0.2%) than in 2015, 2014 and 2012 (2.4%, 2.4%, and 2.9% respectively, Table 11).

Table 11: Estimates of pre-survey mortality for core strata (Core strata) and the entire 2007 stock assessment area (All area) for recruit-sized and pre-recruit new clocks for the 2012, 2014, 2015 and 2016 surveys. Estimates are from randomly selected stations only. Pre-survey mortality (% PS.mort) calculated as the percentage of new clocks (millions) over new clocks and oysters combined (millions).

	Recruit-sized			Pre-recruit		
Core strata						
Year	**Oysters**	**New clocks**	**% PS.mort**	**Oysters**	**New clocks**	**% PS.mort**
2012	688.1	22.4	3.2	297.7	8.9	2.9
2014	538	39.4	6.8	148.4	3.6	2.4
2015	351.4	13.5	3.7	89.2	2.2	2.4
2016	385.2	1.4	0.4	120.5	0.2	0.2
All area						
Year	**Oysters**	**New clocks**	**% PS.mort**	**Oysters**	**New clocks**	**% PS.mort**
2012	918.4	30	3.2	414.3	12	2.8
2014	1020.9	84.1	7.6	226.2	5.3	2.3
2015	509.9	23.7	4.4	122.1	4.5	3.6
2016	561.1	3.6	0.6	191.2	0.8	0.4

4.4 A summary of checks made to ensure consistency amongst qPCR assays between surveys (Objective 7)

Quality control of reagents and procedures was undertaken before the analysis of samples in March 2016. The standard was tested by dnature Ltd and on the NIWA BioRad CFX96 to ensure that the internal control was not affecting the sensitivity of bonamia detection. The standard was diluted in water and in diluent (1:15 dilution) of pooled negative oyster tissue which had the internal control amplifying and competing for reagents. Both dilution schemes went out to the same dilution before flatlining showing that the internal control is not affecting the sensitivity of detection. The synthetic Bonamia standard (tested by dnature Ltd) run in a duplex assay could reliably detect Bonamia in 2 µl of the lowest dilutions representing an average of two gene copies.

Aliquots of the 10^3 copies/µl dilution were used as interplate calibrators to permit collation of data among multiple runs. A dilution of 10^3 copies/µl gave cycles of quantification (Cq) of about 26.7 on the BioRad CFX96 used to run the qPCR assays; which equates to an intensity of infection of 2–3 from heart imprints. Quality control of reagent batches was undertaken by dnature: 20X Bonamia qPCR primer/probe mix incorporated primers and probes for the Bonamia target and internal control as well as the BLOCK system to prevent the high level endogenous internal control outcompeting a low level Bonamia target. Resulting lots of this mix were tested on the synthetic template at standard dilutions to ensure that the same sensitivity was maintained (i.e., detection of the 1 copy/µl dilution). Batches of reagents were tested with the synthetic standard to ensure consistency on the NIWA BioRad CFX96.

Forty three tests of positive controls for both bonamia and β-actin, and corresponding negative controls were undertaken during the qPCR assay run to analyse the 2016 samples. None of the negative controls tested positive. The ranges of positive control values for the FAM (6-carboxyfluorescein) fluorophore used to detect bonamia and the TR (Texas-red, sulforhodamine 101 acid chloride) fluorophore used as a cross check to ensure that the qPCR reaction occurred by detecting DNA from oyster tissue (β-actin) in the sample are shown in Figure 22. There was no overlap in Cqs between FAM dilutions, and Cqs were tightly distributed around the expected mean for high concentrations but Cq ranges increased at the lowest concentrations probably as a result of nonspecific amplification of artefacts in the reaction. Differences in Cq values between the bonamia positive control and β-actin positive control are due to the internal control (IC) block that allows the FAM fluorophore to fluoresce before the TR fluorophore. The IC block causes some variation in the fluorescence levels of the TR fluorophore at low dilutions of the Bonamia standard (Figure 22). The bonamia interplate standard (10^3 copies/µl) produced a mean Cq 26.7 (95%CI 26.6–26.8), which is very similar to previous years.

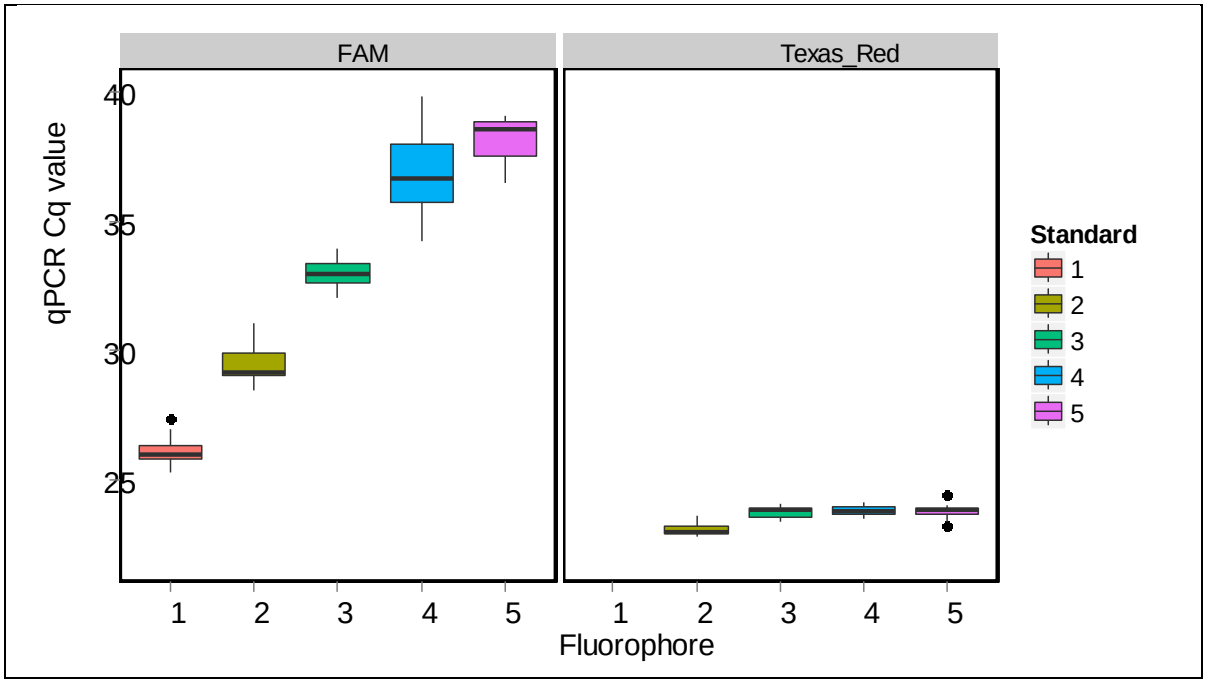

Figure 22: The range of Cq values for positive controls for bonamia FAM (6-carboxyfluorescein) flurophore used to detect bonamia and TR (Texas-red, sulforhodamine 101 acid chloride) flurophore used as a cross check to ensure the qPCR reaction occurred by detecting DNA from oyster tissues in the samples. Serial dilution from 10^3 Bonamia copies/µl to 10^{-2}. Differences in CQ values for FAM and TR are caused by an internal control block that allows the FAM to fluoresce before the TR.

4.5 Estimates of the prevalence and intensity of bonamia in commercial fishery areas (Objective 5)

Sampling effectiveness for the prevalence and intensity of infection by bonamia

Samples of 25 recruit and pre-recruit sized oysters were collected from all but eight stations in 2016. In all, 1706 samples of heart imprint slides were sampled and archived. This sample comprised 1647 recruit-sized oysters, 48 pre-recruits, and 11 small oysters. Almost all of the samples (96.6%) were of recruit-sized oysters, similar to 2015 (97.2%), and to previous surveys. Only a subsample of these were screened (N = 536). Stations with fewer than 15 recruit and pre-recruit sized oysters (52, N = 10; 50, N = 10; 84, N = 7; and 25, N = 6) were not used in the analysis of infection.

Matching heart and gill tissue samples were taken for qPCR. Replicate gill tissue samples were also taken and archived for future reference. Only heart tissues were processed with qPCR.

qPCR detection of bonamia in oyster heart tissues

A summary of qPCR samples tested is given in Table 12. All hearts that showed anomalies in the qPCR data were rerun. The repeat scores were used in the analysis for presence/absence. Samples that failed a second assay were omitted from the qPCR data analysis, and the corresponding heart imprint slides examined (Table 12).

One hundred and twenty four heart tissues (7.3%) didn't amplify and were scored by heart imprint only in 2016 (Table 12), higher than for 2015 (2.3%, Michael et al. 2015a) and 2014 (5.7%, Michael et al. 2015b). There were no heart tissue samples that amplified early in 2016. There were no false negatives,

i.e., no bonamia infection was detected by heart imprints in the 206 random samples selected from qPCR negative samples.

Table 12: The numbers of heart tissue samples screened for bonamia using qPCR, and the numbers of heart imprints in 2016. The summary of qPCR samples gives the total number of samples tested (Sample (N)), the numbers of samples omitted because they failed inclusion criteria after repeat sampling (Omitted), the numbers of valid samples (qPCR.N), and those that tested positive (Positive (≤35Cq)) and those where no bonamia DNA was detected (Negative (>35 Cq)). The number of heart imprint slides screened which included qPCR positives, randomly selected negatives, and qPCR anomalies. The summary statistics for qPCR infection give the numbers of qPCR positive and negative samples (heart tissue only) and the numbers of corresponding heart imprint samples that scored positive for bonamia infection. There were no qPCR false negatives.

qPCR samples					
Bonamia infection	**Sample (N)**	**Omitted**	**qPCR.N**	**Positive(≤35Cq)**	**Negative (>35 Cq)**
Heart	1706	124	1582	198	1381
Histology samples					
Number of slides read	536				

qPCR infection	**Sample (N)**	**Histo+ve**
Heart qPCR +ve	198	128
Selection qPCR -ve	214	214
qPCR anomalies	124	1

Comparison of qPCR and heart imprint methods.

The qPCR method shows higher sensitivity in the detection of bonamia than heart imprints (Maas et al. 2013). A large number of histological samples in which bonamia could not be detected scored positive using qPCR (Figure 23).

The quantification of bonamia cannot be directly compared between qPCR and histology as the qPCR Cq values estimate numbers of bonamia ITS region copies while histology scores categorise the average numbers of bonamia cells in oyster haemocytes. A small number of samples with anomalous qPCR results were included in the subset of heart imprint samples examined for infection.

qPCR tests where samples did not amplify FAM (Bonamia) and amplified Texas Red (β-actin) are bonamia negative. These samples do not have Cq values for FAM (because there was no amplification). Cqs for these samples were set to 43 for graphs to reflect the actual numbers of samples that tested negative for *Bonamia exitiosa*. qPCR tests where samples did not amplify either FAM and Texas Red (flatliners) are anomalous results, i.e., cannot be considered positive or negative. Heart imprint slides for all flatliners were scored for bonamia. Cqs from qPCR were plotted against heart imprint score (Figure 23). There were no false qPCR negatives. One qPCR flatliner scored positive by heart imprint

(category 2, Figure 23). There may have been some inhibition of the qPCR reaction in this sample, possibly because of the small tissue sample sizes (from small oysters), incomplete digestion of tissue, or significant loss of blood during the heart imprint process (Figure 23). Of all the samples that were heart imprint negative, 31% were positive by qPCR. All qPCR negatives not examined by heart imprints were assigned as negatives.

Boxplots of Cq values for heart tissues showed a decreasing trend with increasing intensity of bonamia infection estimated from heart imprints i.e., bonamia scores increasing from 1 to 5 (Figure 23).

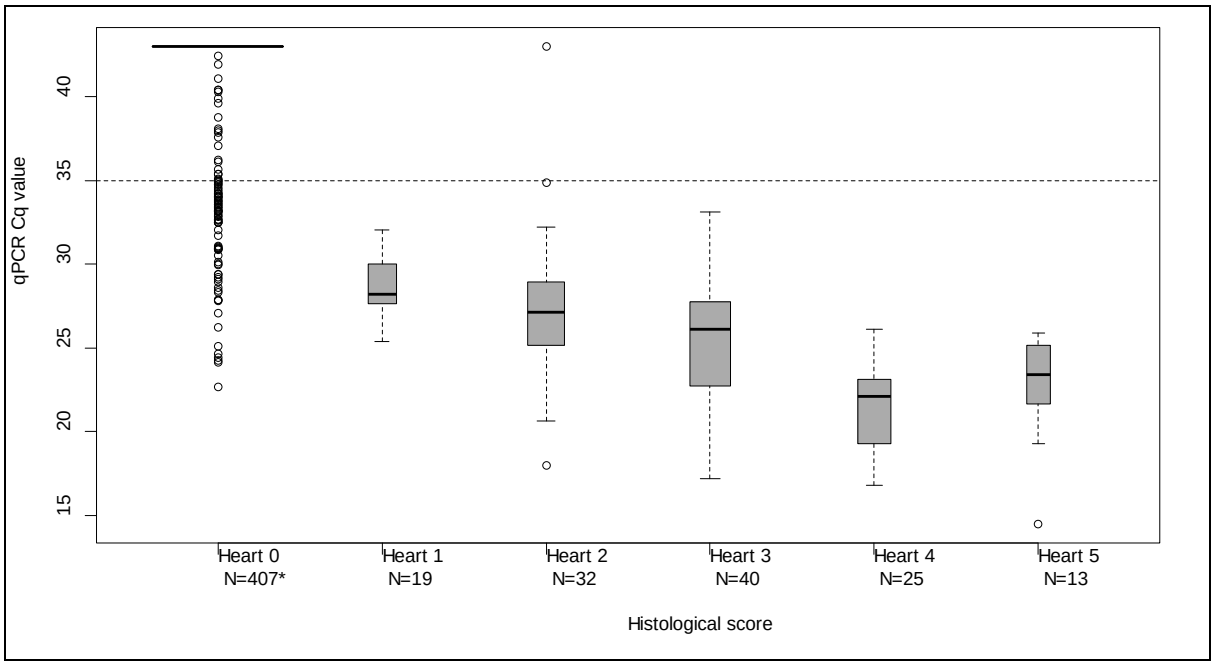

Figure 23: Boxplots of Cq values from qPCR analysis of the bonamia ITS region for samples of heart tissues by histological score (heart imprints) from the February 2016 survey. Cut-off levels set at 35 Cq (dashed line). Outliers for heart tissues denote generally weak reactions most likely caused by inhibitors in the crude samples. Box plots show medians (solid lines), boxes 25 and 75 percentiles, whiskers at 95 percentiles, and outliers shown as black circles above and below whiskers. Samples that didn't amplify FAM (bonamia) and amplified Texas Red (β-actin) were assigned Cq 43 to better account for the numbers of oysters that tested negative.

Prevalence and intensity of infection in oysters by bonamia

We assumed that all heart imprint slides corresponding to samples that were qPCR negative, but not scored for bonamia, were negative. Stations with too few oysters (stations 25, 50, 52, and 84) and target stations were excluded from the analysis of prevalence and intensity of infection (Table 13). Infection intensity was estimated from heart imprint slides using the categorical score of Diggles et al. (2003).

Heart imprints underestimate the true prevalence of bonamia infection, and are lower than the qPCR estimates (Table 13). The mean prevalence from heart imprints in 2016 was lower (7.5%) than in 2015 (15.3%) and 2014 (15.2%), and recent surveys (2009–2012, 8–12%). qPCR analysis of heart tissues was more sensitive than heart imprints, (Table 13). Mean prevalence from qPCR (Table 13) was lower in 2016 (11.8%) than in 2015 (22.4%), 2014 (25.0%), and 2013 (19.6 %). Details of recruit-sized oysters and densities by station, and bonamia infection status from histology and qPCR are shown in Table 14.

Of the 1362 slides taken from random stations with more than 15 recruit and pre-recruit sized oysters in 2016, a subset of 536 heart imprint slides were examined for bonamia. The remaining 726 slides were from oysters screened using qPCR and were not infected. In 2016, 87.3% of oysters had no

detectable infection, similar to 2015 (84.7%), 2014 (85.8%), and for 2010 to 2013 (90%, 88%, 89%, and 88% respectively).

Table 13: Comparisons of infection levels (prevalence and intensity) between 2015 and 2016. Number of samples each method (N), mean and median prevalence (Prev (%) and intensity estimated by histology (heart imprints), and prevalence from qPCR. Standard deviation (s.d.) and upper and lower 95% confidence intervals (L95%CI and U95%CI). Data from random stations sampled for bonamia with more than 15 recruit and pre-recruit oysters in the sample.

	2015				2016		
	Histology Prev (%)	Histology Intensity	qPCR.heart Prev.H (%)		Histology Prev (%)	Histology Intensity	qPCR.heart Prev.H (%)
N	57	52	57	N	55	42	55
mean	15.3	3.2	22.4	mean	7.5	2.8	11.8
median	12	3.1	20.8	median	4.0	2.5	8.0
s.d.	11.6	0.7	15.4	s.d.	7.1	1.1	9.5
L95%CI	12.3	3	18.4	L95%CI	5.7	2.5	9.3
U95%CI	18.3	3.5	26.4	U95%CI	9.4	3.1	14.3

Of the 7.5% of oysters with detectable infections in 2016, 3.1 % had light category 1 and 2 infections (3–5% in 2010–2015), and 4.4% had category 3 and higher infections (7–11% in 2010–2015) which are normally fatal. The prevalence of infection ranged from 0% to 28% in 2016; with no detectable infection at 13 of the 55 stations, a marked increase from 3 in 2015. The median prevalence in 2016 was 4.0%, less than in 2015 (12%).

Intensity of infection was determined from heart imprints to maintain the time series of bonamia survey data. The median level of infection in 2016 (2.5, Table 13) was less than in 2015 (3.1) and 2014 (3.0). Infection levels were generally high with 59% or more of infected oysters in 2016 expected to die within a few weeks of sampling compared with 52% in 2015 and 50% in 2014. The mean intensity of infection in 2016 (2.8) was less than in 2015 (3.2) and years 2009–2014. The percentage of stations in 2016 with category 3 and higher infections was 58% in 2016, which is lower than in 2015 (90%), 2014 (81%), and for the years 2009–2014 (67%–94%, the coverage of sampling and numbers of stations sampled differed between years). The intensity of infection was highly variable within stations, and patterns of variation were similar across the fishery area, in all years.

The prevalence of infection at all sample stations decreased markedly in 2016, and is similar to 2008 and 2009 levels (Figure 24). qPCR samples showed higher prevalence than histology (Figure 24). Prevalence from qPCR was also lower than for 2014 and 2015 (Figure 24). Prevalence appears to have returned to a long term average. The median intensity of infection was lower in 2016 than in recent years (Figure 25).

The percentage of stations with no detectable infection increased in 2016 from a six year low in 2015 (left panel, Figure 26). The percentage of stations with high prevalence of infection shows a cyclic pattern (left panel Figure 26): generally low in 2012, but increasing through to 2015 (the distribution of prevalence shows a marked shift to the right showing more stations with higher prevalence), and then decreasing markedly in 2016 to 2012 levels. The percentage of stations with high mean intensity of infection has been generally high from 2012 to 2015 (right panel, Figure 26), and there was also a marked shift to the left showing lower intensity of infection in 2016 (right panel, Figure 26). The differences in mean intensity between 2012 and 2015 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 re-absorption of ova post spawning.

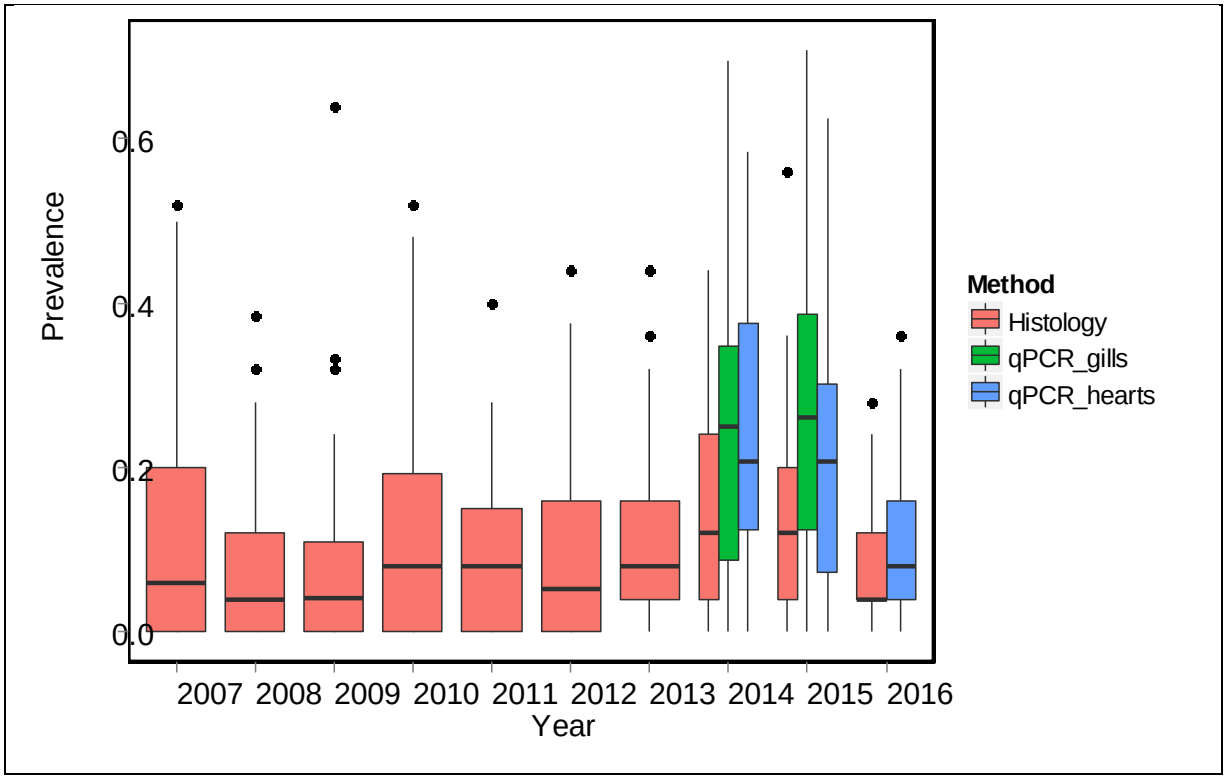

Figure 24: Boxplots of the median prevalence of bonamia infection 2007–2016. The median prevalence of infection at all stations determined from histology (heart imprints) 2007–2013, and for qPCR heart tissues (qPCR_hearts) and gill tissues (qPCR_gills) in 2014 and 2015, but only heart tissues in 2016. Medians shown as solid lines, boxes represent 50 percentiles and whiskers 95 percentiles, and outliers as filled black circles.

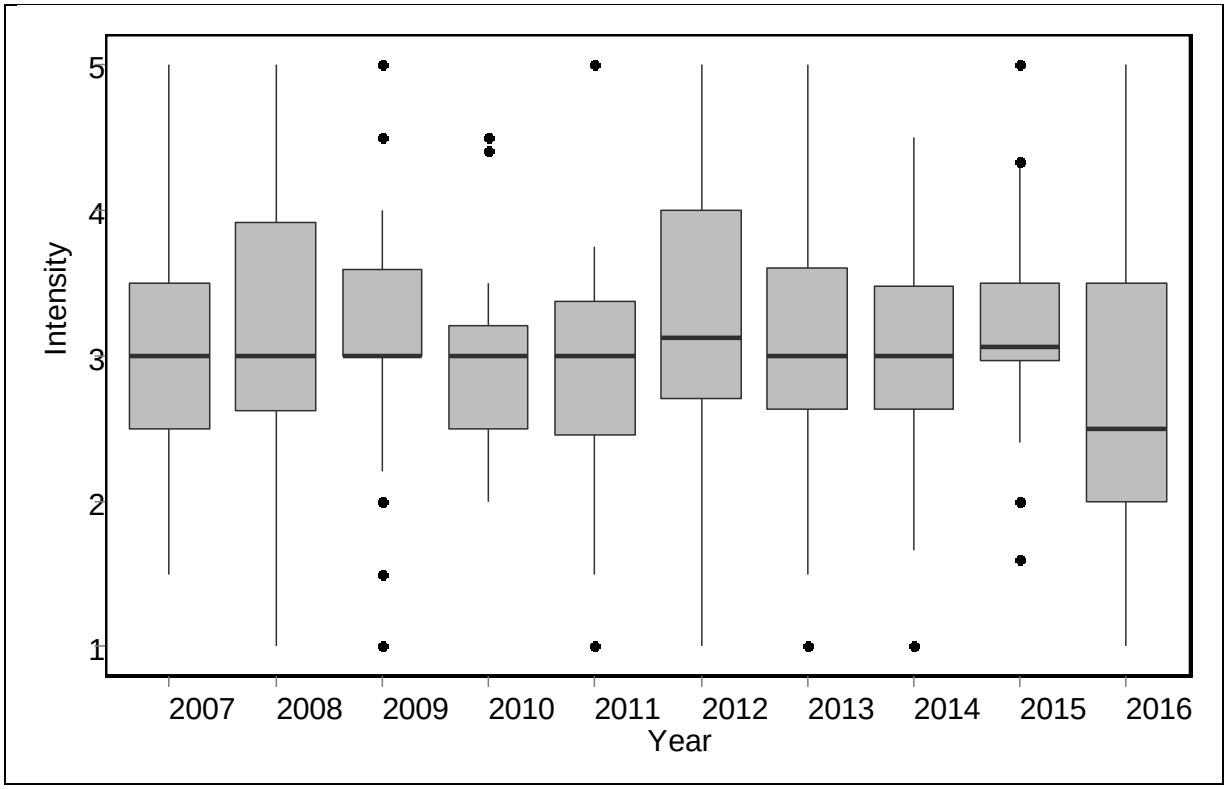

Figure 25: Boxplots of the mean intensity of bonamia infection 2007–2016. The mean intensity of infection at all stations determined from histology. Medians shown as solid lines, boxes represent 50 percentiles and whiskers 95 percentiles, and outliers as filled black circles.

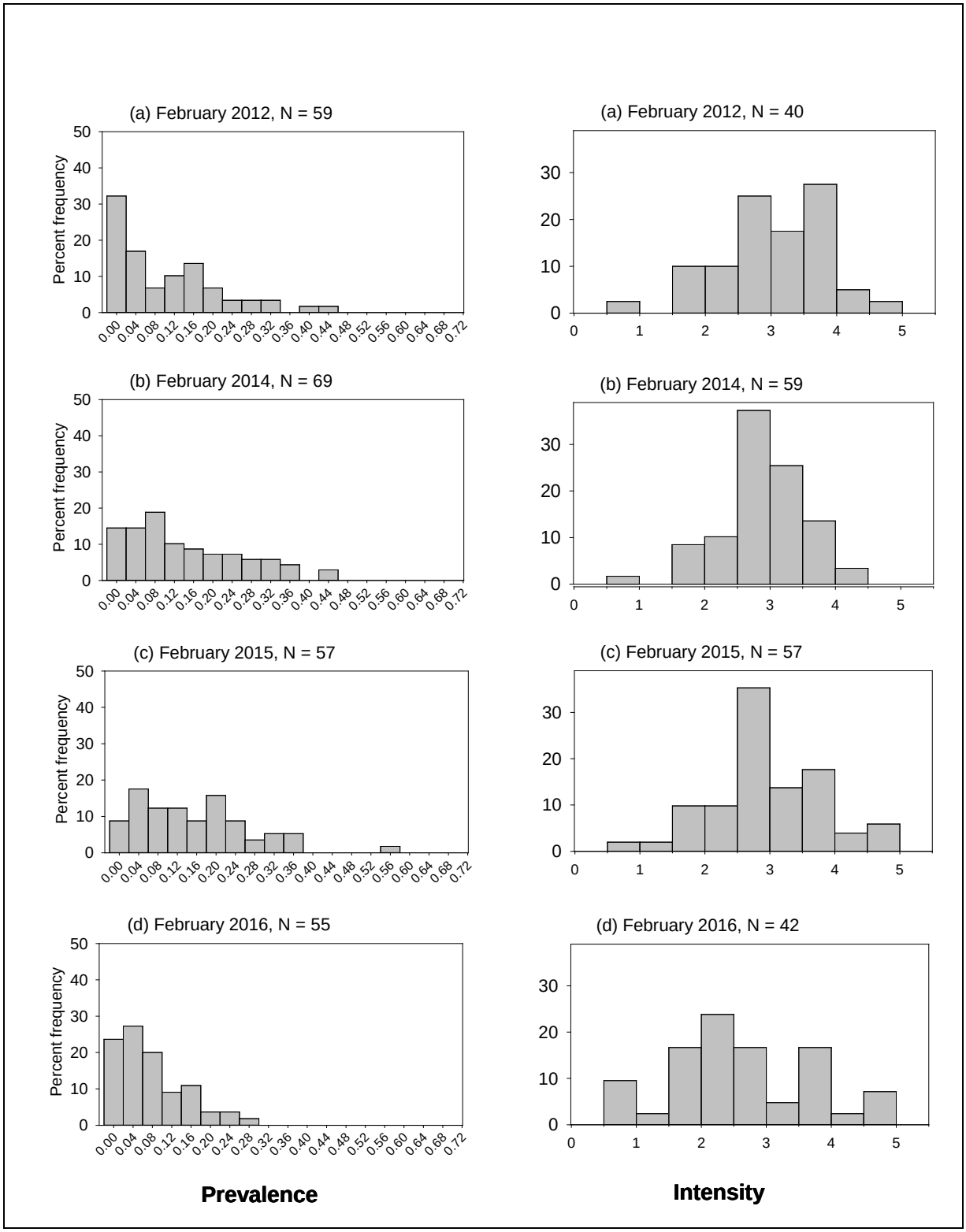

Figure 26: Percentage prevalence (left) and Percentage intensity (right) of bonamia infection at stations sampled in (a) February 2012, (b) February 2014, (c) February 2015, and (d) February 2016.

Table 14: Details of recruit-sized oysters and densities by station; the numbers of histology samples (heart imprint slides) and numbers of uninfected (Un.inf) samples, samples with non-fatal infections (NF.inf) and fatal infections (Fatal.inf) based on category 3 and higher infections, and the prevalence and intensity of infection from heart imprints. The percentage prevalence of bonamia infection detected in heart tissues where qPCR assays met criteria for data inclusion (Prev.H (%) from the February 2016 survey.

			Histology						qPCR assays
Station	Recruits	Density	Total	Un.inf	NF.inf	Fatal.inf	Prev (%)	Intensity	Prev.H (%)
1	139	0.66	25	23	0	2	8.0	4.5	8.0
2	49	0.23	25	19	3	3	24.0	2.7	32.0
3	122	0.58	25	25	0	0	0.0	NA	4.0
4	66	0.32	25	20	0	5	20.0	3.6	20.0
5	242	1.16	25	25	0	0	0.0	NA	0.0
6	67	0.32	25	24	0	1	4.0	3.0	4.0
7	154	0.74	25	19	3	3	24.0	3.2	28.0
8	182	0.87	25	21	2	2	16.0	2.3	16.0
9	224	1.07	25	23	1	1	8.0	2.0	8.0
10	98	0.47	25	23	0	2	8.0	4.0	8.0
13	185	0.88	25	23	1	1	8.0	2.5	8.0
14	119	0.57	25	22	3	0	12.0	1.3	36.0
16	13	0.06	25	24	0	1	4.0	3.0	4.0
17	448	2.14	25	22	2	1	12.0	2.0	12.0
18	387	1.85	25	21	2	2	16.0	2.5	16.0
19	248	1.18	25	18	1	6	28.0	3.6	28.0
20	264	1.26	25	24	1	0	4.0	2.0	12.0
21	145	0.69	25	23	1	1	8.0	2.5	12.0
22	311	1.49	25	24	0	1	4.0	5.0	20.0
23	31	0.15	25	24	1	0	4.0	2.0	4.0
25	5	0.02	8	8	0	0	0.0	NA	0.0
26	18	0.09	20	19	1	0	5.0	1.0	5.0
28	687	3.28	25	25	0	0	0.0	NA	4.0
29	24	0.11	25	23	0	2	8.0	3.0	8.0
30	30	0.14	25	22	1	2	12.0	3.0	32.0
31	65	0.31	25	24	1	0	4.0	2.0	12.0
32	29	0.14	25	22	1	2	12.0	2.3	16.0
33	195	0.93	25	21	2	2	16.0	2.5	20.0
34	127	0.61	25	24	0	1	4.0	4.0	4.0
35	119	0.57	25	25	0	0	0.0	NA	4.0
36	580	2.77	25	24	0	1	4.0	5.0	12.0
37	393	1.88	25	24	1	0	4.0	2.0	4.0
38	128	0.61	25	23	1	1	8.0	2.5	8.0
39	758	3.62	25	25	0	0	0.0	NA	0.0
41	104	0.50	25	21	1	3	16.0	3.3	24.0
42	97	0.46	25	24	1	0	4.0	1.0	8.0
43	119	0.57	25	21	3	1	16.0	2.5	28.0

Histology									qPCR assays
Station	**Recruits**	**Density**	**Total**	**Un.inf**	**NF.inf**	**Fatal.inf**	**Prev (%)**	**Intensity**	**Prev.H (%)**
44	106	0.51	25	21	1	3	16.0	2.8	20.0
45	123	0.59	25	24	0	1	4.0	4.0	8.0
46	47	0.22	25	25	0	0	0.0	NA	0.0
47	188	0.90	25	24	1	0	4.0	1.0	8.0
48	619	2.96	25	25	0	0	0.0	NA	4.0
49	50	0.24	25	24	0	1	4.0	3.0	12.0
50	6	0.03	10	10	0	0	0.0	NA	0.0
51	121	0.58	25	20	4	1	20.0	2.2	28.0
52	5	0.02	13	11	0	2	15.4	3.5	15.4
53	35	0.17	25	22	0	3	12.0	3.7	16.0
55	44	0.21	25	23	0	2	8.0	4.0	8.0
56	111	0.53	25	24	0	1	4.0	5.0	4.0
64	15	0.07	21	20	1	0	4.8	1.0	4.8
68	217	1.04	25	24	1	0	4.0	2.0	16.0
72	208	0.99	25	23	1	1	8.0	2.5	28.0
84	5	0.02	9	7	0	2	22.2	3.5	33.3
88	175	0.84	25	25	0	0	0.0	NA	12.0
89	265	1.27	25	25	0	0	0.0	NA	8.0
90	233	1.11	25	25	0	0	0.0	NA	0.0
99	119	0.57	25	25	0	0	0.0	NA	4.0
107	185	0.88	25	25	0	0	0.0	NA	0.0
108	2	0.01	NA	NA	NA	NA	NA	NA	NA
200	182	0.87	25	25	0	0	0.0	NA	0.0
T1	291	1.39	25	20	1	4	20.0	3.2	24.0
T2	68	0.32	25	25	0	0	0.0	NA	0.0
T3	27	0.13	25	23	1	1	8.0	2.0	16.0
T4	172	0.82	25	23	1	1	8.0	2.5	12.0
T5	427	2.04	25	24	0	1	4.0	4.0	4.0
T6	93	0.44	25	25	0	0	0.0	NA	0.0
T7	267	1.28	25	23	0	2	8.0	3.5	16.0
T8	388	1.85	25	20	3	2	20.0	2.6	24.0
T9	503	2.40	25	22	2	1	12.0	2.3	12.0
T10	29	0.14	25	25	0	0	0.0	NA	4.0
T11	22	0.11	25	25	0	0	0.0	NA	0.0
T12	46	0.22	25	23	0	2	8.0	4.0	12.0

Changes in the distribution of prevalence and intensity of bonamia infection

The distribution of bonamia infection estimated from heart imprints and from qPCR analysis shows that the prevalence of infection and the numbers of infected stations were similar between 2014 and 2015, but greatly reduced in 2016 (Figures 27–29 respectively). Infection levels were very low in 2016, stations with no detectable infection were spread across the fishery; and the eastern fishery area (C3 and B6) showing the highest and most extensive patterns of infection. qPCR showed higher sensitivity than heart imprints.

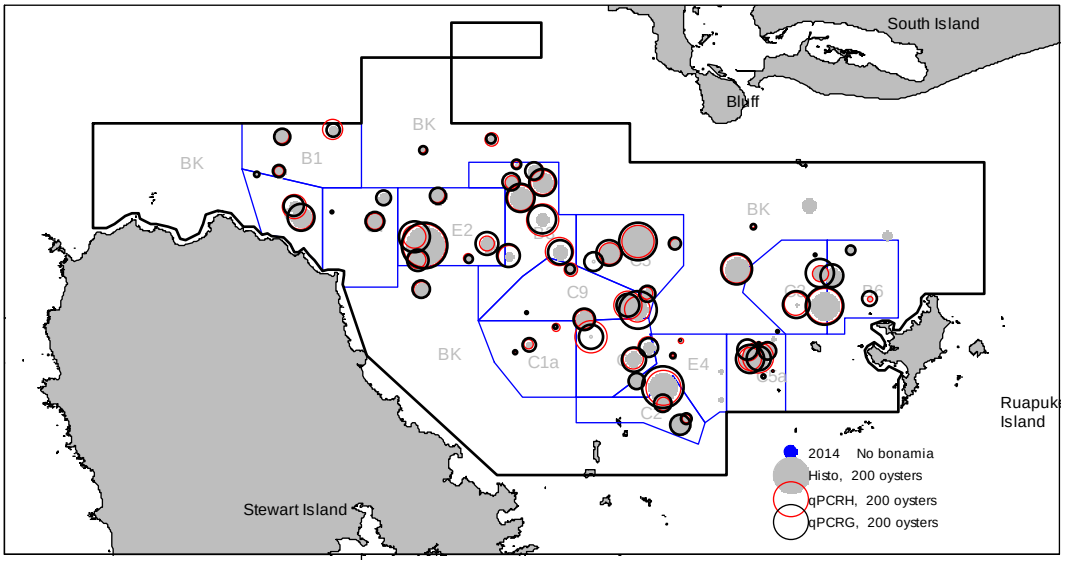

Figure 27: The distributions of bonamia infection in February 2014 estimated from heart imprints, and qPCR analysis of heart and gill tissues. Numbers of oysters with bonamia infection (intensity categories 1–5 combined) from heart imprints (Histo, filled grey circles), qPCR heart tissues (qPCRH, open red circles), and qPCR gill tissues (qPCRG, open black circles). Stations with no bonamia (filled blue circles). The 2007 survey area (black outer line), the February 2014 survey strata (blue lines), and the stratum labels in grey.

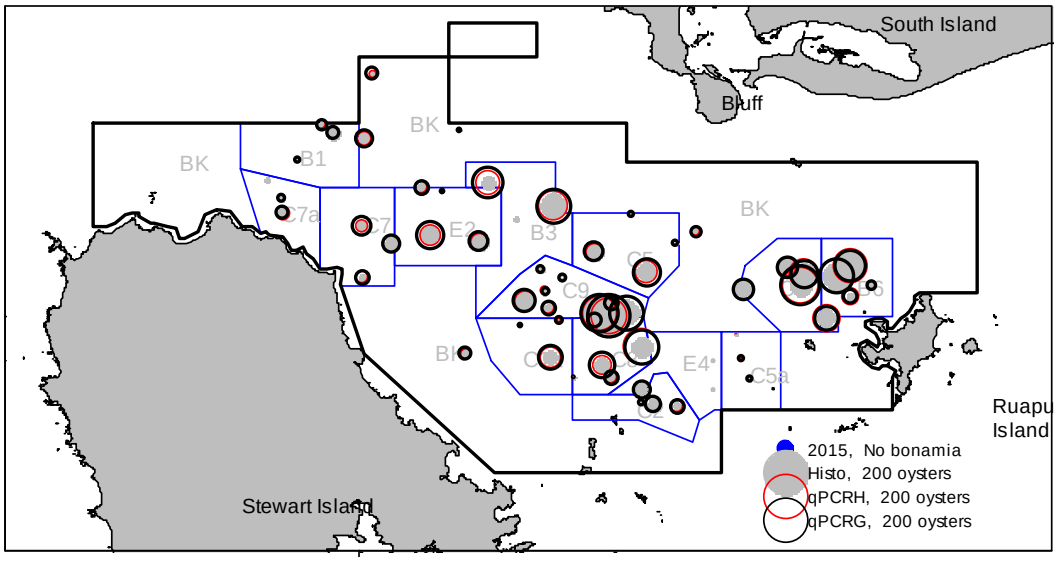

Figure 28: The distributions of bonamia infection in February 2015 estimated from heart imprints, and qPCR analysis of heart and gill tissues. Numbers of oysters with bonamia infection (intensity categories 1–5 combined) from heart imprints (Histo, filled grey circles), qPCR heart tissues (qPCRH, open red circles), and qPCR gill tissues (qPCRG, open black circles). Stations with no bonamia (filled blue circles). The 2007 survey area (black outer line), the February 2015 survey strata (blue lines), and the stratum labels in grey.

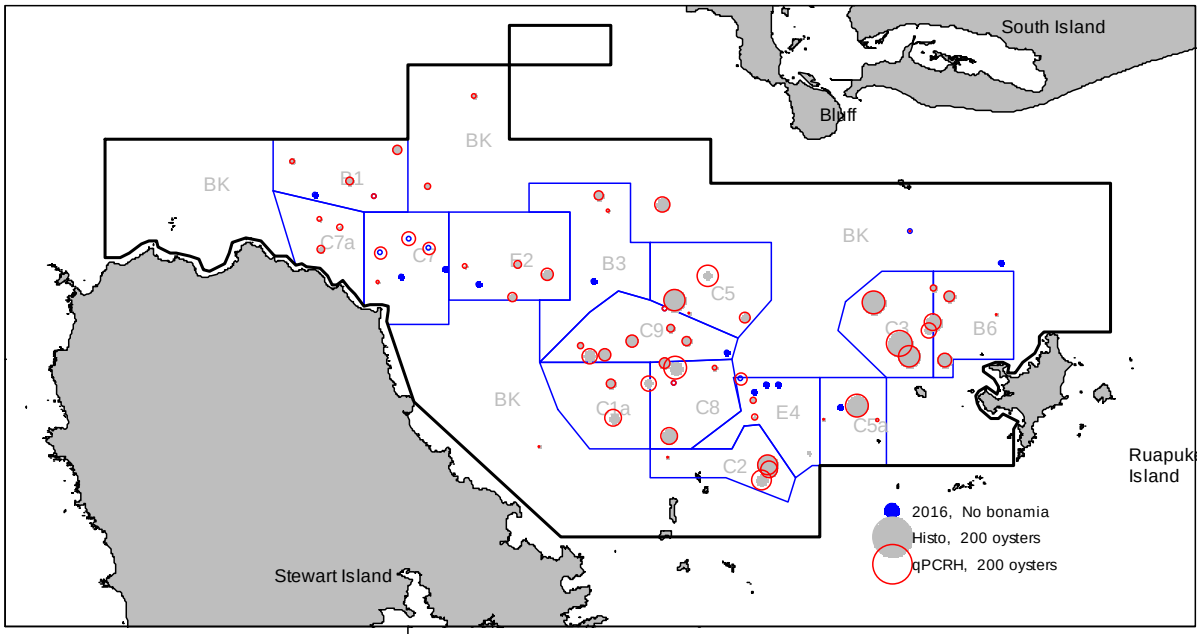

Figure 29: The distributions of bonamia infection in February 2016 estimated from heart imprints, and qPCR analysis of heart tissues only. Numbers of oysters with bonamia infection (intensity categories 1–5 combined) from heart imprints (Histo, filled grey circles) and qPCR heart tissues (qPCRH, open red circles). Stations with no bonamia (filled blue circles). The 2007 survey area (black outer line), the February 2016 survey strata (blue lines), and the stratum labels in grey.

In February 2012 the prevalence of infection was highest in eastern, southern, and western fishery areas, with little infection in the central fishery areas where oyster density was high (Figure 30). In areas with relatively high infection, bonamia infection was widespread and patchy, the prevalence and intensity of infection was highly variable at small spatial scales. Stations with high prevalence and high intensity of infection in 2012 were interspersed amongst stations with no detectable infection. There was a marked increase in bonamia infection in February 2014 from 2012, prevalence of infection was higher and more widespread, and the intensity of infection had increased markedly, especially in the commercially important central fishery areas (Figure 31). The distribution of recruit-sized oyster density and infection in February 2014 showed the marked effects of bonamia mortality between the 2012 and 2014 surveys. Prevalence of infection was widespread, and highly variable at small spatial scales with some stations having a relatively high prevalence of infection. The intensity of infection also varied. Some stations showed high numbers of fatally infected oysters (Figure 31). In 2015 the prevalence of infection was still widespread, but variable at small spatial scales in (Figure 32) with high levels of fatal infection, especially in areas with relatively high oyster density and areas with no detectable infection interspersed amongst areas with high levels of infection. By 2016 bonamia mortality had markedly reduced oyster density (Figure 33), but fatal infection levels were also reduced markedly and confined to the fishery areas east of a line between Saddle Point and Bluff Hill.

Patterns in the distribution of prevalence and intensity of infection between 2012 and 2016 were not consistent with patterns in the distribution of oyster dredging from fishers' logbook data or with oyster density from survey data; there were areas of high oyster density with a relatively high prevalence and intensity of infection in areas that had not been fished since 2008 because of the low meat quality there.

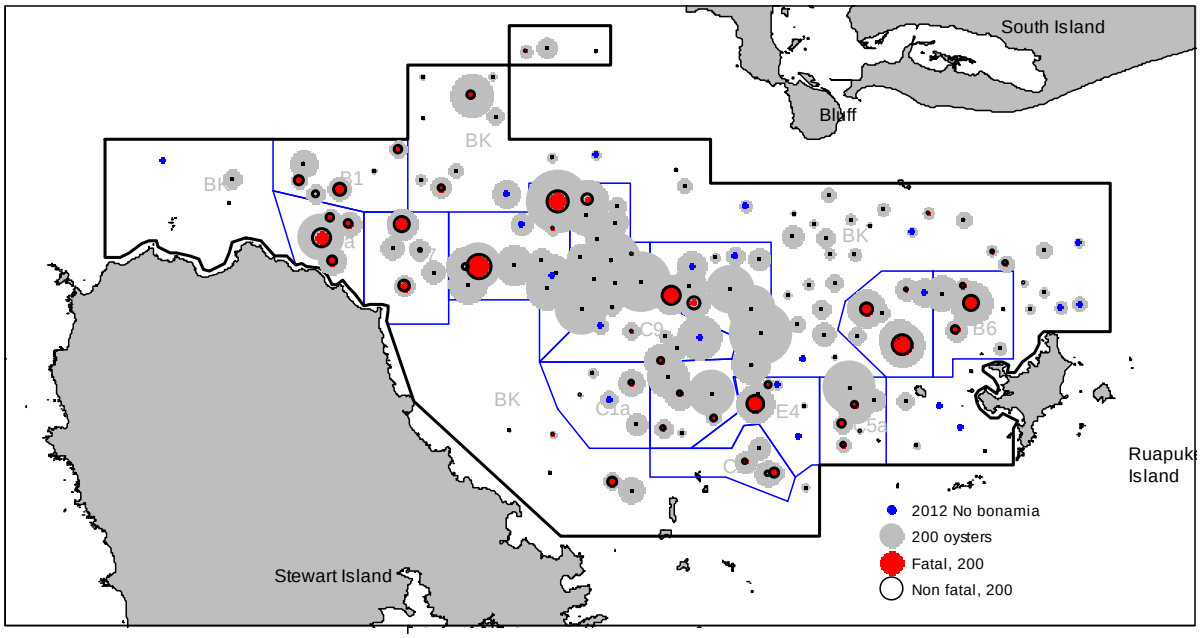

Figure 30: The distributions of oysters and bonamia infection in February 2012. Numbers of oysters (filled grey circles), numbers of oysters with bonamia infection (intensity categories 1–5 combined, open black circles); and fatal infections (intensity categories 3–5 combined, filled red circles). Stations with no bonamia (filled blue circles). The 2007 survey area (black outer line), the February 2014 survey strata (blue lines), and the stratum labels in grey.

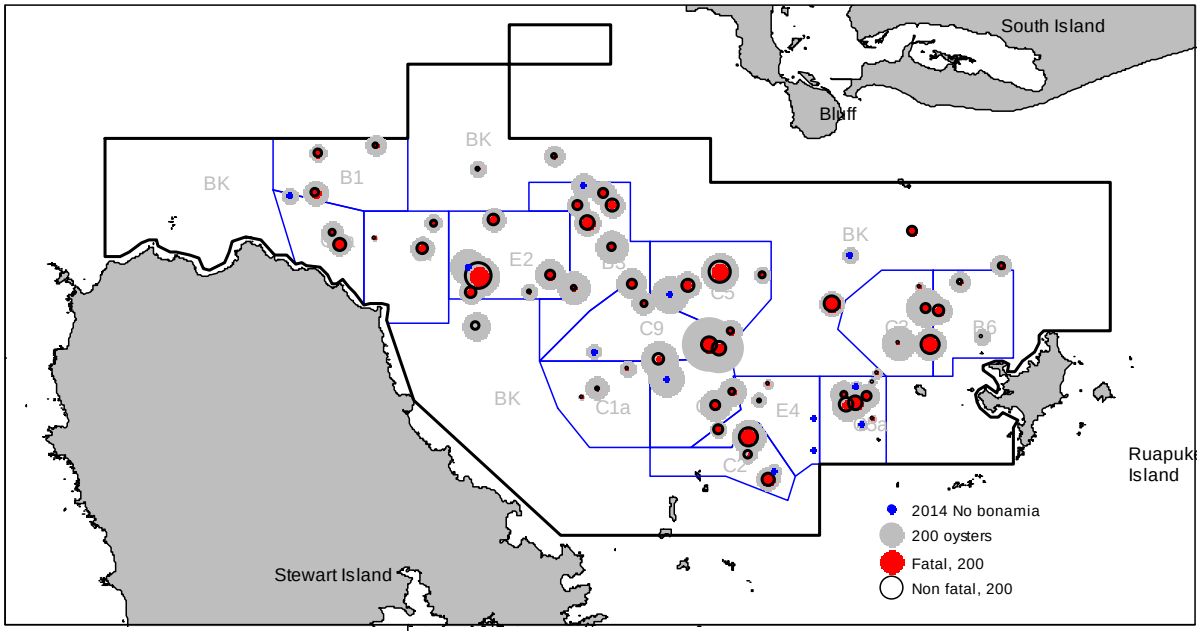

Figure 31: The distributions of oysters and bonamia infection in February 2014. Numbers of oysters (filled grey circles), numbers of oysters with bonamia infection (intensity categories 1–5 combined, open black circles); and fatal infections (intensity categories 3–5 combined, filled red circles). Stations with no bonamia (filled blue circles). The 2007 survey area (black outer line), the February 2014 survey strata (blue lines), and the stratum labels in grey.

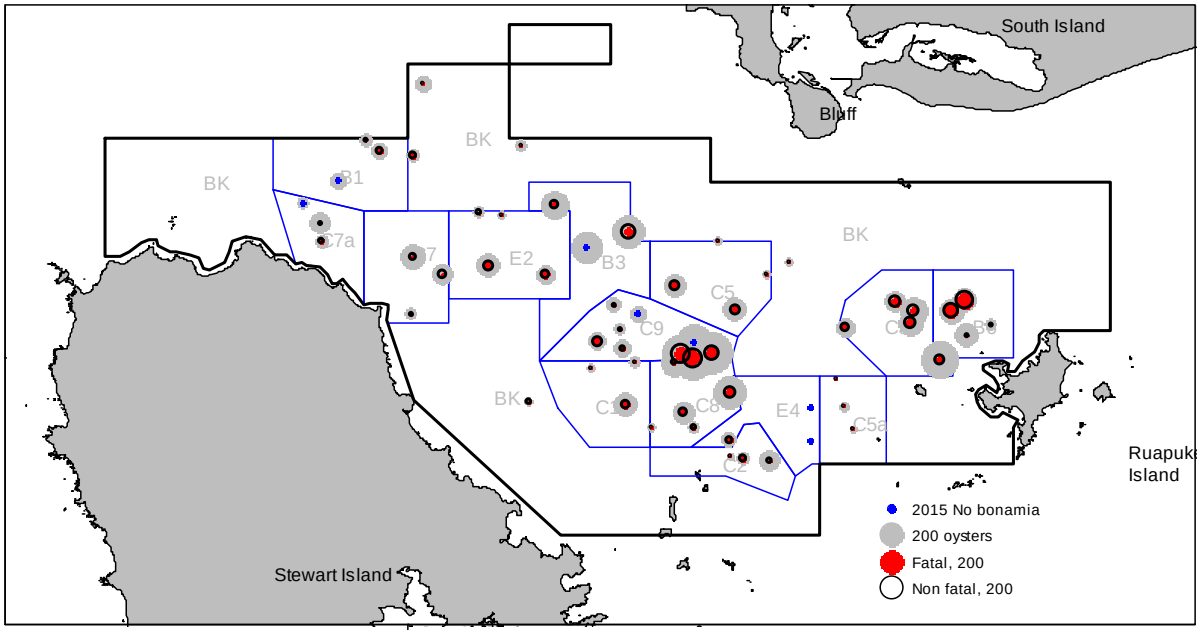

Figure 32: The distributions of oysters and bonamia infection in February 2015. Numbers of oysters (filled grey circles), numbers of oysters with bonamia infection (intensity categories 1–5 combined, open black circles); and fatal infections (intensity categories 3–5 combined, filled red circles). Stations with no bonamia (filled blue circles). The 2007 survey area (black outer line), the February 2015 survey strata (blue lines), and the stratum labels in grey.

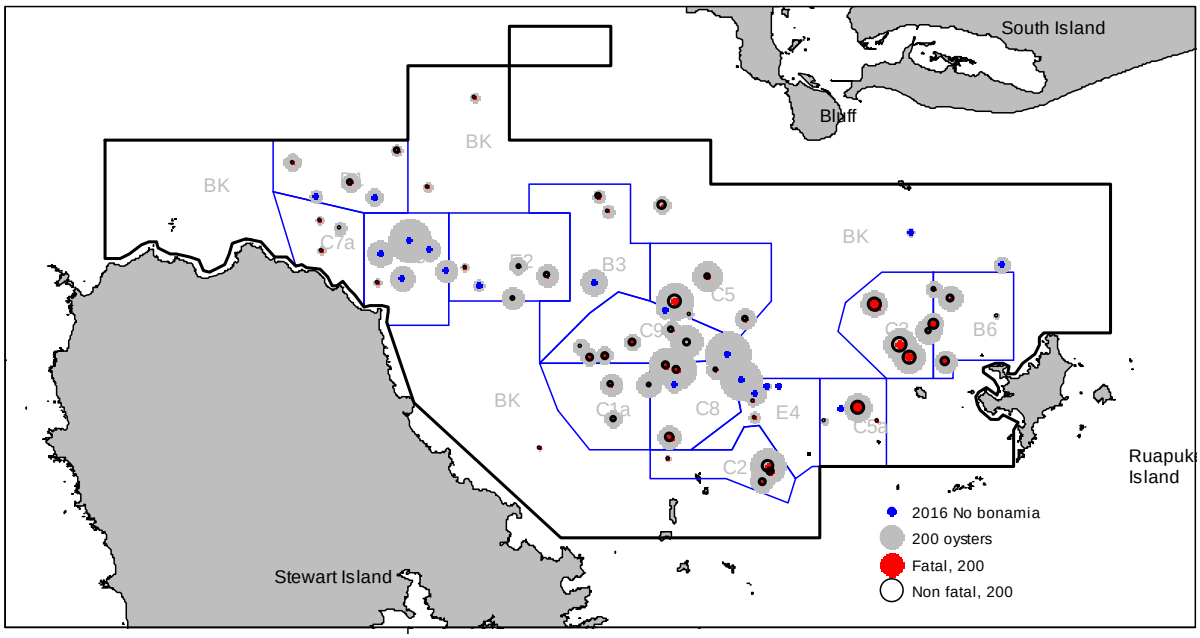

Figure 33: The distributions of oysters and bonamia infection in February 2016. Numbers of oysters (filled grey circles), numbers of oysters with bonamia infection (intensity categories 1–5 combined, open black circles); and fatal infections (intensity categories 3–5 combined, filled red circles). Stations with no bonamia (filled blue circles). The 2007 survey area (black outer line), the February 2016 survey strata (blue lines), and the stratum labels in grey.

The total numbers of recruit-sized oysters infected with bonamia

Estimates from heart imprints of the total numbers of recruit-sized oysters infected with bonamia were scaled up from the catches at randomly selected stations. Table 15 gives population estimates of recruit-sized oysters with bonamia infection (categories 1–5) in 2016, and estimates for 2012 and 2014, and 2015 given for comparison (Appendix 4, Tables A4.1–A4.2 respectively). Infection of recruit-sized oysters in core strata declined 44.3% from 89.5 million (95% CI 50.8–146.1) in 2014 to 49.8 million (95% CI 29.7–78.2) in 2015, and 49.2% to 25.3 million (95% CI 14.6–41.1) in 2016. Estimates of the total numbers of recruit-sized oysters with non-fatal infections for 2016 are given in Table 16 and for 2015 in Appendix 4, Table A4.5.

The estimate for infected oysters over the whole of the 2007 survey area in 2016 was 45.9 million (95% CI 19.7–81.4), lower than in 2015 (71.3 million, 95% CI 42.6–113.3), and in 2014 (176.1 million 95% CI 63.9–325.3). These figures should be viewed with caution as there were only five stations sampled in the background stratum which accounted for 54.0% of the survey area.

Table 15: Scaled up estimates of the population size of recruit-sized oysters with bonamia infection (prevalence) estimated by heart imprints in the core strata, background stratum (BK), and for the whole 2007 stock assessment survey area (Survey total) sampled in 2016. The number of stations sampled (No. stns), the mean oyster density per m^2 (Mean density), the standard deviation of the mean density estimate (Density s.d.), the coefficient of variation (CV) of the density estimate, mean population size in millions of oysters (Pop.n, shaded grey), upper and lower 95% confidence intervals (95% CI) in millions of oysters, and the area of each stratum (Area. km^2) in square kilometres, by stratum.

2016 Core Strata	No. stns	Mean density	Density s.d.	CV	Pop.n	Lower 95%CI	Upper 95%CI	Area.km^2	% of 2015 mortality
B1	3	0.04	0.02	0.50	2.9	0.0	6.4	78.2	81.3
B3	3	0.03	0.02	0.76	1.1	0.0	3.1	44.7	15.9
B6	5	0.09	0.03	0.36	2.7	0.7	5.2	30.0	37.9
C1a	3	0.06	0.01	0.16	1.9	1.1	3.0	31.3	146.0
C2	3	0.12	0.08	0.67	2.5	0.0	6.4	21.9	193.8
C3	3	0.23	0.09	0.39	7.5	1.6	15.2	32.7	107.8
C5	3	0.04	0.02	0.43	1.5	0.3	3.2	37.7	44.3
C5a	3	0.00	0.00	0.51	0.1	0.0	0.2	23.5	NA
C7	6	0.00	0.00	1.00	0.1	0.0	0.2	36.1	1.9
C7a	3	0.02	0.00	0.12	0.4	0.2	0.6	23.6	40.1
C8	4	0.07	0.04	0.49	1.9	0.1	4.2	26.8	73.8
C9	8	0.05	0.01	0.27	1.7	0.7	3.1	34.5	22.5
E2	3	0.02	0.01	0.53	0.9	0.0	1.9	42.8	19.0
E4	4	0.00	0.00	1.00	0.1	0.0	0.2	28.0	NA
Core total	54	0.05	0.01	0.16	25.3	14.6	41.1	491.8	50.8
BK	**5**	0.04	0.02	0.56	20.5	0.0	48.2	578.4	95.6
Survey total	59	0.04	0.01	0.27	45.9	19.7	81.4	1070.2	64.3

Table 16: Scaled up estimates of the population size of recruit-sized oysters with non-fatal infections (category 1 and 2) estimated by heart imprints in the core strata, background stratum (BK), and for the whole 2007 stock assessment survey area sampled in 2016. The number of stations sampled (No. stns), the mean oyster density per m^2 (Mean density), the standard deviation of the mean density estimate (Density s.d.), the coefficient of variation (CV) of the density estimate, mean population size in millions of oysters (Pop.n, shaded grey), upper and lower 95% confidence intervals (95%CI) in millions of oysters, and the area of each stratum (Area. km^2) in square kilometres, by stratum.

2016 Core Strata	No. stns	Mean density	Density s.d.	CV	Pop.n	Lower 95%CI	Upper 95%CI	Area.km^2	% of 2015 mortality
B1	3	0.01	0.01	1.00	0.8	0.0	2.4	78.2	84.2
B3	3	0.00	0.00	0.00	0.0	0.0	0.0	44.7	0.0
B6	5	0.04	0.02	0.43	1.2	0.2	2.5	30.0	112.8
C1a	3	0.05	0.01	0.21	1.5	0.8	2.5	31.3	NA
C2	3	0.07	0.05	0.74	1.6	0.0	4.2	21.9	392.6
C3	3	0.08	0.03	0.40	2.7	0.6	5.5	32.7	76.1
C5	3	0.01	0.01	0.75	0.4	0.0	1.2	37.7	30.8
C5a	3	0.00	0.00	1.00	0.0	0.0	0.1	23.5	NA
C7	6	0.00	0.00	0.00	0.0	0.0	0.0	36.1	0.0
C7a	3	0.01	0.00	0.26	0.2	0.1	0.3	23.6	36.4
C8	4	0.02	0.02	1.00	0.5	0.0	1.6	26.8	55.0
C9	8	0.03	0.01	0.35	1.0	0.3	1.9	34.5	33.8
E2	3	0.01	0.01	1.00	0.5	0.0	1.6	42.8	73.2
E4	4	0.00	0.00	0.00	0.0	0.0	0.0	28.0	NA
Core total	54	0.02	0.00	0.20	10.5	5.7	17.2	491.8	57.5
BK	5	0.02	0.02	1.00	10.6	0.0	33.9	578.4	482.9
Survey total	59	0.02	0.01	0.51	21.1	0.0	46.2	1070.2	103.4

The population estimates of recruit-sized oyster with bonamia infection (categories 1–5) from the qPCR analysis of heart tissues in 2016 are given in Table 17 and for 2015 and 2014 in Appendix 4 (Tables A4.3–A4.4). The estimates from qPCR for core strata in 2016 were lower (42.2 million, 95% CI 26.1–66.2) than in 2015 (72.7 million, 95% CI 44.8–112.5); and lower than the estimates from heart imprints 25.3 million (95% CI 14.6–41.1) in 2016 and in 2015 (49.8 million, 95% CI 29.7–78.2), highlighting the greater sensitivity of the qPCR method in detecting infections.

Table 17: Scaled up estimates of the population size of recruit-sized oysters with bonamia infection (prevalence) estimated by the qPCR analysis of heart tissues in the core strata, background stratum (BK), and for the whole 2007 stock assessment survey area (Survey total) sampled in 2016. The number of stations sampled (No. stns), the mean oyster density per m^2 (Mean density), the standard deviation of the mean density estimate (Density s.d.), the coefficient of variation (CV) of the density estimate, mean population size in millions of oysters (Pop.n, shaded grey), upper and lower 95% confidence intervals (95%CI) in millions of oysters, and the area of each stratum (Area. km^2) in square kilometres, by stratum.

2016 Core Strata	No. stns	Mean density	Density s.d.	CV	Pop.n	Lower 95%CI	Upper 95%CI	Area.km^2	% of 2015 prevalence
B1	3	0.05	0.02	0.30	4.0	1.5	7.4	78.2	112.3
B3	3	0.03	0.02	0.76	1.1	0.0	3.1	44.7	10.0
B6	5	0.10	0.04	0.38	2.9	0.7	5.6	30.0	26.6
C1a	3	0.15	0.04	0.27	4.6	2.0	8.2	31.3	178.6
C2	3	0.18	0.09	0.49	4.0	0.2	8.7	21.9	208.8
C3	3	0.27	0.06	0.21	8.7	4.5	14.3	32.7	68.9
C5	3	0.13	0.09	0.68	5.0	0.0	12.7	37.7	107.7
C5a	3	0.00	0.00	0.56	0.1	0.0	0.2	23.5	NA
C7	6	0.06	0.03	0.43	2.1	0.3	4.3	36.1	52.3
C7a	3	0.03	0.01	0.20	0.8	0.4	1.4	23.6	74.4
C8	4	0.14	0.08	0.53	3.8	0.0	8.7	26.8	69.9
C9	8	0.07	0.02	0.27	2.4	1.1	4.3	34.5	26.3
E2	3	0.04	0.02	0.53	1.7	0.0	3.9	42.8	32.2
E4	5	0.03	0.02	0.79	0.9	0.0	2.4	28.0	NA
Core total	55	0.09	0.01	0.13	42.2	26.1	66.2	491.8	58.0
BK	5	0.05	0.03	0.63	26.6	0.0	65.8	578.4	81.2
Survey total	60	0.06	0.02	0.26	68.8	30.9	120.6	1070.2	65.2

The distribution of recruit-sized oysters with non-fatal bonamia infections

In February 2014 the distribution of non-fatal infections (Figure 34) was widespread and variable across the fishery. The prevalence of non-fatal, category 1 and 2 infections varied at small spatial scales; stations with relatively high prevalence were often close to stations with low prevalence or no infection. Stations with high non-fatal prevalence are likely to be subjected to heightened bonamia mortality in the future. In February 2015 the distribution of non-fatal infections (Figure 35) showed similar spatial patterns, however recruit-sized oyster densities were further reduced by bonamia mortality between 2014 and 2015, as were the numbers of oysters with non-fatal infections. The numbers of stations with heightened non-fatal infections in 2016 were considerably fewer (Figure 36), and mainly in central (C5 and C9) and eastern (C3 and B6) fishery areas.

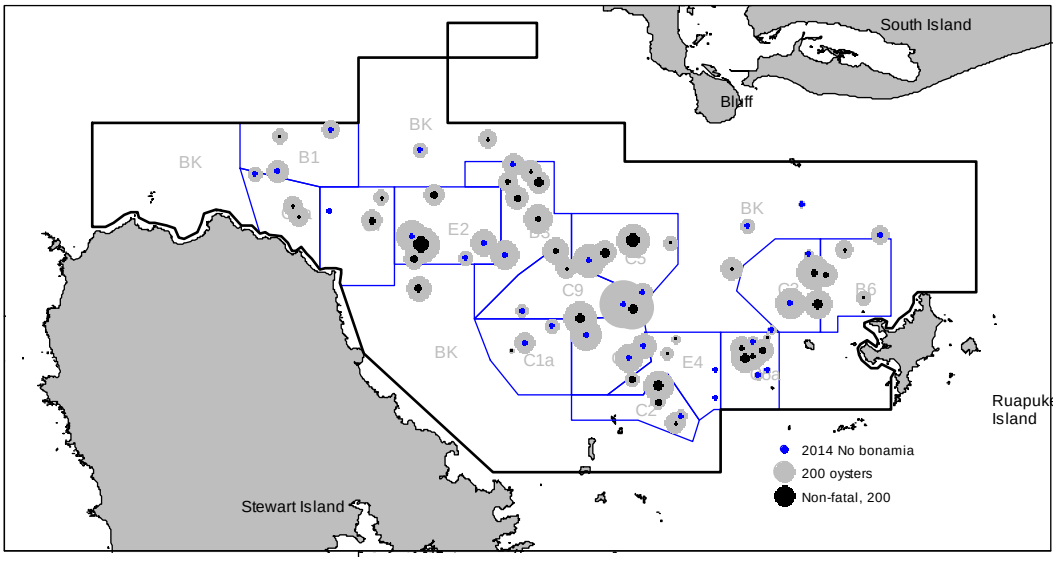

Figure 34: The distribution of recruit-sized oysters (filled grey circles showing numbers per standard tow) and oysters with category 1 and 2 infections (closed black circles, the numbers of oysters scaled to the size of the catch with intensity of infection category 1 and 2) in February 2014. Stations with no bonamia infection are shown by blue circles.

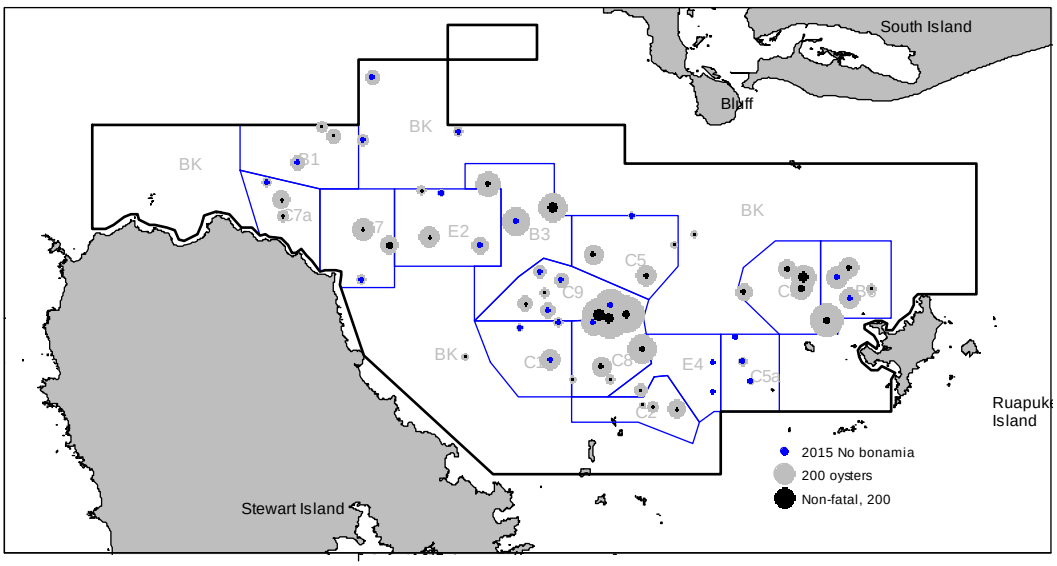

Figure 35: The distribution of recruit-sized oysters (filled grey circles showing numbers per standard tow) and oysters with category 1 and 2 infections (open black circles, the numbers of oysters scaled to the size of the catch with intensity of infection category 1 and 2) in February 2015. Stations with no bonamia infection are shown by blue circles.

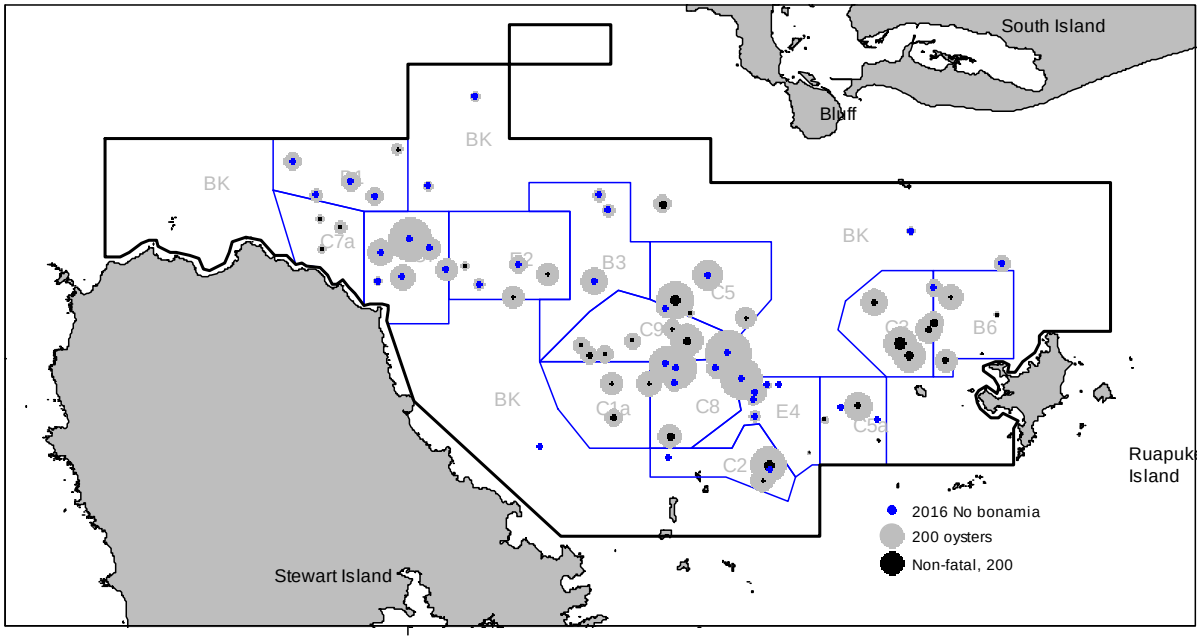

Figure 36: The distribution of recruit-sized oysters (filled grey circles showing numbers per standard tow) and oysters with category 1 and 2 infections (open black circles, the numbers of oysters scaled to the size of the catch with intensity of infection category 1 and 2) in February 2016. Stations with no bonamia infection are shown by blue circles.

4.6 Estimate the summer mortality from bonamia in the commercial fishery area (Objective 4)

Pre-survey mortality was estimated from the population size of recruit-sized new clocks and gapers in Section 4.3. In 2016, pre-survey mortality in all core strata combined was estimated to be 1.4 million recruit-sized oysters (95% CI 1.3–1.4), 0.4% of the recruited population. Projections of post-survey mortality (within about two months of sampling) from the proportion of oysters with categories three and higher (fatal) infections scaled up to the size of the total recruit-sized oyster population are given below. We used two methods to crosscheck the scaled-up estimates of fatal infections: 1, by applying a correction factor to the population estimates derived from the average proportion of infected oysters in the stratum; and 2, post-survey mortality was estimated from the numbers of infected oysters at each sample station scaled to the catch, then to stratum, and to the survey area level.

Projected short-term mortality from bonamia infections

Post-survey mortality of recruit-sized oysters was estimated for core strata with three or more randomly selected stations. Because the abundance of kaeos reduced sampling efficiency in some strata (C5a and E4), insufficient numbers of oysters were caught for a bonamia sample and were omitted from the analysis.

Projected short-term mortality using the mean proportion of oysters infected with category 3 and higher infections in the catch was used to calculate a correction factor for each stratum (1 (the total catch) less the mean proportion of oysters infected with bonamia, Table 18)) and this correction factor was applied to the mean oyster density estimated from all random tows. Using this method, post-survey mortality of oysters was projected to reduce the recruit-sized oyster population in core strata by 14.8 million oysters (3.8%) from 391.2 million oysters at the time of the survey (February 2016) to 376.4 million oysters (Table 18) by early in the new oyster season (March 2016). Estimates of the numbers of recruit

sized oysters in core strata differ from Table 3 because station 108 in stratum E4 was omitted from the estimate because too few oysters were caught. Post-survey mortality of recruit-sized oysters by stratum (Table 18) ranged from 0% in stratum C7 to 10.0% in C3.

Post survey mortality was markedly lower than in 2015, 34.4 million oysters (10.0%), reducing the population from 345.2 million oysters to 310.8 million oysters (Appendix 4, Table A4.6). Estimates for 2012 and 2014 are given in Appendix 4 (Tables A4.7 and A4.8). In 2015, four strata (B3, B6, B1, and E2) had a post-survey mortality greater than 10%, fewer than in 2014 (C2, E2, C5, B1, C7, C7a, E4, and C3).

The estimates of post-survey mortality in core strata from fatally infected oysters scaled to the size of the catch were the same as those estimated using averaged correction factors, 14.8 million oysters (3.8%) (Table 19). Three of the fourteen strata (C3, B1, and B6) accounted for over half of the projected mortalities. Scaled fatal infections in 2015 are given in (Appendix 4, Tables A4.6).

How quickly low level, category 1 and 2 infections progress to category 3+ infections, and the variance amongst individual oysters is not known. Where the prevalence of category 1 and 2 infections was high, and occurred in areas of relatively high oyster density, heightened mortality may eventually occur.

Summer mortality, estimated as the percentage of recruit-sized oyster deaths from the time mortality began at the beginning of summer to the end of the seasonal mortality (about mid-March), calculated as the percentage of all deaths (pre-survey mortality and post survey mortality combined) of the recruit-sized population at the beginning of summer (population size of recruit-sized new clocks and population size of recruit-sized oysters at the time of survey combined), was 4.2% of the recruit-sized population (Table 20). Summer mortality was much lower in 2016 than in 2015 (12.4–13.1%, Table 20).

Table 18: Absolute population estimates for recruit-sized oysters after projected mortality from bonamia based on category 3 and higher infections in the core strata, background stratum (BK), and for the whole 2007 stock assessment survey area (Survey total) sampled in 2016. The number of randomly selected stations sampled (No. stns), the correction factor applied to each stratum (Correction factor), the mean oyster density per m^2 (Mean density), standard deviation (s.d.) of the density estimate, coefficient of variation (CV) of the oyster density, mean population size at the time of survey (Pop.n1), mean post mortality population size (Pop.n2) in millions of oysters, upper and lower 95% confidence intervals (CI) for the post-mortality estimate, the area of each stratum ($Area.km^2$), by stratum for the February 2016 survey.

2016 Core Strata	No. stns	Correction factor	Mean density	Density s.d.	CV	Pop.n1	Pop.n2	Lower 95%CI	Upper 95%CI	$Area.km^2$	Mortality	% of 2015 mortality
B1	3	0.94	0.47	0.12	0.26	39.2	37.1	16.3	65.2	78.2	5.5	36.3
B3	3	0.96	0.58	0.28	0.47	27.2	26.1	2.2	55.4	44.7	4.2	43.5
B6	5	0.93	0.60	0.16	0.27	19.6	18.1	7.8	31.9	30.0	7.4	37.5
C1a	3	0.99	0.83	0.14	0.17	26.2	25.8	15.0	41.3	31.3	1.4	191.7
C2	3	0.96	1.04	0.59	0.57	23.7	22.8	0.0	53.1	21.9	4.0	64.5
C3	3	0.90	1.32	0.19	0.15	47.9	43.1	25.7	67.0	32.7	10.0	183.6
C5	3	0.96	0.76	0.38	0.50	29.8	28.7	0.2	63.7	37.7	3.7	32.1
C5a	3	0.96	0.04	0.02	0.46	1.1	1.0	0.1	2.2	23.5	3.6	NA
C7	6	1.00	1.26	0.45	0.36	45.6	45.6	13.3	87.9	36.1	0.0	0.0
C7a	3	0.96	0.19	0.05	0.26	4.5	4.4	1.9	7.6	23.6	3.9	53.8
C8	4	0.96	1.19	0.52	0.44	33.3	31.8	4.4	66.2	26.8	4.3	32.2
C9	8	0.98	1.08	0.40	0.37	37.9	37.2	10.0	72.7	34.5	1.9	59.3
E2	3	0.99	0.57	0.18	0.32	24.9	24.6	8.4	46.0	42.8	1.4	7.8
E4	4	1.00	1.07	0.71	0.66	30.1	30.0	0.0	76.3	28.0	0.2	NA
Core total	54	-	0.77	0.09	0.11	391.2	376.4	239.9	582.6	491.8	3.8	38.0
Background strata	5	0.95	0.29	0.10	0.35	176.0	166.5	48.4	321.3	578.4	5.4	59.0
Survey total	59	-	0.507209	0.067826	0.133724	567.1	542.8	330.5	838.1	1070.2	4.3	44.0

Table 19: Scaled up estimates of the population size of recruit-sized oysters with fatal infections (category 3–5) estimated by heart imprints in the core strata, background stratum (BK), and for the whole 2007 stock assessment survey area sampled in 2016. The number of stations sampled (No. stns), the mean oyster density per m^2 (Mean density), the standard deviation of the mean density estimate (Density s.d.), the coefficient of variation (CV) of the density estimate, mean population size in millions of oysters (Pop.n, shaded grey), upper and lower 95% confidence intervals (95%CI) in millions of oysters, and the area of each stratum (Area. km^2) in square kilometres, by stratum.

2016 Core Strata	No. stns	Mean density	Density s.d.	CV	Pop.n	Lower 95%CI	Upper 95%CI	Area.km^2	% of 2015 mortality
B1	3	0.03	0.02	0.56	2.2	0.0	5.0	78.2	77.4
B3	3	0.03	0.02	0.76	1.1	0.0	3.1	44.7	36.9
B6	5	0.05	0.02	0.32	1.4	0.5	2.7	30.0	24.2
C1a	3	0.01	0.01	1.00	0.4	0.0	1.2	31.3	28.6
C2	3	0.04	0.02	0.57	0.9	0.0	2.2	21.9	105.4
C3	3	0.15	0.08	0.57	4.8	0.0	11.2	32.7	141.4
C5	3	0.03	0.02	0.59	1.1	0.0	2.7	37.7	53.2
C5a	3	0.00	0.00	1.00	0.0	0.0	0.1	23.5	NA
C7	6	0.00	0.00	1.00	0.1	0.0	0.2	36.1	4.0
C7a	3	0.01	0.00	0.50	0.2	0.0	0.4	23.6	44.9
C8	4	0.05	0.03	0.48	1.4	0.1	3.1	26.8	79.0
C9	8	0.02	0.01	0.45	0.7	0.1	1.5	34.5	15.5
E2	3	0.01	0.01	1.00	0.3	0.0	1.1	42.8	9.0
E4	4	0.00	0.00	1.00	0.1	0.0	0.2	28.0	NA
Core total	54	0.03	0.01	0.23	14.8	7.3	25.5	491.8	47.0
BK	5	0.02	0.00	0.20	9.9	5.3	16.4	578.4	51.4
Survey total	59	0.02	0.00	0.16	24.8	14.4	39.2	1070.2	48.7

Table 20: Summer mortality estimated as the percentage of recruit-sized oyster deaths from the time mortality began at the beginning of summer to the end of the seasonal mortality (about mid-March), calculated as the percentage of all deaths (pre-survey mortality and post survey mortality combined) of the recruit-sized population at the beginning of summer (population size of recruit-sized new clocks and population size of recruit-sized oysters at the time of survey combined).

	2015 Millions	2016 Millions
Pre-survey mortality	**of oysters**	**of oysters**
Recruit-sized new clocks (NC)	13.5	1.4
Post-survey mortality		
Correction factor	34.4	14.8
Scaled catch	31.6	14.8
Combined summer mortality		
Correction factor +NC	47.9	16.2
Scaled catch +NC	45.1	16.2
Population before summer mortality		
Recruit-sized oysters +NC	364.9	386.6
Percent summer mortality	**Percent**	
Correction factor +NC	13.1	4.2
Scaled catch +NC	12.4	4.2

4.7 The current status of the OYU 5 fishery and future trends (Objective 6)

Disease mortality and recruitment to the fishery appear to be the main drivers of future stock size in the OYU 5 fishery. The stock assessment for OYU 5 suggests that an annual commercial harvest of up to 20 million oysters is not likely to have a significant effect on the future (1–3 years) status of the stock (Figure 37).

Between 1993 and 1999, the fishery rebuilt rapidly from a historically low size, mainly due to low and non-detectable bonamia mortality and high recruitment to the fishery. After the second low point in the fishery in 2005, the fishery was again rebuilding rapidly with good spatfall and juvenile survival driving recruitment, with a bonamia mortality of about 10% of the recruit-sized population. Since 2009, the population size of recruit-sized oysters continued to increase and this high number of recruits should have led to increased recruitment, but instead recruitment has been low. The low recruitment to the fishery combined with a continuing bonamia mortality of about 10% flattened the stock trajectory between 2010 and 2013 (Figure 37).

Significant summer mortality from bonamia, 15.9% in 2013, 18.3% in 2014, and 13.6 % in 2015, along with the low recruitment to the fishery has led to a decline in the recruit-sized population since 2012. The number of recruit-sized oysters declined from 538.0 million oysters in 2014 to 351.4 million in 2015, a decrease of 34.7%.

Given the static recruitment to the fishery over the summer of 2015–16, and the lower level of bonamia mortality over the summer of 2015–16, and the slight increase in all size groups of oysters, the current status of the fishery is likely to be best represented by series “b” in Figure 37 which assumes a bonamia mortality of 10% and incorporates the decreased recruitment between the 2009 and 2012 stock assessments.

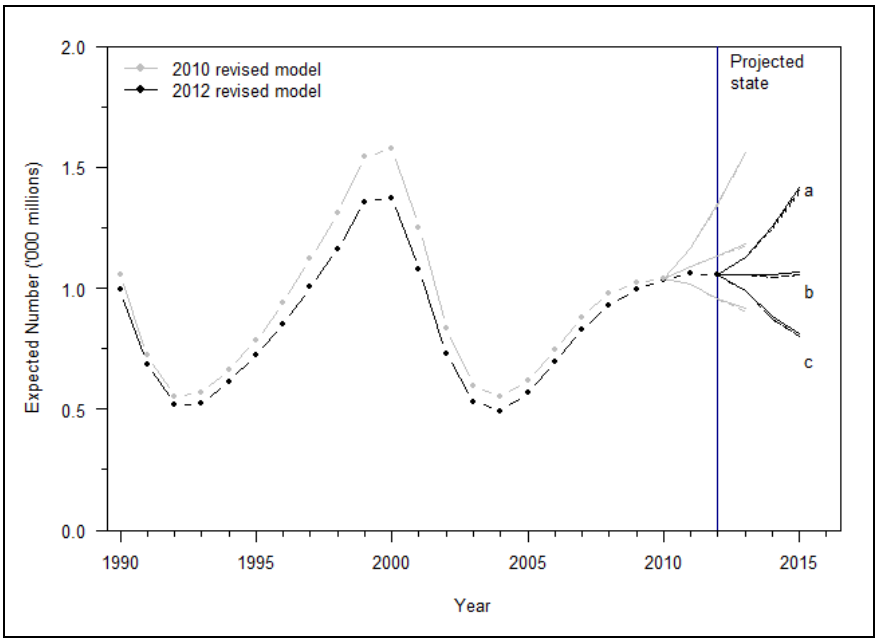

Figure 37: Model estimates of recruit-sized stock abundance (2012) and projected recruit-sized stock abundance for 2013–15 with a catch of 7.5 (solid line), 15 (dash dot), and 20 million oysters (dash line) under assumptions of (a) no disease mortality, (b) disease mortality of 0.10 per year, and (c) disease mortality of 0.20 per year, for the 2010 and 2012 revised models (figure reproduced from Fu 2013).

5. DISCUSSION

Annual bonamia surveys to monitor the status of bonamia infection and mortality in the oyster fishery have been undertaken since 2000. Bonamia surveys were undertaken concurrently with stock assessment surveys, and dedicated bonamia surveys were undertaken in alternate years to stock assessments. Occasionally more than one bonamia survey was undertaken in any given year.

The objectives of bonamia surveys changed over time, from station level comparisons of changes in bonamia status and related mortality, and in oyster density to determine the spread of the epizootic to include information on the effects disease mortality has on oyster density at the stratum level. The March 2000 bonamia survey focused on determining the spread of infection (Dunn et al. 2000). Sampling oysters to determine bonamia infection during stock assessment surveys (in the current epizootic) began in October 2001, but only a subset of the randomly selected stations that were sampled for oyster density were sampled for bonamia infection (Michael et al. 2004). The objective of bonamia surveys has typically been to survey a subset of strata within the stock assessment survey area considered important by oyster skippers, to resample a randomly selected subset of stations sampled during stock assessment surveys to determine the distribution, prevalence and intensity of infection by bonamia, and to estimate the oyster density in the commercial areas sampled for bonamia. Bonamia surveys (2000–2004) were not intended to inform stock assessments or to cover the entire fishery area.

From March 2006 onwards, projections of disease mortality between the February surveys and the start of the oyster season were made from data on the intensity of bonamia infection. Three bonamia surveys since 2009 (2010, 2011, and 2013) provided a suite of information for management of the OYU 5 fishery and for the oyster industry, but were not directly comparable. The February 2010 survey (Michael et al. 2011) estimated total summer mortality based on pre-survey estimates of mortality from new clocks and gapers and the post-survey mortality estimated from fatal bonamia infections. It was

acknowledged that estimates of pre- and post-survey mortality are not directly comparable. However, the combined totals of these two estimates provide the only estimate available for total summer mortality which is important in determining which projection from the previous stock assessment is best able to inform future stock status. The three projections of future stock status are based on 0%, 10%, and 20% disease mortality (Dunn 2007). This estimate of post-survey mortality became a key result for both the stock assessment surveys and bonamia surveys that followed; and there was acceptance that bonamia surveys whilst not representative of the whole fishery area, gave a good indication of what would be likely to occur in the commercial fishery areas important to industry and stakeholders. Projections of future stock status determined by the levels of summer disease mortality were consistent with recruit-sized population estimates from subsequent stock assessment surveys. A new time-series of bonamia and oyster surveys which have incorporated a fully randomised, two-phase sampling design and a standard bonamia survey area to make these surveys comparable from year to year was established in 2014.

The February 2016 survey is the third in this new time-series of bonamia and oyster surveys which incorporates a fully randomised, two-phase sampling design aimed at better estimating oyster density and population size in the three size groups of oysters surveyed, and of new clocks. Because both estimates of new clocks and fatal infections are scaled to the size of the oyster population, better estimates of oyster density are likely to give more precise estimates of total summer mortality. This time series of surveys also samples a standard bonamia survey area to make these surveys comparable from year to year. This area represents the core commercial fishery through the highs and lows in relative oyster abundance driven by bonamia mortality. Core strata comprised 14 of the 26 stock assessment survey strata from 2012 representing 75% of the recruit-sized oyster population and 46% of the stock assessment survey area. There is also some limited sampling in background strata so that the bonamia survey data could provide oyster density estimates for the whole stock assessment survey area and therefore allow these data to be incorporated into the planned five-yearly stock assessments.

5.1 Survey results

The 2016 survey was conducted in mostly calm sea conditions, but during spring tides. These sampling conditions were not expected to affect dredge efficiency. The change in vessel and the winch used to deploy the sampling dredge are unlikely to have affected the population estimates. The CVs obtained from the survey are the same as those predicted for recruit sized oysters (CV of 11%) and well below the target CV of 20%.

The timing of Bonamia surveys coincides with a period of peak seasonal mortality from Bonamia and the shedding infective particles. Because the qPCR method is very sensitive in the detection of bonamia, any exposure of gill tissues to Bonamia in seawater will be detected as a positive sample. If there is no corresponding systemic infection, the positive result will differ to the solely systemic infections detected in heart samples, and quantified in heart imprints. In 2015, there were 26.9% more positives detected in gill tissues than the corresponding heart tissues. In 2016, we took both gill and heart tissues, but tested only heart tissues. Tissue-specific inhibition of DNA amplification is a common problem with qPCR assays of samples from crude extracts. The percentage of samples that did not produce qPCR reactions (flatliners) was higher in 2016 (7.3%) than in 2015 (2.3 %) and in 2014 (5.7%). The higher percentage of flatliners is not likely to be related to the testing of only heart tissues in 2016. The percentage of flatliners in heart and gill samples was similar in 2015, 2.3% and 1.9 % respectively.

Mortality from bonamia infection has been generally low 2009–2012, but increased markedly between 2013 and 2015. Mortality from bonamia declined to low levels in 2016, recruitment to the population up slightly, and the population of recruit-sized oysters increased to 285.5 million.

5.2 Status of the OYU 5 stock

The 2012 stock assessment suggested that the exploitation rates were low, and the stock continued to rebuild since the 2000 outbreak of bonamia reduced the stock to low levels in 2005. These estimates

suggest that the spawning stock population in 2012 was about 35% (31–41%) B_0, and recruit-sized stock abundance (rB_{2012}) was about 30% (26–34%) of initial state (rB_{1907}) (Fu 2013).

By 2012, the trajectory of the future stock size was already starting to flatten due to the continuing low level mortality of between 8% and 12% from 2007 to 2012 and the reduced recruitment since 2009. At 10% bonamia mortality, long-term average recruitment, and a harvest level below 20 million oysters, there was no change expected in stock size between 2013 and 2015.

The increase in summer mortality from bonamia to 18.3% in 2014 and 13.6% in 2015, and the continued low recruitment to the oyster population was expected to further steepen the downward trend in the oyster population. Further, both the population sizes of pre-recruits and small oysters are low, and are likely to result in little recruitment to the fishery in the short to medium term.

The 2016 bonamia survey showed some promising signs for the fishery: bonamia infection and summer mortality are down, and there is an upward trend in the population sizes of all size groups of oysters. The declining trend in the fishery from 2012 to 2015 has levelled off in 2016. Because of the relatively low numbers of pre-recruit and small sized oysters, any rebuilding of the recruit-sized population is likely to be slow.

6. ACKNOWLEDGMENTS

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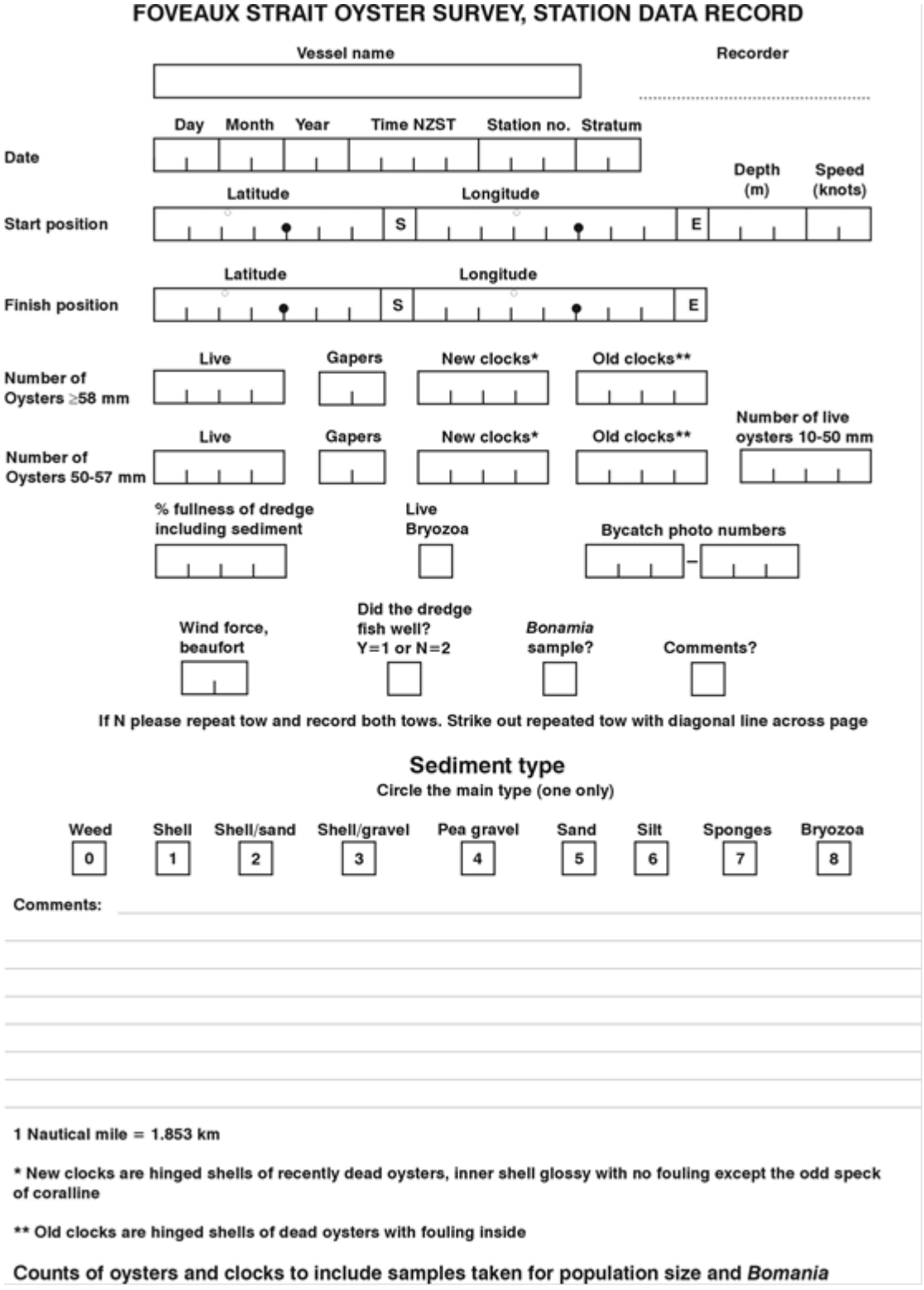
8. APPENDIXICES

8.1 Appendix 1: Survey station form



FOVEAUX STRAIT OYSTER SURVEY, STATION DATA RECORD

Vessel name

Recorder

Day Month Year Time NZST Station no. Stratum

Date

Depth (m) Speed (knots)

Latitude Longitude

Start position S E

Latitude Longitude

Finish position S E

Live Gapers New clocks* Old clocks**

Number of Oysters ≥58 mm

Live Gapers New clocks* Old clocks** Number of live oysters 10-50 mm

Number of Oysters 50-57 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*

8.2 Appendix 2: Survey bonamia form

FOVEAUX STRAIT OYSTER BONAMIA DATA RECORD

Page ___ of ___

Date

Station no. | Day | Month | Year | Time NZST

Recorder

Comments

Oyster no	Length (mm)	Height (mm)	Size category [1]	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'.

8.3 Appendix 3: Population estimates for recruit-sized, pre-recruit, and small oysters from the 2012, 2014 and 2015 surveys. Comparisons between the population estimates in the background stratum in 2012 and 2014 should be made with caution as there were only 5 stations sampled in total in 2014 and 2015.

Table A3.1: Absolute population estimates from randomly allocated stations for recruit-sized oysters in the core strata (Stratum), the background stratum (BK), and for the whole 2007 stock assessment survey area (Survey total) sampled in 2015. The number of stations sampled (No. stns), the mean oyster density per m^2 (Mean density), the standard deviation of the mean density estimate (Density s.d.), the coefficient of variation (CV) of the density estimate, the mean population size in millions of oysters (Pop.n), upper and lower 95% confidence intervals (95% CI) in millions of oysters where an S prefix denotes the sampling CI calculated from the mean, standard deviation and sample size alone, and a B prefix denotes the bootstrapped estimates, and the area of each stratum (Area. km^2) in square kilometres, by stratum for the February 2015 Foveaux Strait oyster survey.

2015 Stratum	No. stns	Mean density	Density s.d.	CV	2015 Pop.n	S.lower 95%CI	S.upper 95%CI	B.lower 95%CI	B.upper 95%CI	Area.km^2
B1	3	0.43	0.05	0.11	33.5	29.2	37.9	21.4	51.3	78.2
B3	3	1.65	0.11	0.07	73.6	67.9	79.4	48.9	108.8	44.7
B6	5	1.15	0.36	0.32	34.5	24.9	44.1	12.0	63.7	30.0
C1a	3	0.43	0.26	0.61	13.5	4.3	22.8	0.0	32.9	31.3
C2	3	0.37	0.19	0.50	8.0	3.4	12.6	0.2	17.8	21.9
C3	4	0.95	0.17	0.17	31.1	25.8	36.4	17.6	49.7	32.7
C5	4	0.52	0.21	0.41	19.7	11.9	27.6	3.6	40.3	37.7
C5a	3	0.10	0.05	0.56	2.3	0.8	3.7	0.0	5.3	23.5
C7	3	0.72	0.27	0.37	25.8	14.9	36.8	6.7	50.7	36.1
C7a	3	0.46	0.17	0.36	10.9	6.4	15.4	2.9	21.1	23.6
C8	5	0.90	0.33	0.37	24.1	16.2	31.9	6.2	47.2	26.8
C9	9	1.43	0.40	0.28	49.3	40.4	58.2	20.8	88.1	34.5
E2	4	0.49	0.19	0.38	21.0	13.1	28.8	5.0	41.8	42.8
E4	3	0.14	0.13	0.91	3.9	0.0	7.9	0.0	11.9	28.0
Core	55	0.71	0.06	0.08	351.4	344.0	358.8	232.1	528.8	491.8
BK	5	0.27	0.06	0.23	158.5	126.1	191.0	77.9	270.1	578.4
Survey total	60	0.48	0.04	0.09	509.9	498.2	521.7	327.4	761.8	1070.2

Table A3.2: Absolute population estimates from randomly allocated stations for recruit-sized oysters in the core strata, the background stratum (BK), and for the whole 2007 stock assessment survey area (Survey total) sampled in 2014. The number of stations sampled (No. stns), the mean oyster density per m^2 (Mean density), the standard deviation of the mean density estimate (Density s.d.), the coefficient of variation (CV) of the density estimate, the mean population size in millions of oysters (Pop.n), upper and lower 95% confidence intervals (95% CI) in millions of oysters where an S prefix denotes the sampling CI calculated from the mean, standard deviation and sample size alone, and a B prefix denotes the bootstrapped estimates, and the area of each stratum (Area. km^2) in square kilometres, by stratum for the February 2014 Foveaux Strait oyster survey.

2014 Core Strata	No. stns	Mean density	Density s.d.	CV	Pop.n	S.lower 95%CI	S.upper 95%CI	B.lower 95%CI	B.upper 95%CI	Area.km^2
B1	3	0.82	0.16	0.2	63.9	49.8	78.0	34.5	105.4	78.2
B3	8	1.31	0.13	0.1	58.7	54.7	62.7	37.8	88.2	44.7
B6	3	0.82	0.23	0.29	24.6	16.8	32.4	9.9	43.9	30
C1a	3	0.53	0.28	0.53	16.5	6.6	26.4	0	37.2	31.3
C2	3	1.2	0.47	0.39	26.4	14.7	38.1	5.9	52.2	21.9
C3	4	1.25	0.63	0.51	40.9	20.7	61.1	0	91.1	32.7
C5	4	1.25	0.42	0.34	46.9	31.5	62.3	14.9	88.5	37.7
C5a	7	0.7	0.25	0.36	16.4	12.1	20.7	4.6	31.8	23.5
C7	3	0.53	0.27	0.52	19	8.0	30.0	0	42.1	36.1
C7a	3	0.78	0.16	0.21	18.5	14.2	22.8	9.7	30.8	23.6
C8	3	1.77	0.24	0.14	47.6	40.3	54.9	28.8	74.6	26.8
C9	4	2.83	1.26	0.45	97.4	54.9	139.9	12.1	206.2	34.5
E2	4	1.33	0.49	0.37	56.8	36.3	77.3	15.7	112.1	42.8
E4	3	0.17	0.15	0.91	4.6	0.0	9.2	0	14.2	28
Core total	55	1.09	0.12	0.11	538.0	522.3	553.7	343.6	832.2	491.8
BK	5	0.83	0.18	0.21	482.9	391.1	574.7	250.7	806.2	578.4
Survey total	60	0.95	0.11	0.12	1020.9	991.0	1050.8	635.1	1554.2	1070.2

Table A3.3: Absolute population estimates from randomly allocated stations for recruit-sized oysters in the core strata, the background stratum (BK), and for the whole 2007 stock assessment survey area (Survey total) sampled in 2012. The number of stations sampled (No. stns), the mean oyster density per m^2 (Mean density), the standard deviation of the mean density estimate (Density s.d.), the coefficient of variation (CV) of the density estimate, mean population size in millions of oysters (Pop.n), upper and lower 95% confidence intervals (95%CI) in millions of oysters where a S prefix denotes the sampling CI calculated from the mean, standard deviation and sample size alone, and a B prefix denotes the bootstrapped estimate, and the area of each stratum (Area. km^2) in square kilometres, by stratum for the February 2012 Foveaux Strait oyster survey.

2012 Core Strata	No. stns	Mean density	Density s.d.	CV	Pop.n	S.lower 95%CI	S.upper 95%CI	B.lower 95%CI	B.upper 95%CI	Area.km^2
B1	5	0.7	0.24	0.34	54.6	38.2	71.0	17.3	103.2	78.2
B3	13	3.56	0.7	0.2	158.9	141.9	175.9	87.2	258.7	44.7
B6	6	1.15	0.5	0.44	34.4	22.4	46.4	4.7	70.8	30
C1a	5	0.58	0.23	0.39	18.2	11.9	24.5	3.9	36.4	31.3
C2	3	0.97	0.16	0.17	21.2	17.2	25.2	12.2	33.9	21.9
C3	6	1.44	0.41	0.29	47.1	36.4	57.8	19.1	84	32.7
C5	8	1.98	0.53	0.27	74.5	60.7	88.3	31.4	132.7	37.7
C5a	5	1.34	0.86	0.64	31.6	13.8	49.4	0	77.8	23.5
C7	5	1.01	0.18	0.18	36.4	30.7	42.1	20.5	58.6	36.1
C7a	4	1.78	0.76	0.43	42	24.4	59.6	6.1	86	23.6
C8	6	1.65	0.64	0.39	44.3	30.6	58.0	10.3	88.2	26.8
C9	6	1.04	0.49	0.47	35.8	22.3	49.3	2.5	76.9	34.5
E2	8	1.87	0.49	0.26	80.3	65.7	94.9	35.6	141.4	42.8
E4	4	0.31	0.22	0.7	8.8	2.7	14.9	0	23.2	28
Core total	84	1.4	0.13	0.09	688.1	674.4	701.8	449.2	1046.7	491.8
BK	62	0.4	0.08	0.2	230.3	218.8	241.8	125.2	376	578.4
Survey total	146	0.86	0.07	0.08	918.4	906.3	930.5	600.1	1383.7	1070.2

Table A3.4: Absolute population estimates from randomly allocated stations for pre-recruit-sized oysters in the core strata (Stratum), the background stratum (BK), and for the whole 2007 stock assessment survey area (Survey total) sampled in 2015. The number of stations sampled (No. stns), the mean oyster density per m^2 (Mean density), the standard deviation of the mean density estimate (Density s.d.), the coefficient of variation (CV) of the density estimate, the mean population size in millions of oysters (Pop.n), upper and lower 95% confidence intervals (95%CI) in millions of oysters where an S prefix denotes the sampling CI calculated from the mean, standard deviation and sample size alone, and a B prefix denotes the bootstrapped estimates, and the area of each stratum (Area. km^2) in square kilometres, by stratum for the February 2015 Foveaux Strait oyster survey.

2015 Stratum	No. stns	Mean density	Density s.d.	CV	Pop.n	S.lower 95%CI	S.upper 95%CI	B.lower 95%CI	B.upper 95%CI	Area.km^2
B1	3	0.26	0.04	0.14	20.4	17.2	23.6	12.5	31.8	78.2
B3	3	0.17	0.07	0.42	7.5	3.9	11.1	1.4	15.2	44.7
B6	5	0.13	0.04	0.31	3.8	2.8	4.9	1.4	7.1	30.0
C1a	3	0.08	0.05	0.63	2.5	0.7	4.3	0.0	6.2	31.3
C2	3	0.25	0.06	0.25	5.5	4.0	7.1	2.6	9.6	21.9
C3	4	0.22	0.05	0.22	7.2	5.6	8.7	3.6	12.0	32.7
C5	4	0.07	0.03	0.45	2.7	1.5	4.0	0.3	5.8	37.7
C5a	3	0.02	0.01	0.62	0.6	0.2	1.0	0.0	1.4	23.5
C7	3	0.42	0.24	0.57	15.1	5.3	24.8	0.0	35.3	36.1
C7a	3	0.19	0.05	0.26	4.4	3.1	5.7	1.9	7.7	23.6
C8	5	0.16	0.05	0.32	4.4	3.2	5.6	1.5	8.2	26.8
C9	9	0.21	0.07	0.31	7.4	5.9	8.9	2.6	13.7	34.5
E2	4	0.16	0.07	0.46	6.7	3.7	9.7	0.6	14.3	42.8
E4	3	0.04	0.03	0.80	1.0	0.1	1.9	0.0	2.9	28.0
Core	55	0.18	0.02	0.12	89.2	86.2	92.1	55.8	139.2	491.8
BK	5	0.06	0.01	0.22	32.9	26.5	39.3	16.7	55.5	578.4
Survey total	60	0.11	0.01	0.11	122.1	118.7	125.4	76.7	184.7	1070.2

Table A3.5: Absolute population estimates from randomly allocated stations for pre-recruit oysters in the core strata, the background stratum (BK), and for the whole 2007 stock assessment survey area (Survey total) sampled in 2014. The number of stations sampled (No. stns), the mean oyster density per m^2 (Mean density), the standard deviation of the mean density estimate (Density s.d.), the coefficient of variation (CV) of the density estimate, mean population size in millions of oysters (Pop.n), upper and lower 95% confidence intervals (95%CI) in millions of oysters where a S prefix denotes the sampling CI calculated from the mean, standard deviation and sample size alone, and a B prefix denotes the bootstrapped estimate, and the area of each stratum (Area. km^2) in square kilometres, by stratum for the February 2014 Foveaux Strait oyster survey.

2014 Core Strata	No. Stns	Mean density	Density s.d.	CV	Pop.n	S.lower 95%CI	S.upper 95%CI	B.lower 95%CI	B.upper 95%CI	Area.km^2
B1	3	0.54	0.15	0.28	42.4	29.1	55.7	17.5	75.9	78.2
B3	8	0.13	0.02	0.17	6	5.4	6.6	3.5	9.5	44.7
B6	3	0.15	0.08	0.55	4.4	1.7	7.1	0	10.1	30
C1a	3	0.08	0.03	0.39	2.6	1.5	3.7	0.6	5.2	31.3
C2	3	0.71	0.26	0.36	15.5	9.1	21.9	4.4	30	21.9
C3	4	0.32	0.14	0.44	10.5	6.0	15.0	1.4	21.9	32.7
C5	4	0.24	0.08	0.34	9	6.1	11.9	2.8	17.1	37.7
C5a	7	0.1	0.03	0.32	2.3	1.8	2.8	0.8	4.3	23.5
C7	3	0.3	0.18	0.61	10.8	3.5	18.1	0	26	36.1
C7a	3	0.35	0.05	0.14	8.2	6.9	9.5	5	12.8	23.6
C8	3	0.37	0.05	0.13	10	8.5	11.5	6.1	15.5	26.8
C9	4	0.27	0.14	0.52	9.3	4.6	14.0	0	20.7	34.5
E2	4	0.31	0.07	0.22	13.2	10.3	16.1	6.6	22.4	42.8
E4	3	0.15	0.15	1	4.1	0	8.7	0	13.3	28
Core total	55	0.3	0.04	0.12	148.4	143.2	153.6	93.7	230.7	491.8
BK	5	0.13	0.05	0.35	77.9	51.6	104.2	22.6	150.3	578.4
Survey total	60	0.21	0.03	0.14	226.2	218.0	234.4	135.1	352.1	1070.2

Table A3.6: Absolute population estimates from randomly allocated stations for pre-recruit oysters in the core strata, the background stratum (BK), and for the whole 2007 stock assessment survey area (Survey total) sampled in 2012. The number of stations sampled (No. stns), the mean oyster density per m^2 (Mean density), the standard deviation of the mean density estimate (Density s.d.), the coefficient of variation (CV) of the density estimate, mean population size in millions of oysters (Pop.n), upper and lower 95% confidence intervals (95%CI) in millions of oysters where a S prefix denotes the sampling CI calculated from the mean, standard deviation and sample size alone, and a B prefix denotes the bootstrapped estimate, and the area of each stratum (Area. km^2) in square kilometres, by stratum for the February 2012 Foveaux Strait oyster survey.

2012 Core Strata	No. stns	Mean density	Density s.d.	CV	Pop.n	S.lower 95%CI	S.upper 95%CI	B.lower 95%CI	B.upper 95%CI	Area.km^2
B1	5	0.6	0.21	0.35	46.6	32.3	60.9	14	89	78.2
B3	13	0.94	0.14	0.15	41.8	38.4	45.2	25.3	65.3	44.7
B6	6	0.52	0.29	0.55	15.5	8.6	22.4	0	35.4	30
C1a	5	0.19	0.05	0.26	6	4.6	7.4	2.6	10.5	31.3
C2	3	0.65	0.2	0.31	14.3	9.3	19.3	5.3	26.4	21.9
C3	6	0.53	0.16	0.29	17.5	13.3	21.7	6.9	31.3	32.7
C5	8	0.58	0.13	0.22	21.8	18.4	25.2	11	36.9	37.7
C5a	5	0.36	0.24	0.67	8.4	3.5	13.3	0	21.2	23.5
C7	5	0.87	0.15	0.17	31.6	26.8	36.4	18	50.6	36.1
C7a	4	1.39	0.52	0.37	32.9	20.8	45.0	8.4	64	23.6
C8	6	0.51	0.13	0.26	13.7	10.9	16.5	6	24.1	26.8
C9	6	0.26	0.1	0.4	9	6.2	11.8	1.9	18.1	34.5
E2	8	0.85	0.31	0.37	36.2	27.1	45.3	9.4	71.1	42.8
E4	4	0.08	0.04	0.54	2.1	1.1	3.1	0	5	28
Core total	84	0.6	0.06	0.1	297.4	291.0	303.8	192.6	454.4	491.8
BK	62	0.2	0.05	0.23	116.9	109.6	124.2	57.6	196.9	578.4
Survey total	146	0.39	0.04	0.1	414.3	407.4	421.2	267.8	629	1070.2

Table A3.7: Absolute population estimates from randomly allocated stations for small oysters in the core strata (Stratum, N = 14), the background stratum (BK), and for the whole 2007 stock assessment survey area (Survey total) sampled in 2015. The number of stations sampled (No. stns), the mean oyster density per m^2 (Mean density), the standard deviation of the mean density estimate (Density s.d.), the coefficient of variation (CV) of the density estimate, the mean population size in millions of oysters (Pop.n), upper and lower 95% confidence intervals (95%CI) in millions of oysters where an S prefix denotes the sampling CI calculated from the mean, standard deviation and sample size alone, and a B prefix denotes the bootstrapped estimates, and the area of each stratum (Area. km^2) in square kilometres, by stratum for the February 2015 Foveaux Strait oyster survey.

2015 Stratum	No. stns	Mean density	Density s.d.	CV	Pop.n	S.lower 95%CI	S.upper 95%CI	B.lower 95%CI	B.upper 95%CI	Area.km^2
B1	3	0.55	0.14	0.25	43.0	30.8	55.2	19.9	74.4	78.2
B3	3	0.22	0.07	0.32	9.7	6.2	13.2	3.6	17.8	44.7
B6	5	0.25	0.06	0.23	7.6	6.1	9.2	3.7	12.9	30.0
C1a	3	0.15	0.06	0.43	4.6	2.4	6.9	0.7	9.6	31.3
C2	3	0.37	0.12	0.33	8.1	5.1	11.0	2.8	15.1	21.9
C3	4	0.50	0.13	0.27	16.4	12.1	20.6	7.2	28.6	32.7
C5	4	0.11	0.06	0.52	4.0	2.0	6.1	0.0	9.0	37.7
C5a	3	0.06	0.01	0.25	1.3	0.9	1.7	0.6	2.3	23.5
C7	3	0.60	0.37	0.61	21.8	6.7	37.0	0.0	52.6	36.1
C7a	3	0.42	0.10	0.25	10.0	7.2	12.8	4.7	17.3	23.6
C8	5	0.28	0.09	0.31	7.6	5.5	9.7	2.8	14.1	26.8
C9	9	0.34	0.06	0.18	11.6	10.2	12.9	6.5	18.9	34.5
E2	4	0.26	0.09	0.34	10.9	7.3	14.6	3.3	20.9	42.8
E4	3	0.07	0.04	0.53	1.8	0.7	2.9	0.0	4.2	28.0
Core	55	0.32	0.04	0.12	158.5	153.4	163.6	99.6	247.1	491.8
BK	5	0.16	0.08	0.51	90.5	49.8	131.2	0.0	202.6	578.4
All	60	0.23	0.05	0.20	249.0	236.3	261.7	130.8	412.4	1070.2

Table A3.8: Absolute population estimates from randomly allocated stations for small oysters in the core strata, the background stratum (BK), and for the whole 2007 stock assessment survey area (Survey total) sampled in 2014. The number of stations sampled (No. stns), the mean oyster density per m^2 (Mean density), the standard deviation of the mean density estimate (Density s.d.), the coefficient of variation (CV) of the density estimate, mean population size in millions of oysters (Pop.n), upper and lower 95% confidence intervals (95%CI) in millions of oysters where a S prefix denotes the sampling CI calculated from the mean, standard deviation and sample size alone, and a B prefix denotes the bootstrapped estimate, and the area of each stratum (Area. km^2) in square kilometres, by stratum for the February 2014 Foveaux Strait oyster survey.

2014 Core Strata	No. Stns	Mean density	Density s.d.	CV	Pop.n	S.lower 95%CI	S.upper 95%CI	B.lower 95%CI	B.upper 95%CI	Area.km^2
B1	3	0.32	0.09	0.29	25.3	17.2	33.4	9.9	45.7	78.2
B3	8	0.22	0.04	0.19	9.7	8.5	10.9	5.3	15.7	44.7
B6	3	0.22	0.09	0.42	6.5	3.5	9.5	1.1	13.1	30
C1a	3	0.2	0.12	0.6	6.3	2.0	10.6	0	15.2	31.3
C2	3	0.72	0.12	0.17	15.9	12.9	18.9	9.2	25.3	21.9
C3	4	0.37	0.17	0.47	12	6.6	17.4	0.9	25.6	32.7
C5	4	0.29	0.16	0.56	10.9	5.0	16.8	0	25.4	37.7
C5a	7	0.29	0.11	0.37	6.8	4.9	8.7	1.8	13.2	23.5
C7	3	0.16	0.06	0.39	5.6	3.2	8.0	1.3	11.2	36.1
C7a	3	0.62	0.24	0.39	14.6	8.2	21.0	3.1	29	23.6
C8	3	0.51	0.05	0.1	13.8	12.3	15.3	8.8	20.9	26.8
C9	4	0.35	0.14	0.4	11.9	7.2	16.6	2.4	24.1	34.5
E2	4	0.31	0.09	0.29	13.2	9.4	17.0	5.3	23.9	42.8
E4	3	0.14	0.13	0.97	3.9	0	8.0	0	12.3	28
Core total	55	0.32	0.03	0.1	156.3	152.4	160.2	101.1	239.4	491.8
BK	5	0.25	0.05	0.2	146.3	120.7	171.9	78.1	242	578.4
Survey total	60	0.28	0.03	0.11	302.6	294.4	310.8	189.2	459.2	1070.2

Table A3.9: Absolute population estimates from randomly allocated stations for small oysters in the core strata, the background stratum (BK), and for the whole 2007 stock assessment survey area (Survey total) sampled in 2012. The number of stations sampled (No. stns), the mean oyster density per m^2 (Mean density), the standard deviation of the mean density estimate (Density s.d.), the coefficient of variation (CV) of the density estimate, mean population size in millions of oysters (Pop.n), upper and lower 95% confidence intervals (95%CI) in millions of oysters where a S prefix denotes the sampling CI calculated from the mean, standard deviation and sample size alone, and a B prefix denotes the bootstrapped estimate, and the area of each stratum (Area. km^2) in square kilometres, by stratum for the February 2012 Foveaux Strait oyster survey.

2012 Core Strata	No. stns	Mean density	Density s.d.	CV	Pop.n	S.lower 95%CI	S.upper 95%CI	B.lower 95%CI	B.upper 95%CI	Area.km^2
B1	5	1.13	0.4	0.36	88	60.7	115.3	24.2	169.9	78.2
B3	13	0.73	0.12	0.17	32.8	29.9	35.7	19.2	52	44.7
B6	6	0.74	0.34	0.45	22.1	14.0	30.2	2.2	46.3	30
C1a	5	0.32	0.07	0.24	9.8	7.9	11.7	4.8	16.8	31.3
C2	3	1.38	0.58	0.42	30.4	15.9	44.9	5.3	62.1	21.9
C3	6	0.49	0.16	0.32	16.1	11.9	20.3	5.6	29.6	32.7
C5	8	0.55	0.12	0.22	20.9	17.7	24.1	10.7	35.3	37.7
C5a	5	0.52	0.28	0.53	12.2	6.4	18.0	0	27.7	23.5
C7	5	1.36	0.29	0.21	49.2	40.0	58.4	25.7	81.7	36.1
C7a	4	4.04	2.56	0.63	95.5	36.2	154.8	0	234.2	23.6
C8	6	0.43	0.12	0.27	11.7	9.1	14.3	5	20.6	26.8
C9	6	0.3	0.09	0.3	10.3	7.8	12.8	3.9	18.9	34.5
E2	8	1.11	0.36	0.33	47.5	36.8	58.2	15.7	89.4	42.8
E4	4	0.18	0.08	0.46	4.9	2.8	7.0	0.6	10.6	28
Core total	84	0.92	0.15	0.16	451.3	435.6	467.0	261.5	731.7	491.8
BK	62	0.28	0.08	0.29	160.9	149.5	172.3	64.2	286.8	578.4
Survey total	146	0.57	0.08	0.14	612.2	598.3	626.1	370.3	967.9	1070.2

Table A3.10: Absolute population estimates from randomly allocated stations for the size 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 the core strata, the background stratum (BK), and for the whole 2007 stock assessment survey area (Survey total) sampled in 2015. The number of stations sampled (No. stns), the mean oyster density per m^2 (Mean density), the standard deviation of the mean density estimate (Density s.d.), the coefficient of variation (CV) of the density estimate, the mean population size in millions of oysters (Pop.n), upper and lower 95% confidence intervals (95%CI) in millions of oysters where an S prefix denotes the sampling CI calculated from the mean, standard deviation and sample size alone, and a B prefix denotes the bootstrapped estimates, and the area of each stratum (Area. km^2) in square kilometres, by stratum for the February 2015 Foveaux Strait oyster survey.

2015 Stratum	No. stns	Mean density	Density s.d.	CV	Pop.n	S.lower 95%CI	S.upper 95%CI	B.lower 95%CI	B.upper 95%CI	Area.km^2
B1	3	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	78.2
B3	3	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	44.7
B6	5	0.49	0.49	1.00	14.8	1.8	27.8	0.0	47.5	30.0
C1a	3	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	31.3
C2	3	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	21.9
C3	4	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	32.7
C5	4	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	37.7
C5a	3	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	23.5
C7	3	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	36.1
C7a	3	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	23.6
C8	5	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	26.8
C9	9	1.18	0.47	0.40	40.6	29.9	51.2	8.8	81.0	34.5
E2	4	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	42.8
E4	3	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	28.0
Core	55	0.11	0.04	0.40	55.4	49.5	61.2	12.0	109.4	491.8
BK	5	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	578.4
Survey total	60	0.05	0.02	0.40	55.4	49.8	61.0	12.0	109.4	1070.2

Table A3.11: Absolute population estimates for the size 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) from randomly allocated stations in the core strata, the background stratum (BK), and for the whole 2007 stock assessment survey area (Survey total) sampled in 2014. The number of stations sampled (No. stns), the mean oyster density per m^2 (Mean density), the standard deviation of the mean density estimate (Density s.d.), coefficient of variation (CV) of the density estimate, mean population size in millions of oysters (Pop.n), upper and lower 95% confidence intervals (95%CI) in millions of oysters where an S prefix denotes the sampling CI calculated from the mean, standard deviation and sample size alone, and a B prefix denotes the bootstrapped estimate, and the area of each stratum (Area. km^2) in square kilometres, by stratum for the February 2014 Foveaux Strait oyster survey.

2014 Core Strata	No. stns	Mean density	Density s.d.	CV	Pop.n	S.lower 95%CI	S.upper 95%CI	B.lower 95%CI	B.upper 95%CI	Area.km^2
B1	3	0	0	0	0	0	0	0	0	78.2
B3	8	0	0	0	0	0	0	0	0	44.7
B6	3	0	0	0	0	0	0	0	0	30
C1a	3	0	0	0	0	0	0	0	0	31.3
C2	3	0.7	0.7	1	15.4	-2.0	32.8	0	49.4	21.9
C3	4	1.16	0.69	0.59	37.8	15.8	59.8	0	89.4	32.7
C5	4	0.6	0.6	1	22.8	0.5	45.1	0	72.6	37.7
C5a	7	0	0	0	0	0	0	0	0	23.5
C7	3	0	0	0	0	0	0	0	0	36.1
C7a	3	0	0	0	0	0	0	0	0	23.6
C8	3	0.75	0.75	1	20	-2.6	42.6	0	64.3	26.8
C9	4	2.49	1.45	0.58	85.7	36.8	134.6	0	202	34.5
E2	4	0.69	0.69	1	29.6	0.6	58.6	0	94.6	42.8
E4	3	0	0	0	0	0	0	0	0	28
Core total	55	0.43	0.14	0.34	211.3	193.1	229.5	69	396.2	491.8
BK	5	0	0	0	0	0	0	0	0	578.4
Survey total	60	0.2	0.07	0.34	211.3	192.6	230.0	69	396.2	1070.2

Table A3.12: Absolute population estimates from randomly allocated stations for the size 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) for the core strata, the background stratum (BK), and for the whole 2007 stock assessment survey area (Survey total) sampled in 2012. The number of stations sampled (No. stns), the mean oyster density per m^2 (Mean density), the standard deviation of the mean density estimate (Density s.d.), coefficient of variation (CV) of the density estimate, mean population size in millions of oysters (Pop.n), upper and lower 95% confidence intervals (95%CI) in millions of oysters where a S prefix denotes the sampling CI calculated from the mean, standard deviation and sample size alone, and a B prefix denotes the bootstrapped estimate, and the area of each stratum (Area. km^2) in square kilometres, by stratum for the February 2012 Foveaux Strait oyster survey.

2012 Core Strata	No. stns	Mean density	Density s.d.	CV	Pop.n	S.lower 95%CI	S.upper 95%CI	B.lower 95%CI	B.upper 95%CI	Area.km^2
B1	5	0	0	0	0	0	0	0	0	78.2
B3	13	3.22	0.81	0.25	143.7	124.0	163.4	66.3	248.9	44.7
B6	6	0.88	0.57	0.65	26.4	12.7	40.1	0	65.2	30
C1a	5	0	0	0	0	0	0	0	0	31.3
C2	3	0	0	0	0	0	0	0	0	21.9
C3	6	0.89	0.57	0.63	29.2	14.2	44.2	0	71.2	32.7
C5	8	1.33	0.68	0.51	50.1	32.3	67.9	0	112	37.7
C5a	5	0.95	0.95	1	22.3	2.8	41.8	0	70.8	23.5
C7	5	0	0	0	0	0	0	0	0	36.1
C7a	4	1	1	1	23.6	0.5	46.7	0	75.4	23.6
C8	6	1.16	0.74	0.64	31.2	15.3	47.1	0	77.5	26.8
C9	6	0.58	0.58	1	19.9	4.0	35.8	0	63.3	34.5
E2	8	1.55	0.6	0.39	66.4	48.6	84.2	15.5	132.1	42.8
E4	4	0	0	0	0	0	0	0	0	28
Core total	84	0.84	0.15	0.17	412.7	396.9	428.5	236.9	660.4	491.8
BK	62	0.11	0.07	0.62	61.2	51.5	70.9	0	146.4	578.4
Survey total	146	0.44	0.08	0.17	473.9	459.9	487.9	274.4	759.6	1070.2

Table A3.13: Recruit-sized new clocks estimated from randomly selected stations in the core strata (Stratum), the background stratum (BK), and for the whole 2007 stock assessment survey area (Survey total) sampled in 2015. The number of stations sampled (No. stns), the mean oyster density per m^2 (Mean density), the standard deviation of the mean density estimate (Density s.d.), coefficient of variation (CV) of the density estimate, mean population size in millions of oysters (Pop.n), upper and lower 95% confidence intervals (95%CI) in millions of oysters where a S prefix denotes the sampling CI calculated from the mean, standard deviation and sample size alone, and a B prefix denotes the bootstrapped estimate, and the area of each stratum (Area. km^2) in square kilometres, by stratum for the February 2015 Foveaux Strait oyster survey.

2015 Stratum	No. stns	Mean density	Density s.d.	CV	Pop.n	S.lower 95%CI	S.upper 95%CI	B.lower 95%CI	B.upper 95%CI	Area.km^2
B1	3	0.01	0.01	0.51	1.1	0.5	1.8	0.0	2.5	78.2
B3	3	0.05	0.02	0.37	2.4	1.4	3.4	0.7	4.6	44.7
B6	5	0.07	0.02	0.25	2.2	1.7	2.7	1.0	3.9	30.0
C1a	3	0.02	0.01	0.45	0.5	0.3	0.8	0.1	1.2	31.3
C2	3	0.01	0.00	0.20	0.2	0.1	0.2	0.1	0.3	21.9
C3	4	0.06	0.01	0.18	1.9	1.6	2.3	1.1	3.1	32.7
C5	4	0.03	0.02	0.50	1.1	0.6	1.7	0.0	2.5	37.7
C5a	3	0.01	0.00	0.66	0.1	0.0	0.3	0.0	0.4	23.5
C7	3	0.03	0.01	0.22	1.2	0.9	1.5	0.6	2.0	36.1
C7a	3	0.02	0.01	0.53	0.4	0.2	0.6	0.0	0.9	23.6
C8	5	0.02	0.01	0.51	0.5	0.3	0.7	0.0	1.0	26.8
C9	9	0.03	0.01	0.24	1.1	0.9	1.3	0.5	1.9	34.5
E2	4	0.01	0.01	0.53	0.5	0.3	0.8	0.0	1.2	42.8
E4	3	0.00	0.00	0.00	0.1	0.1	0.1	0.1	0.2	28.0
Core	55	0.03	0.00	0.11	13.5	13.1	13.9	8.7	20.9	491.8
BK	5	0.02	0.01	0.41	10.2	6.6	13.8	2.0	20.7	578.4
Survey total	60	0.02	0.00	0.19	23.7	22.6	24.8	13.0	38.6	1070.2

Table A3.14: Recruit-sized new clocks estimated from randomly selected stations in the core strata (Stratum), the background stratum (BK), and for the whole 2007 stock assessment survey area (Survey total) sampled in 2014. The number of stations sampled (No. stns), the mean oyster density per m^2 (Mean density), the standard deviation of the mean density estimate (Density s.d.), coefficient of variation (CV) of the density estimate, mean population size in millions of oysters (Pop.n), upper and lower 95% confidence intervals (95%CI) in millions of oysters where a S prefix denotes the sampling CI calculated from the mean, standard deviation and sample size alone, and a B prefix denotes the bootstrapped estimate, and the area of each stratum (Area. km^2) in square kilometres, by stratum for the February 2014 Foveaux Strait oyster survey.

2014 Core Strata	No. stns	Mean density	Density s.d.	CV	Pop.n	S.lower 95%CI	S.upper 95%CI	B.lower 95%CI	B.upper 95%CI	Area.km^2
B1	3	0.06	0.01	0.21	4.7	3.6	5.8	2.5	7.8	78.2
B3	8	0.11	0.03	0.24	5.1	4.3	5.9	2.5	8.7	44.7
B6	3	0.09	0.05	0.6	2.6	0.8	4.4	0	6.1	30
C1a	3	0.04	0.02	0.39	1.2	0.7	1.7	0.3	2.4	31.3
C2	3	0.04	0.01	0.28	1	0.7	1.3	0.4	1.7	21.9
C3	4	0.15	0.07	0.49	4.9	2.5	7.3	0.2	10.7	32.7
C5	4	0.12	0.06	0.51	4.5	2.3	6.7	0	10.1	37.7
C5a	7	0.06	0.02	0.38	1.4	1.0	1.8	0.3	2.8	23.5
C7	3	0.01	0.01	0.5	0.5	0.2	0.8	0	1	36.1
C7a	3	0.1	0.05	0.5	2.3	1.0	3.6	0	5	23.6
C8	3	0.1	0.04	0.41	2.7	1.4	4.0	0.5	5.4	26.8
C9	4	0.11	0.05	0.43	3.9	2.3	5.5	0.6	8.1	34.5
E2	4	0.09	0.02	0.23	3.8	2.9	4.7	1.9	6.5	42.8
E4	3	0.03	0.02	0.91	0.8	0	1.6	0	2.3	28
Core total	55	0.08	0.01	0.12	39.4	38.2	40.6	24.7	61.4	491.8
BK	5	0.08	0.03	0.39	44.7	29.4	60.0	10.3	89	578.4
Survey total	60	0.08	0.02	0.21	84.1	79.6	88.6	42.5	140.6	1070.2

Table A3.15: Recruit-sized new clocks estimated from randomly selected stations in the core strata (Stratum), the background stratum (BK), and for the whole 2007 stock assessment survey area (Survey total) sampled in 2012. The number of stations sampled (No. stns), the mean oyster density per m^2 (Mean density), the standard deviation of the mean density estimate (Density s.d.), coefficient of variation (CV) of the density estimate, mean population size in millions of oysters (Pop.n), upper and lower 95% confidence intervals (95%CI) in millions of oysters where a S prefix denotes the sampling CI calculated from the mean, standard deviation and sample size alone, and a B prefix denotes the bootstrapped estimate, and the area of each stratum (Area. km^2) in square kilometres, by stratum for the February 2012 Foveaux Strait oyster survey.

2012 Core Strata	No. stns	Mean density	Density s.d.	CV	Pop.n	S.lower 95%CI	S.upper 95%CI	B.lower 95%CI	B.upper 95%CI	Area.km^2
B1	5	0.05	0.02	0.5	3.9	2.2	5.6	0.1	8.6	78.2
B3	13	0.11	0.02	0.2	4.7	4.2	5.2	2.6	7.7	44.7
B6	6	0.03	0.01	0.45	0.9	0.6	1.2	0.1	1.9	30
C1a	5	0.01	0.01	0.63	0.4	0.2	0.6	0	0.9	31.3
C2	3	0.02	0.01	0.21	0.5	0.4	0.6	0.3	0.9	21.9
C3	6	0.05	0.01	0.31	1.6	1.2	2.0	0.6	2.8	32.7
C5	8	0.02	0.01	0.27	0.8	0.7	0.9	0.4	1.5	37.7
C5a	5	0.02	0.01	0.51	0.5	0.3	0.7	0	1	23.5
C7	5	0.1	0.07	0.72	3.5	1.3	5.7	0	9.1	36.1
C7a	4	0.08	0.07	0.81	2	0.4	3.6	0	5.6	23.6
C8	6	0.02	0.01	0.45	0.4	0.3	0.5	0	0.9	26.8
C9	6	0.02	0.01	0.31	0.7	0.5	0.9	0.2	1.2	34.5
E2	8	0.06	0.02	0.31	2.4	1.9	2.9	0.8	4.4	42.8
E4	4	0.01	0.01	1	0.2	0.0	0.4	0	0.8	28
Core total	84	0.05	0.01	0.17	22.4	21.6	23.2	12.8	36.6	491.8
BK	62	0.01	0	0.21	7.6	7.2	8.0	4	12.6	578.4
Survey total	146	0.03	0	0.14	30	29.3	30.7	18.4	46.8	1070.2

Table A3.16: Pre-recruit-sized new clocks estimated from randomly selected stations in the core strata (Stratum), the background stratum (BK), and for the whole 2007 stock assessment survey area (Survey total) sampled in 2015. The number of stations sampled (No. stns), the mean oyster density per m^2 (Mean density), the standard deviation of the mean density estimate (Density s.d.), coefficient of variation (CV) of the density estimate, mean population size in millions of oysters (Pop.n), upper and lower 95% confidence intervals (95%CI) in millions of oysters where a S prefix denotes the sampling CI calculated from the mean, standard deviation and sample size alone, and a B prefix denotes the bootstrapped estimate, and the area of each stratum (Area. km^2) in square kilometres, by stratum for the February 2015 Foveaux Strait oyster survey.

2015 Stratum	No. stns	Mean density	Density s.d.	CV	Pop.n	S.lower 95%CI	S.upper 95%CI	B.lower 95%CI	B.upper 95%CI	Area.km^2
B1	3	0.00	0.00	0.01	0.4	0.4	0.4	0.3	0.6	78.2
B3	3	0.00	0.00	1.00	0.1	0.0	0.2	0.0	0.2	44.7
B6	5	0.00	0.00	0.55	0.1	0.1	0.2	0.0	0.3	30.0
C1a	3	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	31.3
C2	3	0.01	0.00	0.26	0.1	0.1	0.2	0.1	0.2	21.9
C3	4	0.00	0.00	0.71	0.2	0.0	0.3	0.0	0.4	32.7
C5	4	0.00	0.00	0.58	0.1	0.0	0.1	0.0	0.2	37.7
C5a	3	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	23.5
C7	3	0.02	0.01	0.66	0.8	0.2	1.3	0.0	1.9	36.1
C7a	3	0.01	0.01	1.00	0.2	0.0	0.3	0.0	0.5	23.6
C8	5	0.00	0.00	1.00	0.1	0.0	0.1	0.0	0.2	26.8
C9	9	0.00	0.00	0.54	0.1	0.0	0.1	0.0	0.2	34.5
E2	4	0.00	0.00	0.64	0.2	0.1	0.3	0.0	0.4	42.8
E4	3	0.00	0.00	1.00	0.0	0.0	0.1	0.0	0.1	28.0
Core	55	0.00	0.00	0.25	2.2	2.1	2.4	1.0	3.9	491.8
BK	5	0.00	0.00	0.73	2.3	0.8	3.7	0.0	6.1	578.4
Survey total	60	0.00	0.00	0.39	4.5	4.1	4.9	1.0	9.1	1070.2

Table A3.17: Pre-recruit-sized new clocks estimated from randomly selected stations in the core strata (Stratum), the background stratum (BK), and for the whole 2007 stock assessment survey area (Survey total) sampled in 2014. The number of stations sampled (No. stns), the mean oyster density per m^2 (Mean density), the standard deviation of the mean density estimate (Density s.d.), coefficient of variation (CV) of the density estimate, mean population size in millions of oysters (Pop.n), upper and lower 95% confidence intervals (95%CI) in millions of oysters where a S prefix denotes the sampling CI calculated from the mean, standard deviation and sample size alone, and a B prefix denotes the bootstrapped estimate, and the area of each stratum (Area. km^2) in square kilometres, by stratum for the February 2014 Foveaux Strait oyster survey.

2014 Core Strata	No. stns	Mean density	Density s.d.	CV	Pop.n	S.lower 95%CI	S.upper 95%CI	B.lower 95%CI	B.upper 95%CI	Area.km^2
B1	3	0.02	0	0.2	1.3	1.0	1.6	0.7	2.1	78.2
B3	8	0.01	0	0.46	0.2	0.1	0.3	0	0.5	44.7
B6	3	0.01	0.01	0.55	0.4	0.2	0.6	0	0.9	30
C1a	3	0	0	0.57	0.2	0.1	0.3	0	0.4	31.3
C2	3	0.01	0	0.5	0.1	0.0	0.2	0	0.3	21.9
C3	4	0	0	1	0.1	0.0	0.2	0	0.3	32.7
C5	4	0.01	0	0.6	0.2	0.1	0.3	0	0.5	37.7
C5a	7	0	0	0.4	0.1	0.1	0.1	0	0.2	23.5
C7	3	0	0	1	0.1	0.0	0.2	0	0.2	36.1
C7a	3	0.02	0.01	0.6	0.4	0.1	0.7	0	1.1	23.6
C8	3	0	0	0.01	0.1	0.1	0.1	0.1	0.2	26.8
C9	4	0	0	0.58	0.1	0.0	0.2	0	0.2	34.5
E2	4	0	0	0.63	0.2	0.1	0.3	0	0.4	42.8
E4	3	0	0	1	0.1	0.0	0.2	0	0.3	28
Core total	55	0.01	0	0.14	3.6	3.5	3.7	2.2	5.7	491.8
BK	5	0	0	0.67	1.7	0.7	2.7	0	4.3	578.4
Survey total	60	0	0	0.24	5.3	5.0	5.6	2.5	9	1070.2

Table A3.18: Pre-recruit-sized new clocks estimated from randomly selected stations in the core strata (Stratum), the background stratum (BK), and for the whole 2007 stock assessment survey area (Survey total) sampled in 2012. The number of stations sampled (No. stns), the mean oyster density per m^2 (Mean density), the standard deviation of the mean density estimate (Density s.d.), coefficient of variation (CV) of the density estimate, mean population size in millions of oysters (Pop.n), upper and lower 95% confidence intervals (95%CI) in millions of oysters where a S prefix denotes the sampling CI calculated from the mean, standard deviation and sample size alone, and a B prefix denotes the bootstrapped estimate, and the area of each stratum (Area. km^2) in square kilometres, by stratum for the February 2012 Foveaux Strait oyster survey.

2012 Core Strata	No. stns	Mean density	Density s.d.	CV	Pop.n	S.lower 95%CI	S.upper 95%CI	B.lower 95%CI	B.upper 95%CI	Area.km^2
B1	5	0.03	0.01	0.39	2.5	1.6	3.4	0.5	4.9	78.2
B3	13	0.03	0.01	0.23	1.3	1.1	1.5	0.6	2.1	44.7
B6	6	0.01	0	0.53	0.3	0.2	0.4	0	0.6	30
C1a	5	0.01	0	0.67	0.2	0.1	0.3	0	0.5	31.3
C2	3	0	0	1	0.1	0	0.2	0	0.3	21.9
C3	6	0.01	0.01	0.37	0.5	0.4	0.6	0.1	0.9	32.7
C5	8	0.01	0	0.39	0.3	0.2	0.4	0.1	0.7	37.7
C5a	5	0.01	0	0.43	0.2	0.1	0.3	0	0.4	23.5
C7	5	0.05	0.03	0.5	1.9	1.1	2.7	0	4.2	36.1
C7a	4	0.03	0.01	0.35	0.6	0.4	0.8	0.2	1.2	23.6
C8	6	0.01	0	0.29	0.3	0.2	0.4	0.1	0.5	26.8
C9	6	0.01	0	0.54	0.2	0.1	0.3	0	0.5	34.5
E2	8	0.01	0.01	0.55	0.5	0.3	0.7	0	1.1	42.8
E4	4	0	0	1	0.1	0	0.2	0	0.2	28
Core total	84	0.02	0	0.17	8.9	8.6	9.2	5.1	14.4	491.8
BK	62	0.01	0	0.34	3.1	2.8	3.4	1	5.9	578.4
Survey total	146	0.01	0	0.15	12.0	11.7	12.3	7.2	18.9	1070.2

8.4 Appendix 4: Estimates of the total numbers of recruit-sized oysters infected with bonamia.

Table A4.1: Scaled up estimates of the population size of recruit-sized oysters with bonamia infection estimated by heart imprints in the core strata, the background stratum (BK), and for the whole 2007 stock assessment survey area (Survey total) sampled in 2014. The 2012 stock assessment survey did not sample for bonamia infection from all strata or the whole survey area, strata sampled for bonamia accounted for 628.6 km^2 (58.7%) of the survey area. Only stratum C6a was sampled in 2012 and not in 2014. The number of stations sampled (No. stns), the mean oyster density per m^2 (Mean density), the standard deviation of the mean density estimate (Density s.d.), the coefficient of variation (CV) of the density estimate, mean population size in millions of oysters (Pop.n), upper and lower 95% confidence intervals (95%CI) in millions of oysters, and the area of each stratum (Area. km^2) in square kilometres, by stratum for the February 2012 and February 2014 Foveaux Strait oyster surveys.

	2012							2014							
Core Strata	**No. stns**	**Mean density**	**Density s.d.**	**CV**	**Pop.n**	**Lower 95%CI**	**Upper 95%CI**	**No. stns**	**Mean density**	**Density s.d.**	**CV**	**Pop.n**	**Lower 95%CI**	**Upper 95%CI**	**Area.km2**
B1	3	0.21	0.06	0.28	16.1	6.6	28.8	3	0.13	0.03	0.26	10.2	4.5	17.9	78.2
B3	3	0.37	0.26	0.70	16.4	0.0	42.1	8	0.18	0.04	0.24	7.8	3.8	13.3	44.7
B6	3	0.24	0.13	0.57	7.1	0.0	16.4	3	0.11	0.07	0.67	3.3	0.0	8.2	30.0
C1a	3	0.02	0.02	0.88	0.6	0.0	1.8	3	0.02	0.01	0.42	0.7	0.1	1.5	31.3
C2	NA	NA	NA	NA	NA	NA	NA	3	0.38	0.15	0.40	8.4	1.8	16.9	21.9
C3	3	0.11	0.10	0.85	3.7	0.0	10.5	4	0.18	0.11	0.64	5.9	0.0	14.4	32.7
C5	3	0.10	0.10	1.00	3.7	0.0	11.7	4	0.35	0.18	0.52	13.1	0.0	29.4	37.7
C5a	3	0.06	0.03	0.53	1.5	0.0	3.3	7	0.10	0.06	0.59	2.4	0.0	5.6	23.5
C7	3	0.24	0.13	0.53	8.8	0.0	19.7	3	0.12	0.06	0.56	4.2	0.0	9.6	36.1
C7a	4	0.27	0.12	0.45	6.4	0.7	13.5	3	0.14	0.09	0.67	3.2	0.0	8.1	23.6
C8	3	0.07	0.01	0.13	1.8	1.1	2.8	3	0.10	0.06	0.56	2.7	0.0	6.2	26.8
C9	3	0.01	0.01	1.00	0.2	0.0	0.7	4	0.23	0.10	0.44	7.8	1.0	16.4	34.5
E2	3	0.37	0.36	0.98	15.8	0.0	50.3	4	0.43	0.26	0.61	18.4	0.0	45.0	42.8
E4	NA	NA	NA	NA	NA	NA	NA	3	0.05	0.05	1.00	1.5	0.0	5.0	28.0
Core total	37	0.19	0.05	0.26	*82.0	36.6	142.3	55	0.18	0.03	0.17	89.5	50.8	146.1	491.8
BK	9	0.01	0.00	0.69	**1.3	0	3.3	5	0.15	0.09	0.60	86.5	0.0	209.9	578.4
Survey total	46	0.13	0.03	0.26	***83.3	37.5	147.6	60	0.16	0.05	0.31	176.1	63.9	325.3	1070.2

*** (90.4%), ** (32.3%), *** (58.7%) of the survey area respectively.**

Table A4.2: Scaled up estimates of the population size of recruit-sized oysters with bonamia infection (prevalence) estimated by heart imprints in the core strata, the background stratum (BK), and for the whole 2007 stock assessment survey area (Survey total) sampled in 2015. The number of stations sampled (No. stns), the mean oyster density per m^2 (Mean density), the standard deviation of the mean density estimate (Density s.d.), the coefficient of variation (CV) of the density estimate, mean population size in millions of oysters (Pop.n), upper and lower 95% confidence intervals (95% CI) in millions of oysters, and the area of each stratum (Area. km^2) in square kilometres, by stratum.

2015 Core Strata	No. stns	Mean density	Density s.d.	CV	Pop.n	Lower 95%CI	Upper 95%CI	Area.km^2
B1	3	0.05	0.03	0.62	3.6	0.0	8.9	78.2
B3	3	0.16	0.11	0.67	7.2	0.0	18.2	44.7
B6	5	0.24	0.10	0.42	7.1	1.2	14.4	30.0
C1a	3	0.04	0.04	0.84	1.3	0.0	3.9	31.3
C2	3	0.06	0.03	0.47	1.3	0.1	2.8	21.9
C3	4	0.22	0.03	0.15	7.0	4.2	11.0	32.7
C5	4	0.09	0.05	0.52	3.5	0.0	8.0	37.7
C5a	2	0.10	0.05	NA	NA	NA	NA	NA
C7	3	0.08	0.02	0.28	3.0	1.2	5.4	36.1
C7a	3	0.04	0.02	0.61	0.9	0.0	2.1	23.6
C8	5	0.10	0.04	0.39	2.6	0.6	5.2	26.8
C9	9	0.22	0.09	0.41	7.6	1.5	15.4	34.5
E2	4	0.10	0.04	0.39	4.5	1.0	9.0	42.8
E4	1	0.14	0.13	NA	NA	NA	NA	NA
Core total	49	0.11	0.02	0.15	49.8	29.7	78.2	440.3
BK	5	0.04	0.01	0.35	21.5	6.2	41.6	578.4
Survey total	54	0.07	0.01	0.15	71.3	42.6	113.3	1018.7

Table A4.3: Scaled up estimates of the population size of recruit-sized oysters with bonamia infection estimated by heart tissues using qPCR in the core strata, the background stratum (BK), and for the whole 2007 stock assessment survey area (Survey total) sampled in 2014. The number of stations sampled (No. stns), the mean oyster density per m^2 (Mean density), the standard deviation of the mean density estimate (Density s.d.), the coefficient of variation (CV) of the density estimate, mean population size in millions of oysters (Pop.n), upper and lower 95% confidence intervals (95%CI) in millions of oysters, and the area of each stratum (Area. km^2) in square kilometres, by stratum for the February 2014 Foveaux Strait oyster survey.

2014 Stratum	No. stns	Mean density	Density s.d.	CV	Pop.n	Lower 95%CI	Upper 95%CI	Area.km^2
B1	3	0.24	0.07	0.29	18.4	7.4	33.1	78.2
B3	8	0.44	0.10	0.22	19.5	10.1	32.5	44.7
B6	3	0.20	0.14	0.69	6.0	0.0	15.4	30.0
C1a	3	0.05	0.02	0.41	1.6	0.3	3.4	31.3
C2	3	0.52	0.27	0.51	11.5	0.2	25.6	21.9
C3	4	0.27	0.19	0.73	8.7	0.0	23.1	32.7
C5	4	0.39	0.18	0.47	14.6	1.0	31.4	37.7
C5a	7	0.15	0.08	0.49	3.6	0.1	7.9	23.5
C7	3	0.15	0.07	0.47	5.4	0.4	11.6	36.1
C7a	3	0.34	0.17	0.51	7.9	0.0	17.5	23.6
C8	3	0.50	0.16	0.33	13.5	4.6	25.3	26.8
C9	4	0.35	0.16	0.46	12.1	1.2	25.6	34.5
E2	4	0.50	0.33	0.65	21.6	0.0	54.4	42.8
E4	3	0.08	0.08	1.00	2.3	0.0	7.5	28.0
Core total	55	0.30	0.04	0.15	146.9	88.2	234.5	491.8
BK	5	0.22	0.11	0.52	127.8	0.0	287.6	578.4
Survey total	60	0.26	0.07	0.25	274.8	124.2	480.4	1070.2

Table A4.4: Scaled up estimates of the population size of recruit-sized oysters with bonamia infection (prevalence) estimated by the qPCR analysis of heart tissues in the core strata, the background stratum (BK), and for the whole 2007 stock assessment survey area (Survey total) sampled in 2015. The number of stations sampled (No. stns), the mean oyster density per m^2 (Mean density), the standard deviation of the mean density estimate (Density s.d.), the coefficient of variation (CV) of the density estimate, mean population size in millions of oysters (Pop.n), upper and lower 95% confidence intervals (95%CI) in millions of oysters, and the area of each stratum (Area. km^2) in square kilometres, by stratum for the February 2015 Foveaux Strait oyster survey.

2015 Core Strata	No. stns	Mean density	Density s.d.	CV	Pop.n	Lower 95%CI	Upper 95%CI	Area.km^2
B1	3	0.05	0.02	0.53	3.6	0.0	8.2	78.2
B3	3	0.25	0.14	0.53	11.4	0.0	25.5	44.7
B6	5	0.36	0.11	0.30	10.8	4.0	19.7	30.0
C1a	3	0.08	0.08	0.92	2.6	0.0	8.0	31.3
C2	3	0.09	0.04	0.42	1.9	0.4	4.0	21.9
C3	4	0.39	0.10	0.26	12.6	5.5	22.0	32.7
C5	4	0.12	0.06	0.51	4.6	0.0	10.4	37.7
C5a	2	0.10	0.05	NA	NA	NA	NA	NA
C7	3	0.11	0.02	0.20	4.0	2.1	6.6	36.1
C7a	3	0.05	0.03	0.67	1.1	0.0	2.8	23.6
C8	5	0.20	0.11	0.54	5.5	0.0	12.3	26.8
C9	9	0.27	0.09	0.34	9.3	2.9	17.7	34.5
E2	4	0.12	0.05	0.39	5.3	1.2	10.5	42.8
E4	1	0.14	0.13	NA	NA	NA	NA	NA
Core total	49	0.17	0.02	0.14	72.7	44.8	112.5	440.3
BK	5	0.06	0.02	0.31	32.8	12.0	60.6	578.4
Survey total	54	0.10	0.01	0.13	105.6	64.9	165.5	1018.7

Table A4.5: Scaled up estimates of the population size of recruit-sized oysters with non-fatal infections (category 1 and 2) estimated by heart imprints in the core strata, the background stratum (BK), and for the whole 2007 stock assessment survey area sampled in 2015. The number of stations sampled (No. stns), the mean oyster density per m^2 (Mean density), the standard deviation of the mean density estimate (Density s.d.), the coefficient of variation (CV) of the density estimate, mean population size in millions of oysters (Pop.n), upper and lower 95% confidence intervals (95%CI) in millions of oysters, and the area of each stratum (Area. km^2) in square kilometres, by stratum for the February 2015 Foveaux Strait oyster survey.

2015 Core Strata	No. stns	Mean density	Density s.d.	CV	Pop.n	Lower 95%CI	Upper 95%CI	Area.km^2
B1	3	0.01	0.01	0.53	0.9	0.0	2.0	78.2
B3	3	0.09	0.07	0.71	4.2	0.0	10.8	44.7
B6	5	0.04	0.02	0.57	1.1	0.0	2.6	30.0
C1a	3	0.00	0.00	0.00	0.0	0.0	0.0	31.3
C2	3	0.02	0.01	0.34	0.4	0.1	0.8	21.9
C3	4	0.11	0.04	0.34	3.6	1.2	6.9	32.7
C5	4	0.04	0.02	0.53	1.4	0.0	3.2	37.7
C5a	2	0.10	0.05	NA	NA	NA	NA	NA
C7	3	0.05	0.03	0.57	1.6	0.0	3.8	36.1
C7a	3	0.02	0.01	0.51	0.5	0.0	1.0	23.6
C8	5	0.03	0.02	0.52	0.9	0.0	1.9	26.8
C9	9	0.08	0.04	0.50	2.9	0.0	6.4	34.5
E2	4	0.02	0.01	0.58	0.7	0.0	1.7	42.8
E4	1	0.14	0.13	NA	NA	NA	NA	NA
Core total	49	0.04	0.01	0.21	18.2	9.7	30.3	440.3
BK	5	0.00	0.00	0.66	2.2	0.0	5.6	578.4
Survey total	54	0.02	0.00	0.20	20.4	10.9	33.5	1018.7

Table A4.6: Absolute population estimates for recruit-sized oysters after projected mortality from bonamia based on category 3 and higher infections for randomly selected stations in the core strata (Stratum), the background stratum (BK), and for the whole 2007 stock assessment survey area (Survey total) sampled in 2015. The number of stations sampled (No. stns), the correction factor applied to each stratum (Correction factor), the mean oyster density per m^2 (Mean density), standard deviation (s.d.) of the density estimate, coefficient of variation (CV) of the oyster density, mean population size at the time of survey (Pop.n1), mean post mortality population size (Pop.n2) in millions of oysters, upper and lower 95% confidence intervals (CI) for the post-mortality estimate, the area of each stratum (Area.km^2), by stratum for the February 2015 survey.

2015 Core Strata	No. stns	Correction factor	Mean density	Density s.d.	CV	Pop.n1	Pop.n2	Lower 95%CI	Upper 95%CI	Area.km^2
B1	3	0.85	0.36	0.04	0.11	33.5	28.4	18.1	43.4	78.2
B3	3	0.90	1.49	0.10	0.07	73.6	66.5	44.1	98.3	44.7
B6	5	0.80	0.92	0.29	0.32	34.5	27.7	9.7	51.2	30.0
C1a	3	0.99	0.43	0.26	0.61	13.5	13.4	0.0	32.7	31.3
C2	3	0.93	0.34	0.17	0.50	8.0	7.5	0.2	16.6	21.9
C3	4	0.95	0.90	0.16	0.17	31.1	29.4	16.7	47.0	32.7
C5	4	0.88	0.46	0.19	0.41	19.7	17.4	3.1	35.5	37.7
C5a	2	NA	0.10	0.05	NA	NA	NA	NA	NA	NA
C7	3	0.94	0.68	0.25	0.37	25.8	24.4	6.2	47.7	36.1
C7a	3	0.92	0.43	0.16	0.36	10.9	10.1	2.8	19.6	23.6
C8	5	0.87	0.78	0.29	0.37	24.1	20.9	5.3	40.7	26.8
C9	9	0.97	1.38	0.38	0.28	49.3	47.7	19.8	84.9	34.5
E2	4	0.82	0.40	0.15	0.38	21.0	17.3	4.2	34.2	42.8
E4	1	NA	0.14	0.13	NA		NA	NA	NA	NA
Core total	49	-	0.71	0.06	0.08	345.2	310.8	205.4	461.0	440.3
BK	5	0.91	0.25	0.06	0.23	158.5	144.0	70.7	245.3	578.4
Survey total	54	"-	0.45	0.04	0.09	503.8	454.8	295.8	687.1	1018.7

Table A4.7: Absolute population estimates for recruit-sized oysters after projected mortality from bonamia based on category 3 and higher infections in the core strata (Stratum), the background stratum (BK), and for the whole 2007 stock assessment survey area (Survey total) sampled in 2014. 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 (CV) of the oyster density, mean post mortality population size (Post mort pop.n) in millions of oysters (Mean population), upper and lower 95% confidence intervals (CI), the area of each stratum (Area.km^2), by stratum for the February 2014 survey. The population size at the time of the survey and mortality in millions of oysters, and percentage mortality.

2014 Stratum	Factor	No. stns	Mean density	Density s.d.	CV	Post mort pop.n	Lower 95%CI	Upper 95%CI	Area.km^2	Pop.n at survey	Mortality	Percentage mortality
B1	0.85	3	0.69	0.14	0.20	54.2	29.2	89.3	78.2	63.9	9.8	15.3
B3	0.91	8	1.20	0.12	0.10	53.6	34.5	80.5	44.7	58.7	5.1	8.7
B6	0.91	3	0.74	0.21	0.29	22.3	8.9	39.8	30.0	24.6	2.3	9.4
C1a	0.95	3	0.50	0.27	0.53	15.7	0.0	35.5	31.3	16.5	0.8	4.6
C2	0.78	3	0.94	0.37	0.39	20.5	4.6	40.7	21.9	26.4	5.8	22.1
C3	0.90	4	1.12	0.57	0.51	36.7	0.0	81.8	32.7	40.9	4.2	10.2
C5	0.84	4	1.04	0.35	0.34	39.3	12.5	74.1	37.7	46.9	7.6	16.2
C5a	0.93	7	0.65	0.23	0.36	15.2	4.3	29.5	23.5	16.4	1.2	7.3
C7	0.85	3	0.45	0.23	0.52	16.1	0.0	35.9	36.1	19.0	2.8	14.9
C7a	0.85	3	0.67	0.14	0.21	15.8	8.2	26.3	23.6	18.5	2.7	14.6
C8	0.94	3	1.66	0.23	0.14	44.7	27.1	70.1	26.8	47.6	2.9	6.0
C9	0.94	4	2.65	1.18	0.45	91.4	11.4	193.5	34.5	97.4	6.0	6.1
E2	0.82	4	1.09	0.41	0.37	46.6	12.9	92.1	42.8	56.8	10.1	17.9
E4	0.89	3	0.15	0.13	0.91	4.1	0.0	12.6	28.0	4.6	0.5	11.3
Core total		55	0.97	0.33	0.34	476.3	153.6	601.8	491.8	538.0	61.7	11.5
BK	0.87	5	0.73	0.16	0.21	422.2	219.2	704.9	578.4	482.9	60.7	12.6
Survey total		60	0.84	0.10	0.12	898.5	558.9	1367.7	1070.2	1020.9	122.4	12.0

Table A4.8: Scaled up estimates of the population size of recruit-sized oysters with fatal bonamia infections estimated by heart imprints in the core strata, the background stratum (BK), and for the whole 2007 stock assessment survey area (Survey total) sampled in 2014. The 2012 stock assessment survey did not sample for bonamia infection from all strata or the whole survey area, strata sampled for bonamia accounted for 628.6 km^2 (58.7%) of the survey area. Only stratum C6a sampled in 2012 and not in 2014. The number of stations sampled (no. stn), the mean oyster density per m^2 (Mean density), the standard deviation of the mean density estimate (Density s.d.), the coefficient of variation (CV) of the density estimate, mean population size in millions of oysters (Pop.n), upper and lower 95% confidence intervals (95%CI) in millions of oysters, and the area of each stratum (Area. km^2) in square kilometres, by stratum for the February 2012 and February 2014 Foveaux Strait oyster surveys.

						2012								2014	
Core Strata	No. stns	Mean density	Density s.d.	CV	Pop.n	Lower 95%CI	Upper 95%CI		No. stns	Mean density	Density s.d.	CV	Pop.n	Lower 95%CI	Upper 95%CI	Area.km^2
B1	3	0.14	0.06	0.41	10.6	2.0	21.3		3	0.12	0.03	0.27	9.7	4.2	17.0	78.2
B3	3	0.23	0.17	0.75	10.4	0.0	27.8		8	0.11	0.03	0.25	5.0	2.4	8.6	44.7
B6	3	0.19	0.09	0.48	5.8	0.3	12.4		3	0.08	0.06	0.83	2.3	0.0	6.6	30.0
C1a	3	0.02	0.02	1.00	0.6	0.0	1.8		3	0.02	0.01	0.46	0.7	0.1	1.5	31.3
C2	NA	NA	NA	NA	NA	NA	NA		3	0.25	0.11	0.44	5.5	0.8	11.5	21.9
C3	3	0.11	0.10	0.85	3.7	0.0	10.5		4	0.11	0.07	0.66	3.5	0.0	8.7	32.7
C5	3	0.02	0.02	1.00	0.9	0.0	2.9		4	0.20	0.09	0.47	7.5	0.5	16.2	37.7
C5a	3	0.04	0.02	0.53	1.0	0.0	2.2		7	0.05	0.03	0.59	1.2	0.0	2.8	23.5
C7	3	0.18	0.09	0.50	6.5	0.2	14.3		3	0.08	0.04	0.56	2.7	0.0	6.3	36.1
C7a	4	0.16	0.06	0.38	3.7	0.9	7.3		3	0.11	0.08	0.73	2.6	0.0	6.9	23.6
C8	3	0.05	0.01	0.29	1.3	0.5	2.3		3	0.10	0.06	0.56	2.7	0.0	6.2	26.8
C9	3	0.01	0.01	1.00	0.2	0.0	0.7		4	0.17	0.09	0.54	5.9	0.0	13.6	34.5
E2	3	0.27	0.26	0.97	11.4	0.0	36.2		4	0.23	0.14	0.61	10.0	0.0	24.4	42.8
E4	NA	NA	NA	NA	NA	NA	NA		3	0.02	0.02	1.00	0.5	0.0	1.7	28.0
Core total	NA	NA	NA	NA	NA	NA	NA		55	0.12	0.02	0.16	59.9	34.9	96.7	491.8
BK	NA	NA	NA	NA	NA	NA	NA		5	0.10	0.09	0.85	59.6	0.0	173.2	578.4
Survey total	46	0.09	0.02	0.27	*56.9	24.4	102.2	628.6	60	0.11	0.05	0.43	119.4	19.4	247.3	1070.2

*** The 2012 stock assessment survey did not sample for bonamia infection from all strata or the whole survey area, strata sampled for bonamia accounted for 628.6 km^2 (58.7%) of the survey area. Only stratum C6a sampled in 2012 and not in 2014.**

Table A4.9: Scaled up estimates of the population size of recruit-sized oysters with fatal infections (category 3–5) estimated by heart imprints in the core strata, the background stratum (BK), and for the whole 2007 stock assessment survey area (Survey total) sampled in 2015. The number of stations sampled (No. stns), the mean oyster density per m^2 (Mean density), the standard deviation of the mean density estimate (Density s.d.), the coefficient of variation (CV) of the density estimate, mean population size in millions of oysters (Pop.n), upper and lower 95% confidence intervals (95%CI) in millions of oysters, and the area of each stratum (Area. km^2) in square kilometres, by stratum.

2015 Core Strata	No. stns	Mean density	Density s.d.	CV	Pop.n	Lower 95%CI	Upper 95%CI	Area.km^2
B1	3	0.04	0.02	0.66	2.8	0.0	7.0	78.2
B3	3	0.07	0.04	0.63	3.1	0.0	7.4	44.7
B6	5	0.20	0.09	0.46	6.0	0.6	12.7	30.0
C1a	3	0.04	0.04	0.84	1.3	0.0	3.9	31.3
C2	3	0.04	0.02	0.58	0.9	0.0	2.1	21.9
C3	4	0.10	0.03	0.30	3.4	1.3	6.1	32.7
C5	4	0.06	0.03	0.52	2.1	0.0	4.8	37.7
C5a	2	0.10	0.05	NA	NA	NA	NA	NA
C7	3	0.04	0.00	0.13	1.4	0.9	2.1	36.1
C7a	3	0.02	0.02	1.00	0.4	0.0	1.3	23.6
C8	5	0.07	0.02	0.36	1.8	0.5	3.4	26.8
C9	9	0.14	0.05	0.36	4.7	1.3	9.0	34.5
E2	4	0.09	0.04	0.43	3.8	0.5	7.8	42.8
E4	1	0.14	0.13	NA	NA	NA	NA	NA
Core total	49	0.07	0.01	0.16	31.6	18.8	49.7	440.3
BK	5	0.03	0.01	0.39	19.3	4.5	38.5	578.4
Survey total	54	0.05	0.01	0.18	50.9	29.0	82.7	1018.7